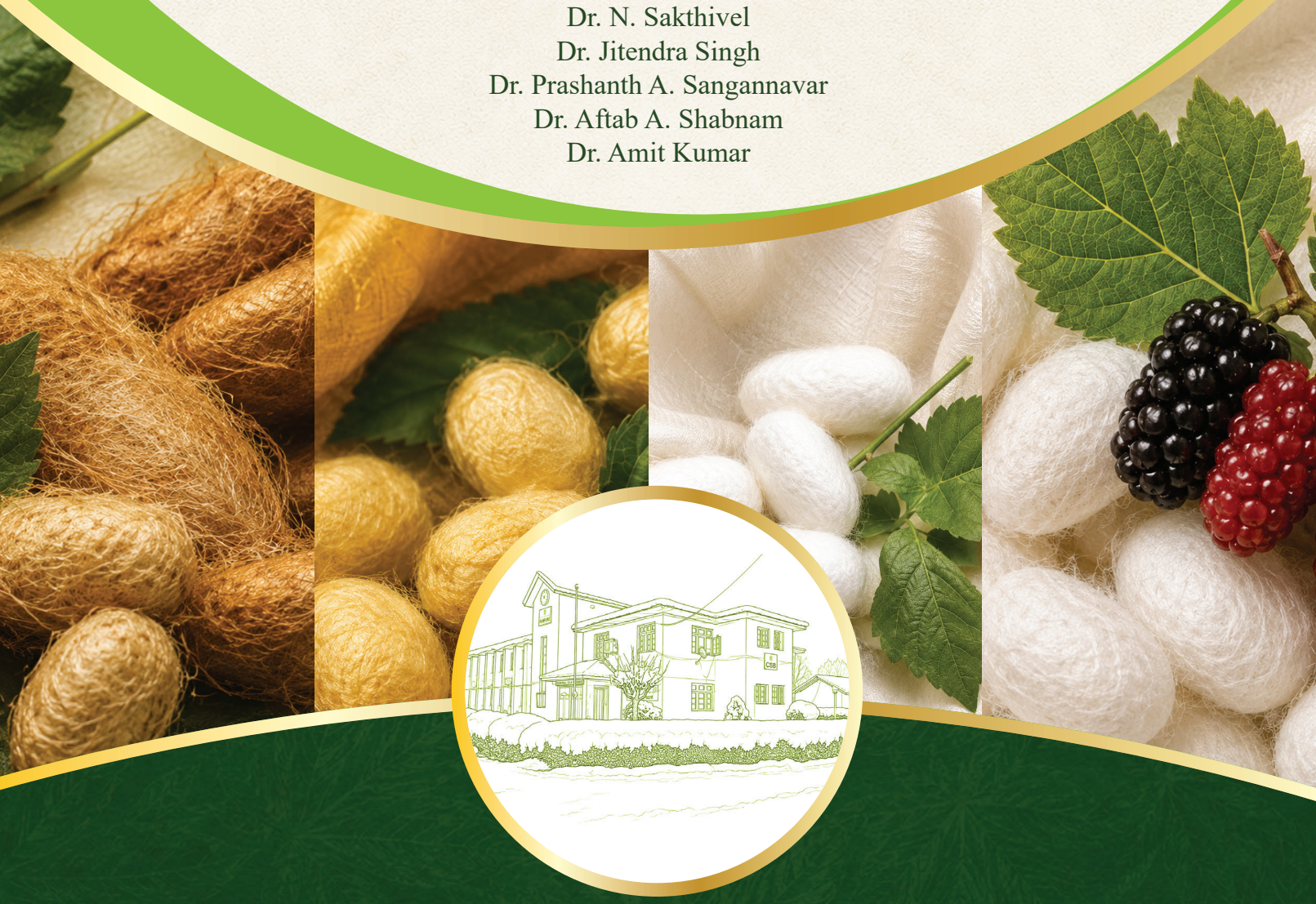
वस्त्र मंत्रालय
MINISTRY OF
TEXTILES
सत्यमेव जयते

केन्द्रीय रेशम बोर्ड, भारत
CENTRAL SILK BOARD, INDIA

CLIMATE-RESILIENT
SERICULTURE IN INDIA:
CHALLENGES, IMPACTS AND ADAPTATION STRATEGIES

Edited By
Dr. N. Sakthivel
Dr. Jitendra Singh
Dr. Prashanth A. Sangannavar
Dr. Aftab A. Shabnam
Dr. Amit Kumar



CSB- CENTRAL SERICULTURAL RESEARCH & TRAINING INSTITUTE
MINISTRY OF TEXTILES, GOVT. OF INDIA, PAMPORE
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CLIMATE-RESILIENT SERICULTURE IN INDIA:

CHALLENGES, IMPACTS AND ADAPTATION STRATEGIES

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Message



I am pleased to note that the book entitled *"Climate-Resilient Sericulture in India: Challenges, Impacts and Adaptation Strategies"* is prepared by CSB–Central Sericultural Research and Training Institute, Pampore.

The *Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6), 2023* has unequivocally established that human activities are driving global warming, with temperatures already rising by approximately 1.1°C above pre-industrial levels (1850–1900). The report further cautions that the 1.5°C threshold is likely to be reached before 2040, underscoring the urgency for climate-responsive actions across all sectors.

Sericulture, being inherently climate-sensitive, is increasingly vulnerable to the impacts of climate variability and change. Fluctuations in agro-climatic conditions such as temperature, humidity, rainfall etc., pose serious challenges to host plant cultivation, silkworm rearing, pest and disease dynamics, and ultimately effects the cocoon productivity. These emerging concerns have significant implications for silk security and the livelihoods who are dependent on this sector.

In the present scenario, this publication fetches significant importance. It comprehensively examines the multifaceted impacts of climate change on mulberry and Vanya sericulture systems and appropriate management strategies. This book maintains a bridge between lab to land, to understand the field problems and to mitigate with sustainable scientific approaches.

The emphasis on scientific adaptation approaches will play a crucial role in safeguarding the future of the silk sector and ensuring that the 'Queen of Textiles' continues to contribute to rural livelihoods and the vision of a Viksit Bharat.

I appreciate the scientific team of CSB-CSRTI, Pampore for their dedicated efforts in bringing out this valuable publication. I am confident that this work will serve as an important guide for researchers, policymakers, and farmers in building a resilient and sustainable sericulture sector in India.

(Sri P. Sivakumar, IFS)
Member Secretary & CEO
Central Silk Board

केंद्रीय रेशम बोर्ड
(वस्त्र मंत्रालय – भारत सरकार)
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Message



It is a matter of great satisfaction to learn that CSB–Central Sericultural Research and Training Institute, Pampore, Jammu & Kashmir UT is bringing out the first edition of the book *"Climate-Resilient Sericulture in India: Challenges, Impacts and Adaptation Strategies"* on the occasion of the "Soil Scientists Meet", coinciding with the celebration of World Environment Day on June 5, 2026.

India holds the unique distinction of producing all five commercially important varieties of silk Mulberry, Tropical and Oak Tasar, Eri, and Muga. Beyond its economic significance, sericulture plays a vital role in promoting inclusive growth, providing sustainable livelihoods to over 97.30 lakh people, particularly women and tribal communities in rural sector.

Climate change has emerged as one of the most pressing global challenges, with far-reaching consequences for developing countries like India. The sericulture sector, being highly climate-sensitive, is especially vulnerable to changing environmental conditions. In this context, adaptation remains the most effective strategy to mitigate adverse impacts and ensure the long-term sustainability of the sector.

The Central Silk Board, continues to lead from the front through focused research and innovation aimed at strengthening climate resilience in sericulture. This publication is a reflection of these sustained efforts. Comprising well-structured chapters, the book comprehensively addresses the diverse impacts of climate change on various silk production systems and offers practical, science-based adaptation strategies. By encompassing mulberry as well as Vanya silks – Tasar, Muga, and Eri – it serves as a valuable resource for understanding and responding to emerging climatic challenges.

The editors and contributing authors deserve commendation for compiling and presenting this wealth of information in a clear and accessible manner. I am confident that this book will prove highly beneficial to students, researchers, and professionals working in the field of sericulture under climate change scenario.

I extend my best wishes to the entire team at CSB–CSRTI, Pampore, for the successful release of this important publication and for their continued contributions to the advancement of the sericulture sector.

(Dr. S. Manthira Moorthy)
Director (Tech)
Central Silk Board

केंद्रीय रेशम बोर्ड
(वस्त्र मंत्रालय – भारत सरकार)
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Message



It is good to learn that the book entitled "Climate-resilient Sericulture in India: Challenges, Impacts and Adaptation Strategies" is being released during the CSB Soil Scientists Meet organized by CSB-CSR&TI, Pampore on the occasion of World Environment Day, 5th June 2026.

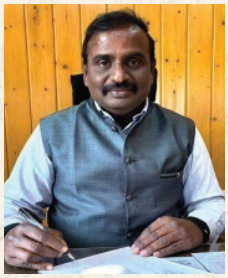
Climate change has emerged as one of the most critical challenges affecting agricultural and allied sectors across the globe, and sericulture is no exception. Variations in temperature, erratic rainfall patterns, declining soil health and increased incidence of pests and diseases have significant implications on mulberry cultivation, silkworm rearing and silk productivity. In this context, the present publication assumes great importance as it comprehensively addresses the emerging challenges, impacts and adaptive strategies required for ensuring sustainable and climate-resilient sericulture in India.

I appreciate the efforts of the scientists and contributors who have compiled valuable scientific knowledge, field experiences and practical adaptation approaches in this publication. I am confident that this book will serve as a useful reference for researchers, extension personnel, students, policy planners and stakeholders associated with the silk sector.

I congratulate the organizers of the CSB Soil Scientists Meet and the editorial team for bringing out this timely and significant publication coinciding with the celebration of World Environment Day. I extend my best wishes for the grand success of the programme and hope that the deliberations will contribute meaningfully towards sustainable development of the sericulture sector in the country.

(Dr. Naresh Babu, N. IFS)
Joint Secretary (Tech.)
Central Silk Board

FOREWORD



It gives me immense pleasure to present the book titled *"Climate-Resilient Sericulture in India: Challenges, Impacts and Adaptation Strategies"*, brought out by CSB–Central Sericultural Research and Training Institute (CSR&TI), Pampore, J&K. This publication is being released on the occasion of the Soil Scientists' Meet, commemorating World Environment Day on June 5, 2026, reflecting our collective commitment towards climate-resilient and sustainable sericulture.

Sericulture, as an agro-based and climate-sensitive enterprise, is intricately linked with environmental conditions. In recent years, the increasing variability in temperature, erratic rainfall patterns, and frequent occurrence of extreme weather events have posed significant challenges to the sustainability and productivity of the silk sector. These changes directly influence host plant growth, silkworm health, pest and disease dynamics, and ultimately cocoon yield and quality. Addressing these emerging challenges requires a scientific, integrated, and forward-looking approach.

This book is a comprehensive effort to examine the multifaceted impacts of climate change across different components of sericulture, including mulberry and Vanya silk sectors. The contributors have systematically documented the vulnerabilities, risks, and region-specific challenges, while also proposing practical and scientifically validated adaptation strategies. The emphasis on climate-resilient technologies, resource management practices, and sustainable production systems makes this publication highly relevant for present and future needs.

One of the key strengths of this book lies in its ability to bridge the gap between research and field application. The insights presented herein are expected to guide researchers in refining their approaches, assist policymakers in formulating informed strategies, and empower farmers with adaptive practices to sustain their livelihoods under changing climatic conditions.

I sincerely appreciate the dedicated efforts of the editors and authors who have contributed their expertise and experience to bring out this valuable document. Their work reflects a strong commitment to addressing one of the most pressing challenges facing the sericulture sector today.

I am confident that this publication will serve as a vital reference for researchers, extension personnel, students, and all stakeholders associated with sericulture. It is my earnest hope that the knowledge disseminated through this book will contribute significantly towards building a resilient, adaptive, and sustainable sericulture sector in India.

(Dr. N. Sakthivel)
Director
CSB–CSR&TI, Pampore, J&K



PREFACE

Climate change has emerged as one of the most critical challenges of the 21st century, influencing natural ecosystems, agriculture, and rural livelihoods across the globe. Sericulture, being a highly climate-sensitive agro-based enterprise, is particularly vulnerable to fluctuations in temperature, precipitation patterns and the increasing frequency of extreme weather events. These changes have profound implications on host plant productivity, silkworm growth and survival, pest and disease incidence, and ultimately the quality and yield of silk.

The book *"Climate-Resilient Sericulture in India: Challenges, Impacts and Adaptation Strategies"* has been conceived as a comprehensive effort to document, analyze, and address these emerging challenges in a scientific and practical manner. It brings together contributions from eminent scientists and experts working across different domains of sericulture, encompassing mulberry as well as Vanya silk sectors – Tasar, Eri and Muga. The chapters collectively highlight the extent of climate-induced vulnerabilities, while offering location-specific and scientifically validated adaptation and mitigation strategies.

The primary objective of this publication is to bridge the gap between research findings and their field-level application. It attempts to provide a holistic understanding of climate change impacts on various components of sericulture, including host plant cultivation, silkworm rearing, soil health, pest and disease management, and cocoon production systems. Special emphasis has been laid on developing climate-resilient technologies, resource-efficient practices, and sustainable production models to enhance the adaptive capacity of farmers and stakeholders.

This book is being brought out on the occasion of the Soil Scientists' Meet at CSB–Central Sericultural Research and Training Institute (CSR&TI), Pampore, in conjunction with the celebration of World Environment Day on June 5, 2026. The timing of this publication underscores the urgency of integrating climate action into sericulture research and development, in alignment with global and national priorities for environmental sustainability.

We express our sincere gratitude to the Central Silk Board, Bengaluru, for its continuous guidance and support in promoting research and innovation in sericulture. We are deeply thankful to all the contributors for their scholarly inputs and commitment in shaping this volume. We also acknowledge the efforts of reviewers and the technical team for their valuable suggestions and assistance in bringing out this publication in its present form.

We sincerely hope that this book will serve as a valuable resource for researchers, academicians, policymakers, extension personnel, and farmers. It is our earnest belief that the knowledge and strategies presented herein will contribute towards building a resilient, sustainable, and climate-adaptive sericulture sector in India.

(Editors)

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MULBERRY



CHAPTER 1: IMPACT OF CLIMATE CHANGE ON MULBERRY SERICULTURE AND ITS ADAPTATION STRATEGIES

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1.1. INTRODUCTION

The sericulture industry in India holds significant economic importance, impacting various aspects of the nation's economy, including cultivation, production, technology, processing, international and domestic trade, employment, and the generation of income for millions of stakeholders. India has the unique distinction of being the only country producing all the known commercial varieties of natural silks *viz.*, Mulberry, Tropical Tasar, Temperate Tasar (Oak Tasar), Eri and Muga. The global silk production in 2023 was 93,986 metric tons. China remains the largest producer, accounting for approximately 53% of the worldwide silk output. It is also the world's top exporter, supplying over 80% of the world's silk, although its domestic consumption is relatively low, at around 20%. India is the world's second- largest producer of silk, accounting for approximately 41% of the global total. However, it stands as the world's leading consumer and importer of raw silk, with annual consumption reaching 41,500 metric tons and imports totaling around 2,650 metric tons. India holds a 5% share in the global silk trade. China and India are the two major international players in the international silk scenario.

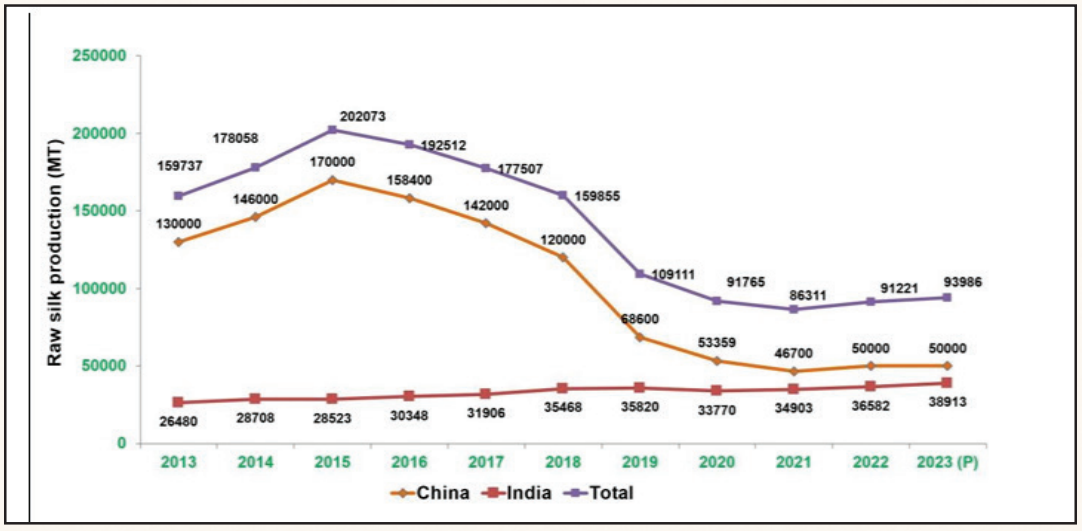


Figure 1: Global Raw Silk Production from 2013 to 2024 (Source: International Sericulture Commission)

In 2023-24, India's total raw silk production reached 38,913 metric tons, with mulberry silk accounting for 29,892 metric tons (76%) and Vanya silks making up 9,021 metric tons (24%). Of the mulberry silk produced, 18,750 metric tons (63%) was multivoltine, and 8,904 metric tons (31%) was bivoltine. Among the Vanya silks, 7,349 metric tons (81.5%) were Eri silk, 1,318 metric tons (14.6%) were Tasar silk, and 252 metric tons (2.8%) were Muga silk. In the year 2023-24, about 10,38,000 farmers and 31,725 reelers were engaged in sericulture across 54,400 villages in 26 states and Union Territories. The sector supports employment for around 9.48 million people in rural and semi-urban areas, covering all stages from cocoon production to finished products.

A significant portion of the workforce belongs to economically weaker sections, with women making up approximately 55% of the labour force, alongside substantial representation from tribal communities. Sericulture is widely practised across India, with Karnataka leading in mulberry silk production, followed by Andhra Pradesh, West Bengal, Tamil Nadu, and Maharashtra. The northeastern states primarily produce Eri and Muga silks, while Tasar silk is mainly produced in Chhattisgarh, Jharkhand, Bihar, and Odisha.

Climate change refers to persistent and long-term alterations in key climatic parameters-including temperature, precipitation patterns, relative humidity, and wind dynamics-that deviate from historical norms. While Earth's climate has naturally fluctuated over millennia, the current epoch is defined by an unprecedented rate of change primarily driven by anthropogenic greenhouse gas (GHG) emissions. These emissions are the direct result of rapid industrialization, the intensive combustion of fossil fuels, and large-scale land-use changes like deforestation. Together, these activities have fundamentally altered the chemical composition of the atmosphere, trapped heat and disrupting the planet's energy balance.

Since the pre-industrial period (around 1850), atmospheric carbon dioxide (CO_2) concentrations have increased by nearly 47%, reaching approximately 415– 420 ppm in recent years (NOAA; IPCC, 2021). This rise in greenhouse gas concentrations has been accompanied by an increase in global mean surface temperature of about 1.1°C above pre-industrial levels, with the past decade being the warmest on record (NASA-GISS; IPCC, 2021). In addition, global mean sea levels are rising at an estimated rate of about 3.3 mm per year, primarily due to thermal expansion of seawater and accelerated melting of glaciers and polar ice sheets. The increasing frequency and intensity of extreme climatic events such as floods, droughts, cyclones, and heat waves further highlight the accelerating impacts of global climate change.

Furthermore, the stability of the global climate system is being compromised, leading to an increase in both the frequency and intensity of extreme climatic events. Weather patterns are becoming increasingly erratic; regions are witnessing more severe floods, prolonged droughts, devastating cyclones, and record-breaking heat waves. These events are no longer "once-in-a-century" occurrences but are becoming seasonal hallmarks.

In the context Indian sericulture, these shifts are particularly impactful. The delicate biological balance required for mulberry growth and silkworm rearing is highly sensitive to the very parameters currently in flux. As precipitation becomes unpredictable and humidity levels swing, the traditional windows for silk production are narrowing. Understanding these foundational climatic shifts is the first step in developing the resilience and adaptation strategies necessary to protect vulnerable industries and the millions of livelihoods that depend on them in a rapidly changing world.

1.2. IMPACT OF CLIMATE CHANGE ON MULBERRY SERICULTURE

1.2.1. Impact on Mulberry Physiology

1.2.1.1. Heat Stress and Photosynthesis

Mulberry (*Morus alba* L.) is a C3 plant and is highly sensitive to elevated temperatures above 35°C. Heat stress adversely affects physiological and biochemical processes in mulberry plants through:

- **Reduction in Photosynthetic Efficiency:** High temperatures denature photosynthetic enzymes such as Rubisco, reducing carbon fixation efficiency.
- **Stomatal Closure:** To minimize transpiration losses, stomata close under heat stress, thereby reducing CO_2 uptake and photosynthesis.

- **Photo-oxidative Damage:** Intense solar radiation damages chlorophyll pigments, causing chlorosis and leaf senescence.

These physiological disturbances ultimately reduce leaf yield and quality.

1.2.1.2. Alteration in Leaf Biochemistry

Elevated atmospheric CO_2 and temperature modify the biochemical composition of mulberry leaves. Although biomass production may increase under elevated CO_2 conditions, nutrient dilution often occurs, reducing concentrations of nitrogen, phosphorus, potassium, and essential amino acids.

Since silkworm growth and silk gland development depend heavily on protein-rich mulberry leaves, altered nutrient composition adversely affects cocoon quality and silk productivity.

1.2.2. Water Scarcity and Drought Stress

Drought is one of the most severe consequences of climate change affecting sericulture. Water stress significantly reduces mulberry productivity through:

- Decline in relative water content (RWC) of leaves
- Reduced leaf succulence and palatability
- Cellular dehydration and premature leaf senescence
- Accumulation of osmoprotectants such as proline

Silkworms fed on drought-stressed leaves exhibit poor digestion, reduced growth, weak immunity, and increased mortality.

Table 1: Impact of Climate Change on Mulberry Leaf Production

Climate Change Factor	Impact on Mulberry Leaf Production	Physiological/Production Effects	Key Findings	Reference
Rising temperature	Reduction in leaf yield and deterioration of leaf quality	Heat stress reduces photosynthesis, leaf moisture and nutrient balance	Elevated temperature adversely affects mulberry growth and leaf nutritional quality required for silkworm rearing	Ashrith *et al.* (2025)
Drought stress	Decline in biomass and leaf productivity	Reduced stomatal conductance, chlorophyll degradation and impaired photosynthesis	Drought is one of the major limiting factors reducing mulberry growth and biomass accumulation	Sun *et al.* (2023)
Erratic rainfall	Lower and unstable leaf production	Water stress, nutrient imbalance and irregular vegetative growth	Unpredictable rainfall patterns significantly reduce mulberry productivity and sustainability of sericulture	Savitha *et al.* (2026)

Climate Change Factor	Impact on Mulberry Leaf Production	Physiological/Production Effects	Key Findings	Reference
Heat waves and moisture stress	Reduced leaf area and poor leaf quality	Increased transpiration and accelerated senescence	Climate variability decreases mulberry leaf yield and silk productivity	Manzoor & Qayoom (2024)
Elevated atmospheric CO_2 with changing climate	Altered leaf phenology and production cycles	Changes in leaf emergence, transpiration and canopy dynamics	Climate variability influences timing and quantity of leaf production	Lüthy *et al.* (2025)
Prolonged drought	Reduced leaf water content and chlorophyll concentration	Premature ageing, poor leaf expansion and decreased photosynthetic activity	Leaf water content declined markedly under drought stress conditions	Jiao *et al.* (2021)
Climate-induced physiological stress	Decline in mulberry growth dynamics and leaf yield	Reduced carbon assimilation and growth efficiency	Drought stress negatively affects growth dynamics and leaf yield production	Guha *et al.* (2010)
Increased frequency of extreme weather events	Fluctuation in seasonal leaf availability	Damage to plant tissues and irregular flushing	Heat and drought stress are major threats to crop growth and productivity under climate change	Tiwari *et al.* (2018)
Temperature and humidity fluctuations	Reduced nutritional quality of leaves	Lower protein and moisture content affecting silkworm feeding	Mulberry physiology is highly sensitive to temperature and moisture variations	Karur & Narmada (2026)
Climate variability in sericulture ecosystems	Decline in sustainable mulberry cultivation	Reduced synchronization between mulberry growth and silkworm rearing	Climate variability disrupts mulberry growth cycles and sericulture productivity	Sudan *et al.* (2025)

Impact of Silkworm Biology

The silkworm (*Bombyx mori* L.) is a poikilothermic insect whose metabolism is highly influenced by ambient temperature and humidity.

1.2.3.1. Thermal Stress

The ideal temperature range for silkworm rearing is 23–27°C. Temperatures exceeding 30°C lead to:

- Accelerated larval metabolism
- Reduced feeding duration
- Inadequate silk protein accumulation
- Impaired digestive enzyme activity

Consequently, cocoon weight and silk quality decline significantly.

1.2.3.2. Reproductive Disturbances

Heat stress during pupal and adult stages reduces reproductive efficiency by causing:

- Reduced fecundity
- Lower egg viability
- Poor hatching percentages
- Defective sericin coating on eggs

These effects disrupt the entire sericulture production cycle.

1.2.4. Increased Disease Incidence

Warm and humid conditions favour the proliferation of pathogens causing major silkworm diseases such as:

- **Grasserie:** Caused by *Bombyx mori* nucleopolyhedrovirus (BmNPV)
- **Flacherie:** Triggered by bacterial and viral infections under stressful environmental conditions

Disease outbreaks during summer often result in severe crop losses.

1.3. SOIL HEALTH AND NUTRIENT DYNAMICS

Climate change also affects soil ecosystems supporting mulberry cultivation.

Major Impacts Include:

- Accelerated decomposition of soil organic matter
- Decline in soil carbon sequestration
- Reduced microbial diversity
- Increased prevalence of soil-borne pathogens such as *Fusarium oxysporum*

Beneficial microorganisms like *Azotobacter* and phosphate-solubilizing bacteria decline under elevated temperatures, affecting nutrient availability and soil fertility.

Table 2: Impact of Climate Change on *Bombyx mori* (Mulberry Silkworm)

Climate Change Factor	Impact on Bombyx mori	Physiological/Economic Consequences	Key Findings	Reference
Rising temperature	Heat stress in larvae	Reduced larval growth, cocoon weight and shell ratio	Optimal temperature for silkworm growth is 22–28°C; temperatures above optimum reduce cocoon quality and survival	Manzoor & Qayoom (2024)
High temperature and low humidity	Increased mortality and poor cocoon traits	Lower silk productivity and poor reeling quality	Exposure to 36 ± 1°C and 35 ± 5% RH adversely affected most bivoltine breeds	Kumar & Nath (2024)

Climate Change Factor	Impact on Bombyx mori	Physiological/Economic Consequences	Key Findings	Reference
Erratic rainfall and drought	Reduced mulberry leaf yield and nutritional quality	Nutritional deficiency in larvae leading to weak cocoon formation	Climate variability negatively influences host plant physiology and silkworm productivity	Sudan *et al.* (2025)
Increased atmospheric CO_2 and warming	Altered mulberry physiology	Reduced leaf protein quality affecting larval metabolism	Elevated temperature and altered CO_2 affect photosynthesis and transpiration in mulberry	Karur & Narmada (2026)
Seasonal fluctuations	Disturbance in voltinism and breeding cycles	Mismatch between leaf availability and larval stages	Seasonal changes alter synchronization between mulberry growth and silkworm rearing	Ashrith *et al.* (2025)
Heat waves	Cellular and metabolic stress	Increased susceptibility to diseases and oxidative damage	Silkworms possess limited tolerance to thermal extremes due to long domestication	Manjunatha *et al.* (2010)
Fluctuating temperature and humidity	Altered silk gland development	Reduction in silk protein synthesis and cocoon quality	Environmental fluctuations affect larval weight, cocoon diameter and silk gland protein content	Sarkhel *et al.* (2017)
Extreme climatic variability	Increased disease incidence	Higher crop loss and economic instability in sericulture	Climate stress weakens immunity and enhances pathogen susceptibility	Sujatha *et al.* (2024)
Suboptimal rearing environment	Reduced survival and cocoon traits	Lower commercial cocoon yield	Best performance observed at 25°C and 85% RH	Darshan *et al.* (2026)
Long-term climate change	Decline in sericulture sustainability	Threat to rural livelihoods and silk economy	Climate change affects both mulberry cultivation and silkworm biology simultaneously	Ashrith *et al.* (2025); Sudan *et al.* (2025)

1.4. DROUGHT MANAGEMENT IN MULBERRY CULTIVATION

Mulberry (*Morus alba* L.) is food plant of silkworm (*Bombyx mori* L.) cultivated over 2.8 lakh hectares in the country mainly in the traditional sericulture states namely Karnataka, Andhra Pradesh, Telangana, West Bengal and Tamil Nadu. About 80 percent of mulberry garden in the country is under irrigated condition which shows the importance of water sources for the mulberry crop. Therefore, sustainable production of mulberry leaf for silkworm rearing and cocoon production is mainly depending upon the availability of irrigation water. However, in the absence of adequacy of water resources for irrigation, rainfed mulberry farming is also practiced in few parts of the country.

1.4.1. Climate change impact on rainfall

In India, rainfall is the main water source with two major monsoons *viz*., southwest and northeast. The southwest monsoon begins in the month of June and fade away by the end of September. Northeast monsoon spans for 3 months *i.e*., October, November and December and mainly covers southern states where the sericulture activities are predominant. With changing scenario of the present weather conditions and global warming, showers in these monsoon seasons are not well spread throughout the period and poor which leads to acute water scarcity for irrigation.

1.4.2. Limiting factor in silk production

Therefore, in recent past, drought is a perpetual problem in mulberry farming and most of the commercial fields experience water stress at different growth stages due to inadequate precipitation and non-availability of irrigation water, especially during the dry months. Many silk producing states of India are suffering year by year with acute water scarcity due to poor rainfall and depleting water table. Drought is a major threat to sustaining mulberry leaf production under current and more so in future climates. Insufficient irrigation water availability for agriculture purpose in general and for mulberry cultivation in particular due to low rainfall or failure of monsoon or frequent droughts are found to be the major factor responsible for limiting mulberry silk production in India.

1.4.3. Drought management approaches

Keeping in mind challenges of drought and quality leaf production in stress prone areas, the present need before researchers and growers is to fight with the challenges posed by drought. There are many approaches like cultivation of drought resistant mulberry varieties, adoption of proper cultivation techniques for deep rooting, tree plantations, mulching, drip irrigation, water conservation, proper nutrient management *etc*., through which we can manage these challenges. The use of desirable method under different conditions not only meets the requirement of quality leaf production but also provides an alternative approach to mitigate the drought.

1.5. MANAGEMENT PRACTICES UNDER THE IMPACT OF CLIMATE CHANGE

1.5.1. Drought Tolerant Mulberry Varieties

In order to overcome water crisis, several mulberry varieties which give adequate yield of quality leaf under water stress and limited input conditions are evolved and introduced by the Central Silk Board.

1.5.1.1. AGB8

Mulberry variety AGB8 is developed for cultivation under sub-optimal irrigated conditions in semi-arid regions where soil moisture stress is a limiting factor for sericulture. The variety developed during 2012 has a leaf yield potential of 47 MT/ha/yr under sub-optimal irrigated conditions. The variety AGB 8 is a hybrid of (Sujanpur-5 x Phillipines) and (K-2 x Black cherry) exhibited significantly higher leaf yield over RC1 in the sub-optimal irrigated conditions of south India. The foliage of AGB8 is of excellent quality and ideally suited for silkworm rearing. The variety is characterized by erect branches, thick dark-green leaves and medium inter-nodal distance. It is having high rooting ability (Anonymous, 2018).

1.5.1.2. MSG2

MSG2 is a mulberry variety specially evolved for cultivation in semi-arid regions where soil moisture stress is a limiting factor for sericulture. The variety developed during 2014 has a leaf yield potential of 22-23 mt/ha/yr under moisture stress conditions. The variety a hybrid of BR-4

and S13 is poised to replace S13 in the semi-arid tracts. The foliage of MSG2 is of excellent quality and ideally suited for silkworms rearing. The variety is characterized by erect branches, thick dark-green leaves and short inter-nodal distance. It has high rooting ability (> 80%) and survival rate in the nursery. This variety is moderately tolerant to foliar diseases. Suitable for growing as small trees under protective irrigation (Rajashekar, K. and S. Gandhi Doss, xxxx).

1.5.1.3. RC1

Recommended for cultivation under sub-optimal conditions of chemical fertilizers and irrigation. Mulberry leaf productivity for sericulture wholly depends upon the adoption of recommended cultural practices and fertilizer applications. The variety RC1 is recommended in those areas where irrigation is limited and the farmers are unable to spend on fertilizer due to socio-economic conditions. The variety is characterized by fast growth, medium branching, slightly spreading, pinkish branches with short internodes, large leaves, predominantly lobed, thick, cordate, glossy and green in colour. The variety is tolerant to low input conditions up to 5O % of fertilizers and yields 23 - 25 MT/ha/ year (Thippeswamy *et al.*, 2014a).

1.5.1.4. RC2

The variety RC2 is also recommended in those areas where irrigation is limited and the farmers are unable to spend on fertilizers due to socio-economic conditions. The variety is characterized by fast growth, medium branching, and slightly spreading, pinkish branches with short internodes, large leaves, predominantly lobed, thick, cordate, glossy and green in colour. The variety is tolerant to low input conditions (50% reduction in fertilizer dosage) and yields 2l -23 MT/ha/ year under sub-optimal irrigation (Thippeswamy *et al.*, 2014b).

1.5.1.5. C-2038

It is a high yielding mulberry variety recommended for Eastern and North Eastern states. It is most suitable for cultivation under irrigation and rainfed conditions with recommended package of practices. The leaf yield potential of C-2038 is 54 MT/ha/year in five crop scheduleof shoot harvest under irrigation and 17-21 MT/ha/year in three crop schedules under rainfed condition. C-2038 variety is hybrid of CF1-10 & C763 characterized by erect growth with slightly curved branches bearing large thick glabrous dark-green leaves with high moisture content [78.50%]. The foliage is of excellent quality and ideal for silkworm rearing (Suresh *et al.*, 2020).

1.5.1.6. C1730

C1730 is an improved mulberry variety by crossing a tetraploid female (T-25) with a diploid male parent (S-162). This variety found more suitable for drought prone areas of rainfed and laterite soil of West Bengal, Odisha and Madhya Pradesh. Leaf yield is 15-16 MT/ha/year (Reference, xxx).

1.6. RAINWATER HARVEST AND FARM PONDS

1.6.1. In-situ rainwater harvesting decrease surface run-off:

Rainwater conservation in mulberry plantations reduces irrigation frequency by improving soil moisture in the root zone. Trenches opened across slopes, manually or with tractor-operated trenchers, help collect rainwater and enhance deep percolation into the soil. Annual trenching is beneficial for maintaining moisture and promoting healthy mulberry growth with high-moisture leaves. Another effective method is impounding rainwater within the field by raising bunds around it, especially in red and light soils where infiltration rates are high, ensuring quick absorption and better water conservation.

1.6.2. Trenching and Mulching in Mulberry Gardens

Trenching and mulching in mulberry gardens involve digging knee-deep trenches between rows and filling them with mulberry leaves, shoots, and silkworm litter before covering with soil. These trenches conserve rainwater, improve soil moisture, and promote quick decomposition into nutrient-rich compost. Developed by Karnataka sericulture farmers, this technology is widely adopted in Bangalore and other regions of Karnataka, Tamil Nadu, and Andhra Pradesh.

1.6.3. Runoff collection pits

Runoff collection pits are dug in lower parts of mulberry gardens to collect excess rainwater during heavy rains and help it percolate into the soil. Pit depths range from 30 cm to 3 m, with bunds formed around them to prevent soil erosion.

1.6.4. Farm ponds

A farm pond is a rectangular pit dug to collect and store rainwater for future use, mainly irrigation. It includes an inlet, outlet, and surrounding bunds to regulate water flow and prevent erosion. The size depends on land availability, soil type, water needs, and excavation cost. Farm ponds can be constructed manually or with machines. They provide irrigation during dry periods, improve crop yield, support multiple cropping, and increase farm productivity. Bunds around ponds can be used for growing vegetables and fruit trees, adding income and nutrition. Farm ponds also reduce soil erosion, recharge groundwater, improve drainage, supply water for domestic use and livestock, support fish farming, and provide excavated soil useful for land levelling and road construction.

1.7. DRIP IRRIGATION IN MULBERRY GARDEN FOR WATER BUDGETING

Drip irrigation is an efficient method for water budgeting in mulberry gardens, especially under conditions of water scarcity and global warming. In India, about 80% of mulberry cultivation depends on irrigation to produce quality leaves for healthy silkworm growth and better silk yield. Traditional irrigation methods consume large amounts of water, nearly 500 liters for every kilogram of mulberry leaves produced. With increased biomass removal under shoot harvest systems, water demand has further increased. Drip irrigation supplies water directly to the root zone in small quantities through emitters, reducing water wastage and improving efficiency. Since mulberry is a widely spaced crop, drip irrigation is highly suitable and helps achieve optimum leaf yield and quality with high water savings. Various emitters such as inline drippers, online drippers, micro tubes, and pressure-compensated drippers are commonly used in mulberry gardens for effective irrigation management and sustainable silk production.

1.7.1. Advantages

1. The best part of the drip irrigation system is that it suits every type of soil
2. Irrigation water savings up to 65% comparable to flood irrigation
3. Drip irrigation delivers water directly to the soil surface close to the plant roots avoiding wastage of water through evaporation or flooding.
4. Low growth of weeds and saves weeding cost
5. Facilitates fertigation through irrigation and saves cost of manual fertilizer application
6. Saves labour for irrigation
7. Saves cost of field preparation
8. Higher leaf yield and good leaf quality with less water

1.7.2. Disadvantage

1. High initial investment
2. Clogging of emitters
3. Damage of system by rats

1.8. MICROCLIMATE MANAGEMENT IN SILKWORM REARING HOUSES

Temperature and humidity play vital role in growth and development of silkworms. Cocoon Productivity and its quality are optimized only when ample environmental conditions are maintained in silkworm rearing sheds besides hygiene and feeding quality mulberry leaves. The temperature and humidity range between 23^{0}C & 28^{0}C and 70% & 80% are ideal for silkworms. Very hot or chill climatic condition affects silkworm health which reflects adversely on cocoon yield. High temperature shortens life span of silkworm whereas the chillness leads to prolongation. However, major silk producing states of India *viz.* Andhra Pradesh, Karnataka, Tamil Nadu, Telangana and West Bengal are fall under tropical zones where the warm ambience is unfavorable for silkworm in majority of the months.

1.8.1. Effect of Seasons on Silk Production in Tropics and Limitations of Conventional Microclimate Management

Seasonal variation has a profound influence on silk production in tropical regions where environmental conditions fluctuate considerably throughout the year. Cocoon production in tropical sericulture is generally higher during winter months and moderate during the rainy season because temperature and relative humidity remain comparatively favourable for silkworm growth and cocoon formation. In contrast, cocoon productivity declines drastically during summer due to extreme heat stress and low atmospheric humidity. In many tropical regions, summer temperature frequently exceeds 40°C while relative humidity falls below 30%, creating highly unfavourable conditions for silkworm rearing.

Silkworm (*Bombyx mori* L.) is a poikilothermic organism whose body temperature and physiological activities are strongly influenced by ambient environmental conditions. High temperature during summer directly disturbs metabolic and physiological processes such as feeding behaviour, digestion, growth, moulting, and silk gland development. At the same time, low atmospheric humidity rapidly desiccates the mulberry leaves supplied to silkworms before they are consumed. Fresh mulberry leaves are the sole source of nutrition and moisture for silkworm larvae, and therefore their quality is extremely important for successful cocoon production.

Wilted mulberry leaves with poor moisture content fail to satisfy the water requirement necessary for digestion, nutrient absorption, and efficient utilization of ingested food. As a result, larval growth becomes weak and irregular, reducing feeding efficiency and cocoon development. Continuous exposure to heat stress and nutritional deficiency weakens the immune system of silkworm larvae, making them highly susceptible to bacterial, viral, fungal, and protozoan diseases. This is one of the major reasons behind frequent disease outbreaks and crop failures during summer seasons in tropical sericulture regions. Consequently, high temperature and low humidity conditions significantly reduce cocoon yield, shell ratio, cocoon weight, filament quality, and overall silk productivity.

Management of microclimate inside silkworm rearing houses during summer therefore becomes one of the most important challenges in tropical sericulture. Farmers in different regions adopt several conventional methods for regulating temperature and humidity inside rearing sheds depending on local traditions, shed structure, resource availability, and convenience. One of the common

practices is growing trees around the rearing house to reduce direct sunlight and heat radiation on the walls. Similarly, spreading thatch materials over roofs made of asbestos sheets, metal sheets, or tiles is widely practiced to minimize heat absorption. Such passive cooling methods are considered essential in tropical regions.

During silkworm rearing, additional cooling and humidification practices are commonly employed. Hanging wet gunny cloths around rearing sheds is a traditional technique used to facilitate the entry of cool and moist air into the rearing house. Water is also sprinkled manually over roofs or through rooftop sprinkler systems to reduce roof temperature and lower indoor heat. Some farmers place wet sand along the floor and walls to increase humidity levels and reduce thermal stress. Spraying water over porous or hollow brick walls is another method used for cooling. Besides these traditional methods, humidifiers and water misting machines are increasingly utilized to maintain suitable environmental conditions during summer months.

Among all conventional methods, humidifiers and water misting devices are comparatively more effective in maintaining desired temperature and humidity inside silkworm rearing houses. However, despite their effectiveness, many farmers discontinue their use because of several operational and maintenance problems. One of the major drawbacks is the longer time required to achieve the desired ambient conditions inside the rearing shed. Humidifiers also consume considerable electricity, increasing operational costs for farmers. Problems related to electrical shock under wet conditions further reduce farmer preference for such systems.



Figure 2: Effect of seasons on silk production and limitation of conventional microclimate management

Another limitation of humidifiers is the uneven distribution of mist because air flow generally moves in a single direction. These machines also occupy substantial space inside rearing houses,

creating congestion and reducing working convenience. Frequent refilling of water tanks becomes necessary during operation, leading to high water consumption and excessive wetting of floors. Accumulation of salts inside water tanks, pipes, hoses, and fans reduces operational efficiency and increases maintenance requirements. Dust particles, mulberry leaf fragments, and silkworm litter often block the system during rearing operations. In addition, disinfectants applied inside rearing sheds may cause rusting of machine components. Due to these factors, humidifiers often become expensive to maintain and are prone to mechanical breakdown.

Therefore, the limitations of conventional humidification systems have highlighted the need for efficient, economical, and farmer-friendly technologies capable of maintaining stable microclimatic conditions in tropical silkworm rearing houses.

1.8.2. Fogging Technology for Microclimate Management in Silkworm Rearing Houses

Maintenance of optimum temperature and relative humidity inside silkworm rearing houses is one of the most critical requirements for successful cocoon production. Climatic stress, particularly high temperature and low humidity during summer months, adversely affects silkworm growth, feeding efficiency, moulting, cocoon formation, and silk productivity. Under tropical climatic conditions, sudden fluctuations in temperature and humidity often result in poor larval health, reduced cocoon weight, low shell ratio, and inferior silk quality. Therefore, technologies capable of maintaining a stable microclimate inside rearing houses are becoming increasingly important for sustainable sericulture production. Fogging technology has emerged as an effective environmental management system for regulating greenhouse climatic conditions in many countries. The technology is widely used for plant propagation by reducing air temperature and increasing humidity inside greenhouses without wetting plant surfaces. Similar systems are also successfully employed in the poultry industry, particularly in Salem and Namakkal districts of Tamil Nadu, to reduce heat stress in birds, which otherwise affects feed conversion efficiency, body weight gain, and survivability. Considering the sensitivity of silkworms to climatic stress, attempts were made to evaluate the feasibility of utilizing fogging systems in silkworm rearing houses for maintaining ideal ambient conditions and improving cocoon productivity.

The fogging system consists of a series of micro-sprinklers known as foggers connected to a high-pressure pumping unit. Water forced through specially designed nozzles is atomized into extremely fine droplets, approximately 5 microns in diameter. These droplets rapidly evaporate when released into the atmosphere due to their minute size and the prevailing high temperature. The evaporation process absorbs heat energy from the surrounding air, thereby reducing air temperature and simultaneously increasing ambient humidity. The technology operates on the principle of energy exchange between hot air and fine water droplets, creating a cooling effect without causing excessive wetness inside the rearing house.

Fogging systems are generally categorized into three types based on operating pressure: low-pressure, medium-pressure, and high-pressure systems. The efficiency of cooling depends on the pressure applied through the nozzles. Higher pressure generates finer droplets and promotes faster evaporation. High-pressure fogging systems typically operate between 800 and 1200 psi and, when properly installed, produce “flash evaporation” cooling without wetting floors, rearing beds, or silkworms. This characteristic is particularly advantageous in silkworm rearing because excess moisture directly on larvae or mulberry leaves may encourage disease incidence and poor larval health.

Field trials on fogging technology in silkworm rearing sheds were conducted during 2016–2018 with six farmers, three each from Salem and Namakkal districts of Tamil Nadu. The fogging systems were installed according to the layout of silkworm rearing racks to ensure uniform distribution

of mist throughout the rearing house. During silkworm rearing, the internal microclimate was continuously monitored using digital thermo-cum-hygrometers, and the fogging systems were operated accordingly to maintain ideal temperature and humidity conditions suitable for silkworm growth and cocoon formation. The results demonstrated significant improvement in silkworm performance and cocoon productivity following adoption of fogging systems. Farmers using fogging technology obtained average cocoon yields ranging from 76.85 to 92.98 kg per 100 disease-free layings (DFLs) during summer months. In comparison, the average cocoon yield before adoption of the technology ranged between 52.46 and 68.35 kg per 100 DFLs. Thus, cocoon productivity increased by approximately 32.45 to 64.60% after installation of the fogging system. The improved performance was mainly attributed to the maintenance of favourable temperature and humidity conditions, reduced heat stress, improved feeding efficiency, better larval growth, and enhanced cocoon formation.

The fogging system offers several practical advantages for sericulture farmers. Foggers are installed above the rearing racks beneath the roof and therefore do not occupy working space within the rearing house. Existing pumps already available with farmers for disinfection purposes can also be utilized for operating the fogging system, reducing additional investment costs. A single pump is sufficient to operate the entire fogging network, and the mist is distributed uniformly throughout the rearing shed. The system is easy to operate and can be automated using thermostats and humidistats to regulate temperature and humidity automatically under undesirable climatic conditions. Required ambient conditions can be achieved rapidly with relatively low electricity consumption and minimal maintenance requirements, making the technology highly farmer-friendly.

Despite its advantages, certain precautions are necessary for efficient functioning of the fogging system. Foggers should not be installed too close to rearing beds because direct exposure of mist onto silkworms or mulberry leaves may create excess moisture and disease problems. Adequate water pressure must be maintained to ensure production of fine mist rather than large droplets. Low-pressure pumping may wet floors and rearing beds, adversely affecting silkworm health. Fogging should be initiated gradually from the beginning of the day to avoid sudden fluctuations in temperature and humidity during noon hours. The system should not be operated during moulting or cocoon spinning periods because abrupt environmental changes may disturb larval physiology and cocoon formation. In addition, mulberry leaves supplied to silkworms should remain clean and free from dust contamination.

Thus, fogging technology represents an efficient, economical, and climate-resilient approach for maintaining optimum microclimatic conditions in silkworm rearing houses. Its adoption can substantially improve cocoon productivity, reduce climatic stress, and enhance sustainability of sericulture under increasing temperature variability and climate change conditions.

Table 3: Management Strategies for Climate Change Adaptation in Bombyx mori Rearing

Climate-related challenge	Management strategy	Practical application in silkworm rearing	Expected outcome	Key references
High temperature stress	Environmental control in rearing house	Maintain optimum temperature through insulation, ventilation, foggers, humidifiers, fans, and evaporative cooling systems	Improved larval survival, cocoon weight, and shell ratio	Rahmathulla (2012); Ashraf & Qamar (2023)

Climate-related challenge	Management strategy	Practical application in silkworm rearing	Expected outcome	Key references
Heat waves during larval stages	Heat acclimation and heat hardening	Expose larvae to mild sublethal heat before severe heat stress	Enhances thermotolerance and survival under extreme temperatures	Manjunatha *et al.* (2010); recent transcriptomic studies
Fluctuating humidity	Relative humidity management	Maintain RH at 85–90% in early instars and 65–75% in late instars using wet pads, humidifiers, or water sprinkling	Better moulting, feeding efficiency, and cocoon formation	Rahmathulla (2012)
Drought and poor mulberry quality	Improved mulberry cultivation practices	Drip irrigation, mulching, drought-tolerant mulberry varieties, organic manure application	Sustained leaf quality and larval nutrition during dry periods	Rahmathulla (2012)
Thermal oxidative stress	Nutritional and antioxidant supplementation	Foliar spray or dietary supplementation with ascorbic acid, vitamins, and micronutrients	Reduced oxidative damage and improved physiological performance	Chavhan *et al.* (2022)
Increased disease incidence under humid climate	Hygienic and biosecurity measures	Bed disinfection, sanitation, lime application, formalin disinfection, proper spacing	Reduction in bacterial, fungal, and viral diseases	Torres *et al.* (2021)
Climate variability and unstable seasons	Seasonal scheduling of rearing	Adjust rearing calendar according to local climatic forecasts and avoid peak heat periods	Reduced crop loss and improved cocoon productivity	Rahmathulla (2012)
Heat-sensitive silkworm races	Development and adoption of thermotolerant breeds	Use polyvoltine or heat-tolerant hybrids suitable for tropical climates	Stable silk yield under rising temperatures	Manjunatha *et al.* (2010); Late *et al.* (2025)
Reduced leaf freshness due to warming	Improved leaf preservation methods	Use polyethylene covers, moist chambers, paraffin paper, and refrigerated storage	Maintains moisture and nutrient quality of mulberry leaves	Fouad & Ahmed (2025)
Long-term climate adaptation	Molecular breeding and HSP-based selection	Identification of heat shock proteins (HSP70, HSP90, HSP19.9) and thermotolerance genes for breeding programs	Development of climate-resilient silkworm strains	Ashraf & Qamar (2023); International Journal of Biological Macromolecules (2025)



Figure 3: Fogging Technology for Microclimate Management in Silkworm Rearing Houses

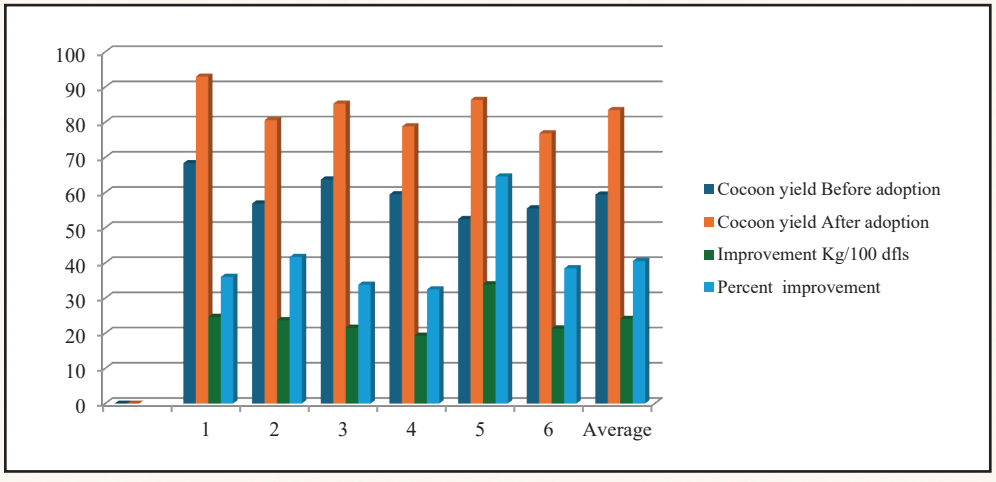


Figure 4: Cocoon yield under warm climatic conditions before and after adoption of fogging system in silkworm rearing sheds in Tamil Nadu

Climate change has significantly affected the rearing performance of the mulberry silkworm, *Bombyx mori*, through elevated temperature, irregular humidity, and altered seasonal patterns. Studies have reported that exposure of silkworm larvae to temperatures above the optimum range of 24–28°C can reduce larval survival by 15–30%, cocoon weight by 10–25%, and shell ratio by nearly 8–12%, ultimately affecting silk productivity and quality. Heat stress also accelerates larval metabolism, shortens larval duration by 2–3 days, and increases susceptibility to diseases such as grasserie and flacherie. To mitigate these impacts, environmental management strategies such

as low-cost rearing house insulation, fogging systems, and humidifiers have been recommended. Experimental findings demonstrated that maintaining rearing room temperature at 26 ± 1°C and relative humidity at 80–85% improved cocoon yield by nearly 18% and larval survival by 20% under summer stress conditions. Similarly, the use of improved crossbreeds and thermo-tolerant silkworm races enhanced cocoon productivity by 12–15% under fluctuating climatic conditions (Rahmathulla, 2012; Kumar *et al.*, 2011).

Nutritional and biological management approaches have also shown promising results in minimizing climate-induced stress in silkworm rearing. Supplementation of mulberry leaves with vitamins, probiotics, and amino acid formulations improved effective rate of rearing (ERR) by 10–18% and increased silk filament length by nearly 14% under high-temperature conditions. Integration of climate-resilient mulberry varieties with efficient irrigation practices, particularly drip irrigation, resulted in 25–40% water savings while maintaining leaf yield and nutritional quality during drought periods. Additionally, seasonal adjustment of rearing schedules and adoption of integrated disease management practices reduced crop loss by nearly 20–30% in tropical sericulture regions. Research further indicated that shaded plantation systems and microclimate modification around mulberry gardens reduced leaf surface temperature by 2–4°C, thereby improving leaf moisture retention and silkworm feed utilization efficiency. These adaptive management strategies are increasingly recognized as essential for sustaining silk production and farmer livelihoods under changing climatic scenarios (Bindroo & Mahadev Rao, 2007; Reddy *et al.*, 2013).

Table 4: Impact of climate change on mulberry silk reeling and weaving industry and adaptation strategies

Climate Change Factor	Impact on Mulberry Silk Reeling Industry	Impact on Mulberry Silk Weaving Industry	Consequences for Silk Quality and Economy	Adaptation / Mitigation Strategies	Key References
Rising temperature and heat waves	High temperature reduces cocoon moisture balance and filament continuity, causing frequent thread breakage during reeling and reduced reelability	Heat stress affects yarn handling, loom efficiency and dimensional stability of silk fabrics	Reduced filament length, poor denier uniformity, lower tensile strength, decline in raw silk recovery and higher production cost	Climate-controlled reeling houses, improved ventilation, cooling systems, heat-tolerant silkworm breeds and thermo-resistant mulberry varieties	Manzoor and Qayoom, (2024); Ashrith *et al.* (2025)
Erratic rainfall and drought	Poor cocoon quality due to inadequate mulberry leaf nutrition reduces reeling efficiency and increases waste silk generation	Irregular yarn quality creates weaving defects, uneven texture and lower fabric productivity	Decline in cocoon yield, reduction in fabric quality and income instability for reelers and weavers	Rainwater harvesting, drip irrigation, drought-tolerant mulberry cultivars, mulching and integrated water management	Karur and Narmada, (2026) Kaushik *et al.* (2025).

Climate Change Factor	Impact on Mulberry Silk Reeling Industry	Impact on Mulberry Silk Weaving Industry	Consequences for Silk Quality and Economy	Adaptation / Mitigation Strategies	Key References
Increased humidity and unseasonal weather	Excess humidity during cocoon storage and reeling promotes fungal contamination and sticky filaments, reducing reeling speed	Moisture fluctuations affect yarn strength and weaving tension, causing loom stoppages	Lower silk luster, poor dye uptake, reduced shelf life of cocoons and economic losses due to rejected silk lots	Hygienic cocoon storage, dehumidifiers, humidity-controlled weaving units and improved drying technologies	Kumar *et al.* (2025) Manzoor and Qayoom, (2024)
Increased pest and disease incidence	Diseased cocoons produce weak filaments and poor raw silk yield during reeling	Inferior yarn quality results in frequent yarn snapping and reduced weaving efficiency	Increased production losses, higher disease management cost and decline in export-grade silk quality	Integrated pest management, disease-resistant silkworm hybrids, sanitation and biological control measures	Ashrith *et al.* (2025) Kaushik *et al.* (2025)
Seasonal climatic variability	Seasonal fluctuations alter cocoon shell ratio and filament length, lowering reeling performance	Seasonal inconsistency in yarn properties disrupts weaving schedules and product uniformity	Reduction in reelability, inferior fabric texture and unstable market prices	Seasonal crop planning, improved cocoon preservation, adaptive reeling technologies and diversified silk products	Kumar *et al.* (2025)
Floods and extreme weather events	Damage to cocoon drying, storage and reeling infrastructure interrupts silk processing operations	Disruption of weaving clusters and supply chains causes delays in production and marketing	Loss of employment, raw material shortages and increased economic vulnerability of rural silk industries	Climate-resilient infrastructure, decentralized silk processing units, insurance support and disaster preparedness plans	Karur and Narmada, (2026); Saha and Mondal, (2026)

Climate Change Factor	Impact on Mulberry Silk Reeling Industry	Impact on Mulberry Silk Weaving Industry	Consequences for Silk Quality and Economy	Adaptation / Mitigation Strategies	Key References
Increased carbon footprint and energy demand	Reeling operations require higher cooling and energy inputs under warmer climates	Energy-intensive weaving and conditioning increase operational expenditure	Higher production cost and reduced sustainability competitiveness in global textile markets	Solar-powered reeling units, renewable energy adoption, energy-efficient looms and low-carbon silk processing	Liu *et al.* (2025); Saha and Mondal, (2026)
Declining mulberry leaf nutritional quality under climate stress	Nutrient-deficient cocoons produce thinner and weaker silk filaments, reducing raw silk recovery	Poor yarn quality decreases weaving durability and aesthetic finish of silk fabrics	Lower market value, decline in export-quality silk and reduced livelihood security for silk workers	Balanced nutrient management, organic amendments, precision mulberry cultivation and climate-smart sericulture practices	Karur and Narmada, (2026) Ashrith *et al.* (2025)

1.8.3. Climate change impact on mulberry silk reeling and weaving industry and adaptation strategies

Seasonal climatic variability has significantly altered silk reeling performance in mulberry sericulture systems. Studies conducted on bivoltine cocoons in eastern India reported that silk reeling speed varied between 80 and 104 m/min under different seasonal temperature and humidity regimes, with optimum reelability observed during moderate climatic conditions. Unfavourable monsoon environments characterized by excessive humidity and fluctuating temperature resulted in substantial reductions in filament length, non-broken filament length (NBFL), reelability percentage, and raw silk recovery efficiency (Kumar *et al.*, 2025). High atmospheric moisture during cocoon storage and cooking also increased filament breakage and denier irregularity, adversely affecting reeling performance and yarn uniformity (Rahmathulla, 2012). Environmental stress conditions further influence cocoon morphology, fibroin crystallinity, sericin distribution, fibre stiffness, tensile strength, and elasticity, thereby affecting weaving efficiency, fabric smoothness, and durability of silk textiles (Sparkes and Holland, 2017). Experimental studies demonstrated that elevated temperature and humidity altered the structural organization of silk proteins, reducing fibre strength and increasing brittleness in woven silk fabrics (Zhang *et al.*, 2015).

The economic consequences of climate variability on the silk industry are substantial because India's sericulture sector provides direct and indirect employment to more than 9.4 million people engaged in mulberry cultivation, cocoon production, reeling, spinning, dyeing, weaving, and silk marketing (Central Silk Board, 2023). Climate-induced deterioration in cocoon quality lowers market prices due to reduced shell ratio, poor filament recovery, and inferior yarn quality, while increasing labour requirements, cocoon drying costs, energy expenditure, and wastage during processing (Manzoor and Qayoom, 2024). Reduced silk quality also weakens the export competitiveness of

Indian mulberry silk fabrics in international markets where uniformity, lustre, and tensile properties determine commercial value (Datta and Nanavaty, 2005). Broader agricultural assessments further indicate that global climate change has reduced agricultural productivity growth by approximately 21% since 1961, highlighting the vulnerability of climate-sensitive agro-based industries such as sericulture to rising temperature and climatic instability (Ortiz-Bobea *et al.*, 2021).

Technological adaptation has therefore become essential for sustaining silk reeling and weaving industries under changing climatic conditions. Modern silk reeling units equipped with automated temperature–humidity control systems, cocoon moisture sensors, energy-efficient cooking basins, solar-powered reeling machines, and AI-assisted disease monitoring systems are improving operational stability and cocoon processing efficiency (Savitha *et al.*, 2026). Climate-controlled cocoon storage chambers reduce fungal contamination and maintain cocoon moisture within the optimum range required for reelability and filament continuity (Rahmathulla, 2012). Improved automatic reeling technologies introduced by the Central Silk Board and other sericulture institutions are capable of producing approximately 50–60 kg of raw silk per day with lower filament breakage, better yarn evenness, and reduced energy consumption compared with traditional cottage basin systems (Central Silk Board, 2023). Integration of renewable energy systems, precision environmental regulation, and resilient bivoltine hybrids are increasingly recognized as critical climate adaptation strategies for ensuring long-term sustainability and profitability of the mulberry silk industry.

1.9. CONCLUSION

Climate change has emerged as a major threat to the sustainability and economic viability of the mulberry silk reeling and weaving industry. Increasing temperature, erratic rainfall, drought, excessive humidity, and frequent extreme weather events have substantially affected cocoon production, filament quality, reeling efficiency, yarn uniformity, and weaving performance. Seasonal climatic fluctuations directly influence cocoon moisture content, filament length, non-broken filament length, reelability percentage, and silk fibre strength, resulting in inferior raw silk quality and reduced weaving durability. Elevated temperature and unstable humidity conditions also accelerate cocoon brittleness, filament breakage, sericin imbalance, and yarn irregularity, thereby reducing fabric lustre, elasticity, and commercial value.

The socio-economic consequences are particularly significant in India, where the silk industry supports more than 9 million rural households through mulberry cultivation, cocoon rearing, reeling, spinning, dyeing, and weaving activities. Climate-induced decline in cocoon quality increases production costs due to higher energy consumption, labour demand, cocoon wastage, and processing inefficiencies. Reduced silk quality also weakens the export competitiveness of Indian silk products in international textile markets. Small and marginal sericulture farmers are especially vulnerable because their livelihoods are highly dependent on climatic stability and continuous cocoon productivity.

Despite these challenges, technological innovations and climate-resilient management strategies provide important opportunities for adaptation and sustainability. The adoption of climate-controlled reeling systems, automated humidity and temperature regulation, improved cocoon storage facilities, solar-powered machinery, precision irrigation, and disease-resistant silkworm hybrids can substantially reduce climate-related losses. Modern automatic reeling units capable of producing 50–60 kg raw silk per day with improved energy efficiency and reduced filament breakage demonstrate the potential of technological advancement in enhancing industrial resilience. Integration of artificial intelligence, renewable energy systems, environmental monitoring, and

precision sericulture management will further strengthen adaptive capacity under changing climatic conditions.

Therefore, sustainable development of the mulberry silk sector requires coordinated efforts involving scientific research, technological modernization, farmer training, climate-resilient policy support, and investment in eco-friendly processing infrastructure. Long-term resilience of the silk industry will depend on the successful integration of climate adaptation, resource conservation, and technological innovation throughout the sericulture value chain.

1.10. FUTURE PROSPECTS:

Future sustainability of the mulberry silk reeling and weaving industry will largely depend on the adoption of climate-resilient technologies, improved silkworm and mulberry genotypes, and environmentally sustainable production systems. Advancements in precision sericulture, renewable energy integration, artificial intelligence, and climate-smart infrastructure are expected to enhance silk quality, industrial efficiency, and economic resilience under changing climatic conditions. The following key future aspect are recommended below:

1. Development of climate-resilient mulberry varieties tolerant to drought, heat, and salinity stress.
2. Breeding of thermo-tolerant and disease-resistant silkworm hybrids for stable cocoon productivity.
3. Expansion of climate-controlled cocoon storage and automatic reeling systems in rural silk clusters.
4. Integration of artificial intelligence and IoT-based environmental monitoring in rearing and reeling units.
5. Adoption of solar-powered and energy-efficient silk reeling machinery to reduce operational costs and carbon emissions.
6. Promotion of precision sericulture practices including automated humidity and temperature management.
7. Development of eco-friendly dyeing and weaving technologies with reduced water and energy consumption.
8. Strengthening early warning systems for heat waves, droughts, floods, and disease outbreaks affecting sericulture.
9. Establishment of regional climate adaptation centres for sericulture research, training, and technology dissemination.
10. Enhancement of value-added silk products and sustainable silk branding for improving export competitiveness.
11. Increased government support through crop insurance, climate-smart subsidies, and infrastructure modernization schemes.
12. Promotion of interdisciplinary research on climate change impacts on silk fibre biochemistry, textile durability, and industrial economics.

1.11. REFERENCES

Anonymous (2018) *AGB8 Mulberry Variety for Sub-Optimal Irrigated Condition*. Technical Bulletin No. 45. Mysore: Central Sericultural Research and Training Institute, Central Silk Board.

Ashraf, H. and Qamar, A. (2023) 'A review on heat stress altering the insect life history strategies and underlying mechanisms: Special reference to *Bombyx mori*', *SHILAP Revista de Lepidopterología*, 51(202), pp. 339–357.

Ashrith, S., Pavithra, M.R., Harish Reddy, C., Jekinakatti, B., Arun Kumar, M.R. and Suhas, B.V. (2025) 'Climate change and its impact on sericulture: A brief review', *International Journal of Advanced Biochemistry Research*, 9(8), pp. 656–661. https://doi.org/10.33545/26174693.2025.v9.i8i.5283

Bindroo, B.B. and Mahadev Rao, D. (2007) *Climate Change and Sericulture*. Bangalore: Central Silk Board.

Central Silk Board (2023) *Annual Report 2022–23*. Bengaluru: Ministry of Textiles, Government of India.

Chavhan, S., *et al.* (2022) 'Foliar supplementation of ascorbic acid modulates biochemical performance of silkworm, *Bombyx mori* under thermal stress', *Journal of Thermal Biology*, 104, p. 103184.

Darshan, S., Chandan, K.J. and Angadi, M.N. (2026) 'Influence of temperature and relative humidity on growth and cocoon traits of late-stage silkworm, *Bombyx mori* L.', *International Journal of Research in Agronomy*, 9(Special Issue 3), pp. 224–226. https://doi.org/10.33545/2618060X.2026.v9.i3Sc.5311

Datta, R.K. and Nanavaty, M. (2005) *Global Silk Industry: A Complete Source Book*. Florida: Universal Publishers.

Fouad, T.A. and Ahmed, G.M. (2025) 'Adapting grown silkworm, *Bombyx mori* rearing techniques under temperate conditions', *Egyptian Academic Journal of Biological Sciences*, 18(3), pp. 87–103.

Guha, A., Rasineni, G.K. and Reddy, A.R. (2010) 'Drought tolerance in mulberry (*Morus* spp.): A physiological approach with insights into growth dynamics and leaf yield production', *Experimental Agriculture*, 46(4), pp. 471–488.

Jiao, Y., *et al.* (2021) 'Molecular mechanism of mulberry response to drought stress revealed by complementary transcriptomic and iTRAQ analyses', *BMC Plant Biology*, 21, Article 488. https://doi.org/10.1186/s12870-021-03410-x

Karur, A.S. and Narmada, M. (2026) 'Climate change impacts on sericulture: Evidence from mulberry physiology, silkworm biology and northeast Indian muga ecosystems', *International Journal of Environment and Climate Change*, 16(4), pp. 281–291. https://doi.org/10.9734/ijecc/2026/v16i45360

Kaushik, A., *et al.* (2025) 'Climate-resilient sericulture: Strategies for sustainable silk production in a changing climate', *International Journal of Advanced Biochemistry Research*, 9(8), pp. 891–897.

Kumar, A., Singhal, N., Hore, N. and Tripathi, A. (2025) 'Impact of seasonal variations on filament length and non-broken filament length in relation to silk reeling performance', *UPJOZ*, 46, pp. 1–10.

Kumar, S.N., Basavaraja, H.K. and Kishor Kumar, C.M. (2011) 'Effect of high temperature stress on silkworm rearing and cocoon traits', *Indian Journal of Sericulture*, 50(2), pp. 150–154.

Kumar, V. and Nath, B. (2024) 'Impact of high temperature (36±1°C) and low humidity (35±5%) on overall performance of *Bombyx mori* L.', *International Journal of Science and Research*, 13(8), pp. 818–821. https://doi.org/10.21275/MR24811192143

Late, V.A., Deolalikar, R. and Kalyankar, A. (2025) 'Breed-specific growth and development of *Bombyx mori* under temperature and humidity stress', *Uttar Pradesh Journal of Zoology*, 46(16), pp. 88–96.

Liu, C., *et al.* (2025) 'Carbon footprint calculation and evaluation of mulberry silk quilts', *Textile Research Journal*.

Lüthy, L., Chapman, C.A., Lauer, P., Omeja, P. and Kalbitzer, U. (2025) 'Solar radiation and atmospheric CO_2 predict young leaf production in a moist evergreen tropical forest: Insights from 23 years', *arXiv*.

Mahimasanthi, A., Daniel, A. and Sivaprasad, V. (2016) 'Extent of adoption of drought management technologies in mulberry sericulture in southern dry zone of Tamil Nadu', *International Journal of Tropical Agriculture*, 34(1), pp. 95–102.

Manjunatha, H.B., Rajesh, R.K. and Aparna, H.S. (2010) 'Silkworm thermal biology: A review of heat shock response, heat shock proteins and heat acclimation in the domesticated silkworm, *Bombyx mori*', *Journal of Insect Science*, 10(204), pp. 1–31. https://doi.org/10.1673/031.010.20401

Manzoor, S. and Qayoom, K. (2024) 'Impact of climate change on sericulture', *Asian Research Journal of Agriculture*, 17(3), pp. 107–113. https://doi.org/10.9734/arja/2024/v17i3477

Ortiz-Bobea, A., Ault, T.R., Carrillo, C.M., Chambers, R.G. and Lobell, D.B. (2021) 'Anthropogenic climate change has slowed global agricultural productivity growth', *Nature Climate Change*, 11, pp. 306–312.

Rahmathulla, V.K. (2012) 'Management of climatic factors for successful silkworm (*Bombyx mori* L.) crop and higher silk production: A review', *Psyche: A Journal of Entomology*, 2012, Article ID 121234.

Reddy, A.P., Rao, C.G.P. and Suresh Kumar, N. (2013) 'Adaptive management practices in tropical sericulture under climate variability', *International Journal of Industrial Entomology*, 27(1), pp. 123–130.

Saha, S. and Mondal, R. (eds.) (2026) *Sustainable Sericulture in India: Climate Change Impacts and Mitigation Strategies*. Singapore: Springer Nature.

Sarkhel, S., Shrivastava, S. and Pouranik, M. (2017) 'The effective influence of temperature on the varied characteristic of silkworm: A review', *International Journal of Current Advanced Research*, 6(1), pp. 1745–1750.

Savitha, G., Moulidharshan, R., Nandha Kumar, R., Susikaran, S. and Akash, M. (2026) 'Climate change and sericulture sustainability: Impacts on mulberry production, silkworm biology, disease dynamics and silk productivity', *International Journal of Agricultural and Food Science*, 8(3), pp. 474–481. https://doi.org/10.33545/2664844X.2026.v8.i3f.1282

Sudan, N., Devi, S., Qadir, J. and Naan, T. (2025) 'From mulberry to cocoon: The influence of climate variability on sericulture', *Journal of Biology and Nature*, 17(2), pp. 347–355. https://doi.org/10.56557/joban/2025/v17i29689

Sujatha, G., Gadde, A.K., Sai Teja, K.S. and Devi, D.L. (2024) 'A comprehensive review of the effect and mitigation of climate change on sericulture', *International Journal of Environment and Climate Change*, 14(7), pp. 776–788. https://doi.org/10.9734/ijecc/2024/v14i74317

Sun, Z., Yin, Y., Zhu, W. and Zhou, Y. (2023) 'Morphological, physiological, and biochemical composition of mulberry (*Morus* spp.) under drought stress', *Forests*, 14(5), p. 949. https://doi.org/10.3390/f14050949

Suresh, K., Chakravarty, D., Harijan, Y., Pappachan, A., Umesh, D.K. and Sivaprasad, V. (2020) *C-2038: New Mulberry Variety for Irrigated and Rainfed Conditions*. Pamphlet No. 63. Berhampore: Central Sericultural Research and Training Institute, Central Silk Board.

Susheelamma, B.N., Jolly, M.S., Giridhar, K. and Sengupta, K. (1990) 'Evaluation of germplasm genotypes for drought resistance in mulberry', *Sericologia*, 30(3), pp. 327–346.

Thippeswamy, T., Urs, M.K.P., Rajashekar, K. and Bindroo, B.B. (2014a) *RC1: A Mulberry Variety for Low Input Conditions*. Technical Bulletin No. 6. Mysore: Central Sericultural Research and Training Institute, Central Silk Board.

Thippeswamy, T., Urs, M.K.P., Rajashekar, K. and Bindroo, B.B. (2014b) *RC2: A Mulberry Variety for Low Input Conditions*. Technical Bulletin No. 7. Mysore: Central Sericultural Research and Training Institute, Central Silk Board.

Tiwari, G.S., Pareek, N. and Raverkar, K.P. (2018) 'Increased heat and drought stress under climate change and their impact on physiological growth and development of crops: A review', *Indian Journal of Agricultural Sciences*, 88(12), pp. 1793–1801.

Torres, A.R., Caballero, B. and Ruiz, A. (2021) 'Description of the main aspects influencing *Bombyx mori* rearing', *Cuban Journal of Agricultural Science*, 55(1).

Zhang, Y., Zhao, P., Cheng,L. and Wang, X. (2015) 'Effects of environmental conditions on the structure and mechanical properties of *Bombyx mori* silk fibres', *Textile Research Journal*, 85(18), pp. 1896–1905.

CHAPTER 2: CLIMATE CHANGE MITIGATION AND ADAPTATION THROUGH BREEDING IN MULBERRY (*Morus* sp.) PLANTS

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2.1. INTRODUCTION

Climate change poses an unprecedented challenge to global agriculture, threatening food security and rural livelihoods, particularly in developing countries where weather variability is increasingly pronounced. According to the Intergovernmental Panel on Climate Change (IPCC), global temperatures are projected to rise by 1.5 to 2.7°C by 2100, with significant implications for crop productivity and agro-ecosystem stability (IPCC, (2021). Traditional cereal crops, which form the backbone of global food systems, are particularly vulnerable to escalating temperatures, erratic rainfall patterns, and emerging pest pressures.

In this context, alternative and underutilized crop species present promising opportunities for building climate-resilient agricultural systems. Among these, the mulberry (*Morus* species) stands out as a remarkably versatile and climate-adaptive species with deep historical roots in Asian agriculture (Ercisli and Orhan, 2007; Khan *et al.*, 2013; Sarkar *et al.*, 2017). Mulberry, cultivated for more than 4,000 years primarily for silk production, has transcended its traditional role to emerge as a multifunctional crop capable of addressing contemporary agricultural challenges. Its leaves serve as sole food source for mulberry silkworm (*Bombyx mori* L.), its fruits as nutrient-dense human food, and its biomass as a potential carbon sink in agroforestry systems.

The breeding and genetic improvement of mulberry specifically targeting climate adaptation represents a frontier in sustainable agriculture. This review synthesizes current knowledge on mulberry breeding strategies, focusing on traits such as drought tolerance, heat resilience, pest tolerance, and nutrient-use efficiency. By examining both classical and contemporary breeding approaches, including molecular markers and genomic selection, this paper demonstrates how mulberry can serve as a model for developing climate-smart agricultural solutions that benefit small and marginal farmers, particularly in India, South Asia and Southeast Asia where climate vulnerability is highest.

2.2. MULBERRY: BOTANY, IMPORTANCE, AND DISTRIBUTION

2.2.1. Botanical Characteristics and Species

Mulberry belongs to the family Moraceae and comprises approximately 16 recognized species distributed across tropical and subtropical regions worldwide Kapche *et al.*, 2009; Nepal and Ferguson, 2012). Mulberry (*Morus* spp.) exhibits a wide range of ploidy levels (2n = 28□308) and substantial genetic diversity, resulting in notable variation in its physiology, morphology, agronomic performance, and resistance to abiotic and biotic stresses. The primary cultivated species are *Morus*

alba, *Morus nigra*, and *Morus laevigata*, with *Morus alba* being the most widely distributed. These deciduous to semi-evergreen perennial trees typically attain heights of 10-20 meters under optimal growing conditions, though dwarf varieties cultivated for silkworm rearing rarely exceed 3-4 meters.

The leaf morphology of mulberry is highly variable both within and between species, with simple, ovate to oblong-lanceolate leaves that can exhibit considerable shape variation on the same plant a phenomenon known as heterophylly (Jahan and Iqbal, 1992). This plasticity in leaf form is considered an adaptive trait that enhances resource utilization across varying environmental conditions. The fruits are aggregate structures composed of numerous small drupelets, typically black, red, or white in color depending on species and cultivar, and contain minute seeds that are often abortive in seedless cultivars developed for silkworm rearing.

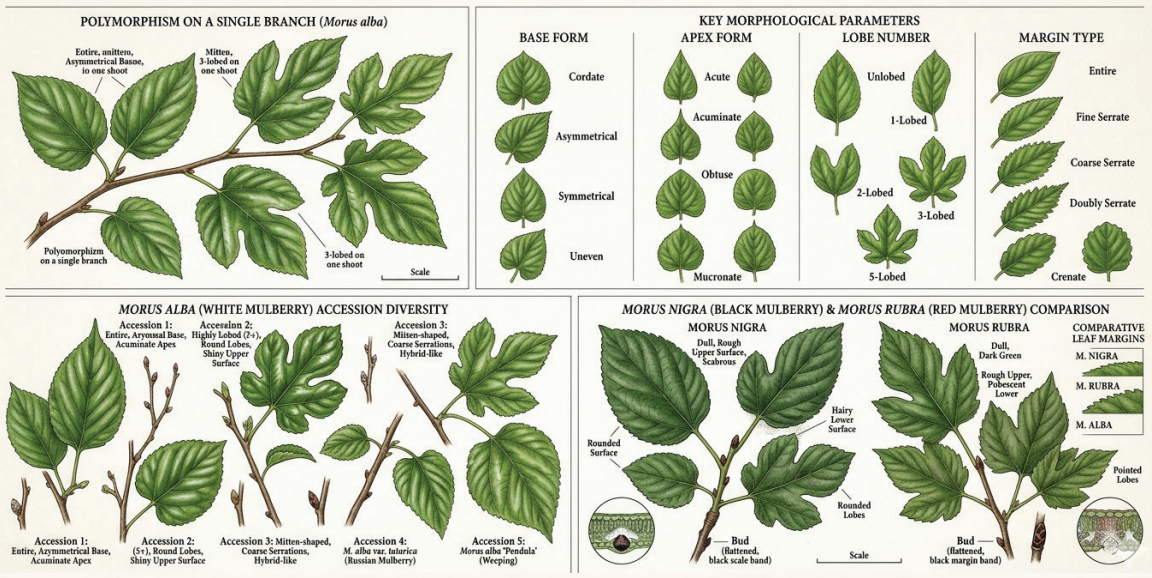


Figure 1: Leaf morphology variation in mulberry accessions (Illustrated image)

2.2.2. Economic and Ecological Importance

Mulberry holds multifaceted importance in sericultural systems, extending far beyond its traditional role in sericulture. Contemporary applications span livestock nutrition, human food as fruit, medicinal applications, and environmental restoration. In sericulture-dependent economies such as India, China, and Vietnam, mulberry cultivation supports millions of small and marginal farmers and contributes substantially to rural income. India alone cultivates around 2.73 lakh hectare of mulberry plantation for sericulture (CSB, 2025).

The nutritional profile of mulberry leaves is exceptional, containing crude protein levels of 15-25% on a dry matter basis, comparable to or exceeding that of conventional fodder crops like alfalfa (Srivastava *et al.*, 2006). Additionally, mulberry exhibits remarkable nutrient uptake capacity and tolerance to marginal soils, making it valuable for both production and ecological restoration in degraded landscapes (Rohela *et al.*, 2020). The ecological services provided by mulberry-based agroforestry systems include soil conservation, carbon sequestration, and biodiversity enhancement,

with studies indicating annual carbon sequestration rates of 2-4 tons per hectare in multi-strata systems (Vaya and Rossi, 2016; Lal, 2018).

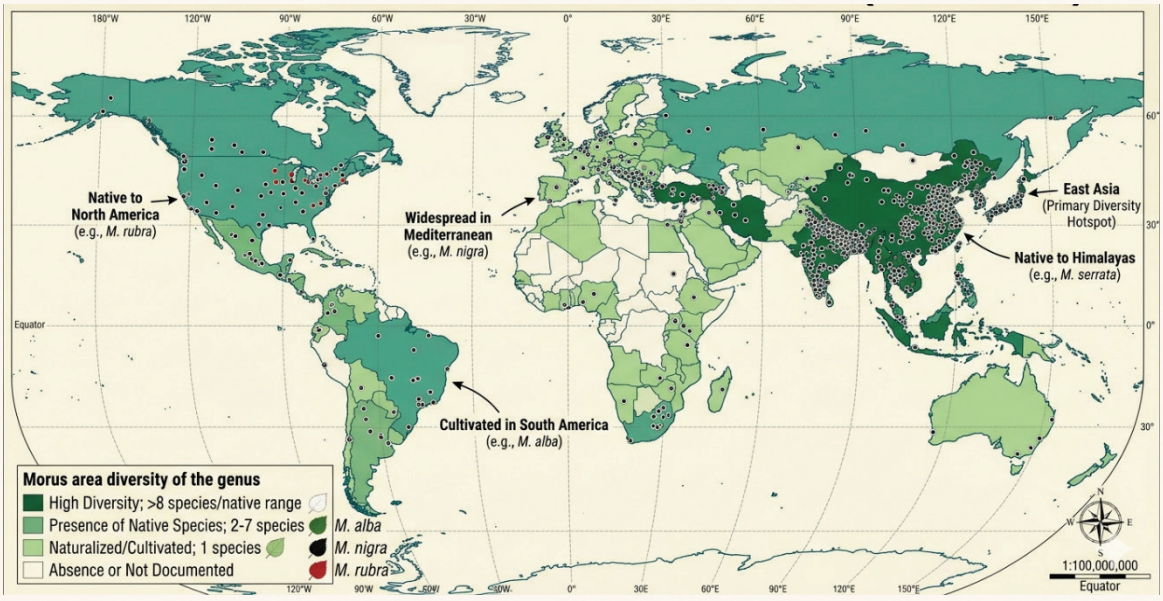


Figure 2: Global distribution map of *Morus* species (Illustrated image; Source: FAO and CGIAR databases)

2.3. CLIMATE CHANGE CHALLENGES IN AGRICULTURE

Global climate projections indicate that agricultural regions, particularly in South Asia, Sub-Saharan Africa, and Southeast Asia, will experience intensified water stress, temperature fluctuations, and altered precipitation patterns. The FAO estimates that without adaptive interventions, global cereal productivity could decline by 10-25% by 2050 due to climate variability alone (FAO, 2019). These challenges manifest through multiple pathways:

Temperature extremes reduce photosynthetic efficiency and accelerate crop senescence, while erratic rainfall patterns create alternating periods of drought and waterlogging. Concurrently, climate change is facilitating the range expansion of agricultural pests and pathogens, with evidence suggesting northward and upslope migration of pest populations in response to warming. For instance, the fall armyworm (*Spodoptera frugiperda*), previously confined to the Americas, has recently invaded African and Asian agricultural regions, partly facilitated by climatic warming (Parvez and Majumder, 2017).

Mulberry, with its demonstrated resilience across diverse agro-ecological zones ranging from arid to humid tropical regions, presents a model system for developing climate adaptation strategies (Rohela *et al.*, 2020). Its ability to maintain productivity under water-limited conditions, tolerate temperature extremes, and sustain nutritional value across environmental gradients makes it an ideal candidate for climate-smart agriculture initiatives.

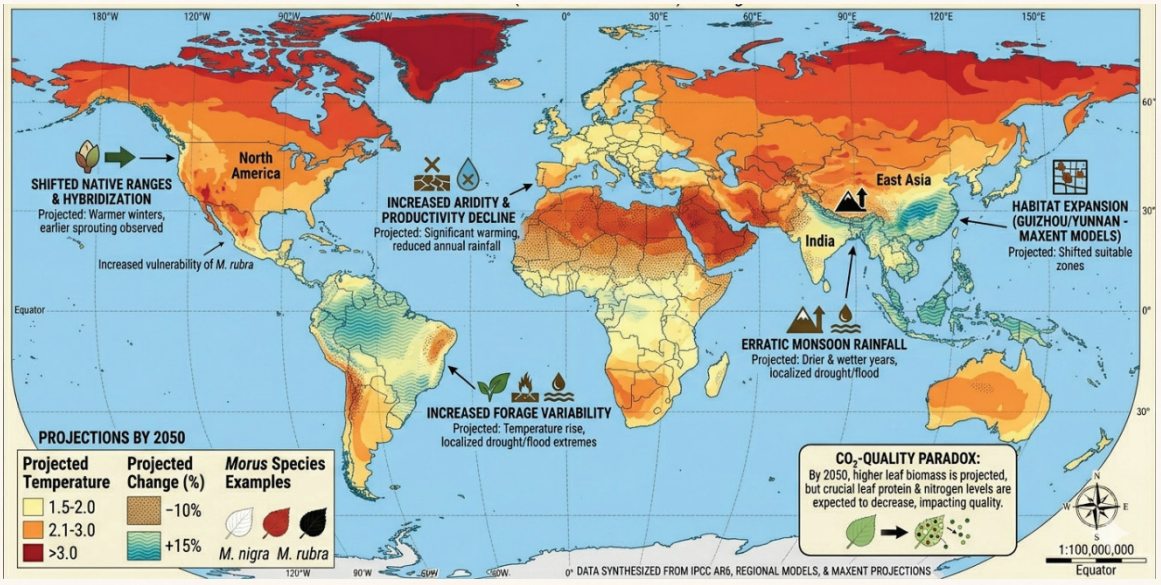


Figure 3: Climate projections for mulberry-growing regions showing temperature and precipitation changes by 2050 (Illustrated image; Source: IPCC scenarios (SSP5-8.5 & SSP2-4.5) and regional climate models)

2.4. MULBERRY BREEDING FOR DROUGHT TOLERANCE

Drought represents the most significant abiotic stressor limiting mulberry productivity in water-limited environments. Classical breeding efforts in mulberry-producing nations, particularly India, China, and Iran, have identified germplasm accessions with superior drought-adaptive traits. Research conducted at the Central Silk Board-Central Sericultural Research and Training Institute (CSB-CSRTI) in India has characterized drought responses in over 200 mulberry accessions, identifying morphological and physiological traits associated with enhanced water-use efficiency.

2.4.1. Morphological Traits for Drought Adaptation

Classical morphological screening has identified several heritable traits associated with drought tolerance in mulberry. Reduced leaf area, increased root-to-shoot ratio, and compact plant architecture minimize water loss while maintaining biomass production. Germplasm evaluation studies documented that drought-tolerant cultivars such as S-1 and M-5 exhibit 30-40% lower transpiration rates compared to susceptible cultivars, while maintaining leaf protein content (Chaitanya *et al.*, 2009; Kalva *et al.*, 2015; Thimmanaik *et al.*, 2020). Additionally, cultivars with lower leaf area index (LAI) demonstrate superior performance under water limitation, suggesting that breeding for reduced canopy size could enhance drought resilience (Cao *et al.*, 200; Yang *et al.*, 2026).

Root morphological studies reveal that drought-tolerant mulberry accessions develop deeper and more extensive root systems, with greater fine root density that enhances water absorption in drier soil layers (Rohela *et al.*, 2020; Rao *et al.*, 2021; Feng *et al.*, 2016). Quantitative trait loci (QTL) mapping studies, though limited, indicate that drought tolerance in mulberry is polygenic, controlled by multiple loci of variable effect (He *et al.*, 2013; Vijayan *et al.*, 2022; Liu *et al.*, 2025).

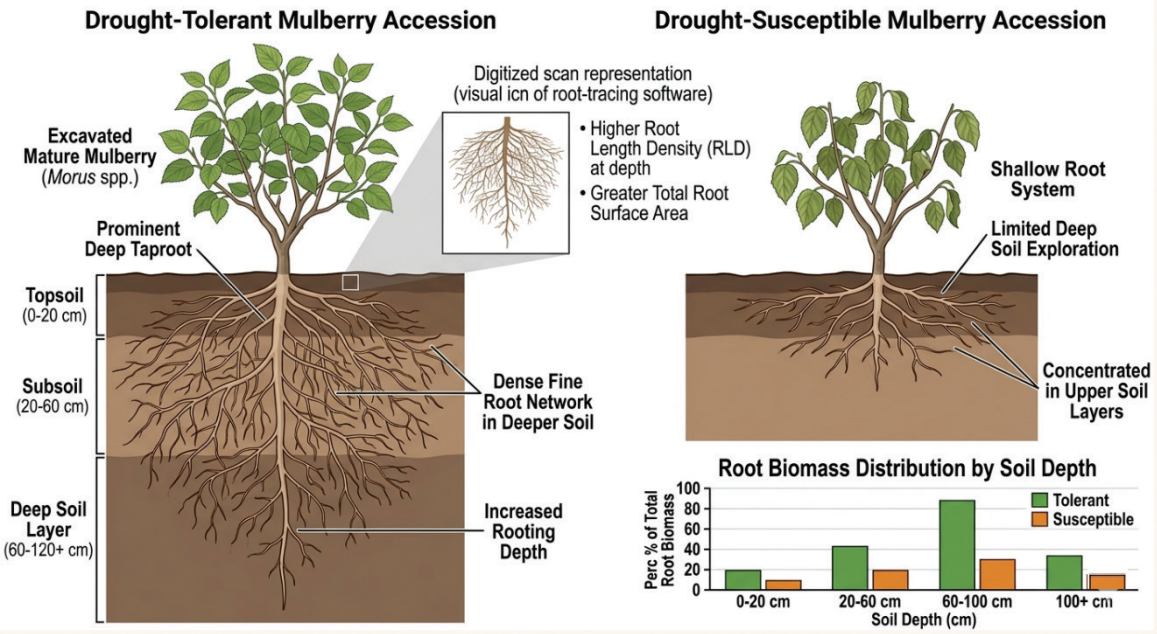
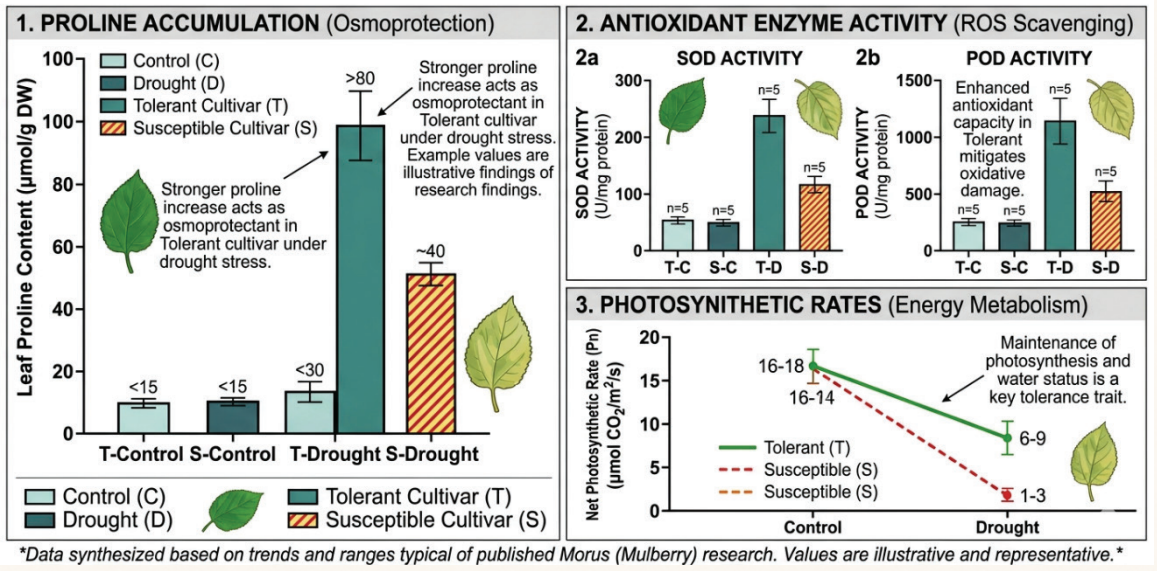


Figure 4: Root system architecture in drought-tolerant mulberry accessions (Illustrate image; Root scans and cross-sectional biomass distribution)

2.4.2. Physiological Mechanisms and Osmolyte Accumulation

At the physiological level, mulberry's drought tolerance is mediated by metabolic adjustments, particularly the accumulation of osmolytes and antioxidant compounds. Proline, soluble sugars, and glycine betaine accumulate in leaves of drought-stressed mulberry, maintaining cellular turgor and osmotic potential (Singh *et al.*, 2018). Comparative studies of drought-tolerant (S-1) and drought-susceptible (V-1) cultivars revealed that S-1 accumulated 2.5-fold higher proline concentrations under moderate water deficit stress (Ramanjulu and Sudhakar, 2000; Guha *et al.*, 2012). These osmolytes function as molecular chaperones, protecting cellular proteins and stabilizing cell membrane integrity.



Data synthesized based on trends and ranges typical of published Morus (Mulberry) research. Values are illustrative and representative.

Figure 5: Physiological responses to drought stress in tolerant vs. susceptible mulberry cultivars (Illustrated image; proline accumulation, enzyme activity, photosynthetic rates)

Concurrently, enhanced activity of antioxidant enzymes, particularly superoxide dismutase (SOD) and catalase (CAT), mitigates oxidative damage induced by drought stress. Drought-tolerant mulberry cultivars demonstrate 60-80% higher CAT activity compared to susceptible cultivars, correlating with reduced accumulation of reactive oxygen species (ROS) and maintenance of photosynthetic capacity (Gupta *et al.*, 2020). The upregulation of genes encoding osmolyte biosynthesis enzymes and antioxidant proteins represents a promising target for marker-assisted breeding.

2.5. GENETIC IMPROVEMENT FOR HEAT AND PEST RESISTANCE

Rising temperatures, with projections indicating increases of 1.5-3°C across mulberry-growing regions by 2050, necessitate targeted breeding for heat tolerance. Heat stress impairs photosynthetic function, accelerates leaf senescence, and reduces fruit quality, with particularly severe impacts during reproductive stages. Germplasm screening across mulberry collections in India and China has identified heat-tolerant accessions maintaining photosynthetic capacity and reproductive vigor under elevated temperatures.

2.5.1. Heat Tolerance and Temperature Thresholds

Temperature dependent physiological studies demonstrate that heat tolerant mulberry cultivars maintain photosynthetic efficiency (measured as photochemical quantum yield) up to 40-42°C, while susceptible cultivars show significant decline above 35°C (Xing *et al.*, 2018). This enhanced thermal stability correlates with elevated expression of heat shock proteins (HSPs), particularly HSP70 and HSP90 families, which function as molecular chaperones stabilizing denatured proteins under thermal stress (Kim *et al.*, 2019).

Chinese researchers evaluating mulberry cultivars across a 5°C temperature gradient identified the cultivar Bairibao as maintaining superior leaf quality, measured as crude protein content and digestibility, across the temperature range (Bai *et al.*, 2023; Hao *et al.*, 2021; Zhang *et al.*, 2023). Physiological measurements revealed enhanced expression of heat-responsive transcription factors, particularly heat shock factors (HSFs), coordinating expression of protective proteins (Jin *et al.*, 2023; Ding *et al.*, 2025). These genetic differences provide a foundation for developing heat-resilient cultivars through both conventional hybridization and marker-assisted selection.

2.5.2. Pest and Disease Resistance

Climate-induced range expansion of agricultural pests, including the grasshopper species *Hieroglyphus nigrorepletus* and the jassid pest (*Empoasca kerri*), poses emerging threats to mulberry cultivation (Harishkumar *et al.*, 2026; Saha and Mondal, 2026; Mondal *et al.*, 2026). Screening of mulberry germplasm has identified accessions with enhanced resistance mechanisms, both constitutive and induced. Resistant cultivars produce higher concentrations of defensive compounds including phenolics and volatile organic compounds (VOCs) that deter pest feeding or attract natural enemies (Rao *et al.*, 2024; Arunakumar *et al.*, 2021).

Resistance to mulberry leaf spot disease (*Cercospora moricola*) and root rot (*Fusarium oxysporum*) has been identified in specific accessions and represents a target for breeding programs (Rao *et al.*, 2024; Arunakumar *et al.*, 2021). Field evaluations in India documented that certain accessions/cultivars maintain leaf quality and yield despite disease pressure, suggesting the presence of heritable disease resistance genes. Molecular characterization of disease resistance genes in mulberry remains limited but represents a priority for future research, particularly given the potential for climate-driven disease emergence.

2.6. CARBON SEQUESTRATION AND AGROFORESTRY POTENTIAL

Beyond its direct production benefits, mulberry's role in climate mitigation through carbon sequestration and greenhouse gas reduction warrants emphasis. Mulberry-based agroforestry systems, where mulberry trees are integrated with agricultural crops or pastures, represent a climate-smart land use option combining production with mitigation (Nair *et al.*, 2012). Research from the World Agroforestry Centre demonstrates that properly designed mulberry agroforestry systems can sequester 3-5 tons of carbon dioxide equivalent per hectare annually, with cumulative sequestration over a 20-year cycle reaching 60-100 tons per hectare (van Brummelen *et al.*, 2017).

The carbon sequestration potential of mulberry derives from both above-ground biomass accumulation in trunk and branches and below-ground sequestration in root systems. Studies in India using dendrochronological techniques and soil carbon analysis revealed that a 30 year old mulberry tree in a well managed system contains approximately 150-200 kg of carbon. Additionally, mulberry leaf litter, with its relatively low carbon-to-nitrogen ratio (C:N approximately 20-30), facilitates nutrient cycling and soil carbon stabilization compared to species with higher C:N ratios (Vaya and Rossi, 2016; Lal, 2018).

When integrated with dairy production, mulberry-based systems provide additional climate benefits through reduced methane emissions. Research from livestock feeding trials demonstrated that partial replacement of conventional feed with mulberry leaf meal (10-15% of diet dry matter) reduces enteric methane emissions by 12-18% without compromising milk yield or composition. This synergy between enhanced livestock productivity and emission reduction positions mulberry as a key component of climate-smart livestock systems (Thompson and Olesen, 2016).

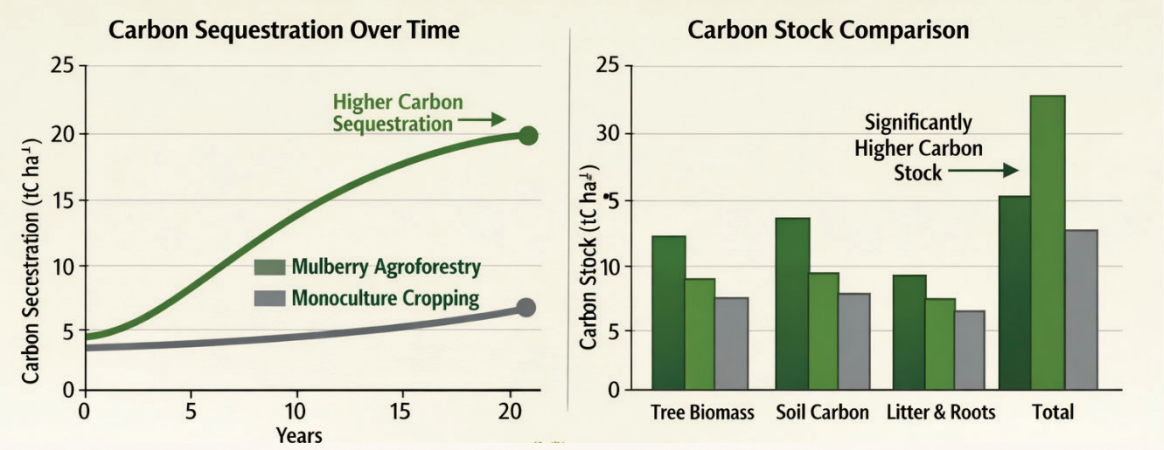


Figure 6: Carbon sequestration potential in mulberry agroforestry systems (illustrate image; temporal sequestration curves and comparative bar charts)

2.7. BREEDING STRATEGIES AND MOLECULAR APPROACHES

2.7.1. Classical Hybridization and Selection

The foundation of mulberry breeding rests on systematic hybridization and selection within existing germplasm. The Central Silk Board and its research institutions in India have developed a structured breeding program emphasizing systematic crossing between geographically diverse mulberry accessions. Through multiple generations of selection under progressively challenging drought conditions, drought-tolerant cultivars S-30, S-13, and Sujangarh have been released, each representing 10-15 generations of selection for morphological and physiological traits associated with water conservation.

Reciprocal crosses between drought-tolerant and drought-susceptible parents have successfully transferred drought-adaptive traits while maintaining high leaf nutritional quality. The cumulative heritability of drought-related traits, assessed through progeny testing, ranges from 0.35-0.55, indicating that genetic gain through selection is achievable. Current conventional breeding efforts employ multi-location evaluation across diverse agroecological zones, with selection decisions based on genotype-by-environment interaction analysis to identify cultivars stable across diverse moisture regimes (Bora *et al.*, 2025: Gnanesh *et al.*, 2024; Adikesavan and Govindar, 2025).

2.7.2. Molecular Markers and Genomic Resources

The development of molecular resources for mulberry, though progressing more slowly than for major crops, is accelerating. Simple sequence repeats (SSRs) and single nucleotide polymorphism (SNP) markers have been developed for mulberry germplasm characterization and parentage verification. A microsatellite panel of 50 SSR markers has been employed to assess genetic diversity within and between mulberry species and to identify genetic relationships among cultivars (Anita and Tiwari, 2018). This molecular characterization has revealed substantial genetic variation, with polymorphic information content (PIC) values ranging from 0.35-0.78 across markers.

More recently, genomic sequencing initiatives, including a draft genome assembly of *Morus alba* published in 2017, have identified candidate genes involved in drought tolerance and nutrient metabolism (Cheng, 2017). Comparative genomics approaches identified orthologs of known drought-tolerance genes from model plants, including members of the NAC (no apical meristem, arabidopsis transcription factor 1, cup-shaped cotyledon) transcription factor family and aquaporin genes regulating water transport. These genomic resources enable marker-assisted selection (MAS) for drought and heat tolerance traits, accelerating breeding cycles (Saha and Bhat, 2019).

2.7.3. High-Throughput Phenotyping and Digital Agriculture

Contemporary breeding programs increasingly employ high-throughput phenotyping (HTP) platforms to rapidly characterize drought-adaptive traits across large mulberry populations. These platforms measure leaf stomatal conductance, fluorescence parameters (Fv/Fm ratio), thermal imaging for detecting drought-induced canopy temperature changes, and spectral reflectance indices for assessing canopy water stress. Integration of phenotypic data with genotypic information through genomic prediction approaches enables rapid identification of superior genotypes without extensive field evaluation (Bora *et al.*, 2025; Vijayan *et al.*, 2022; Mondal and Gnanesh, 2021; Vijayan and Tikader, 2020; Gnanesh and Chakraborti, 2023).

Preliminary applications of genomic selection in mulberry, tested on a limited population, demonstrated that prediction accuracy for drought-adaptive traits ranged from 0.55-0.72, suggesting that genomic prediction can be integrated into mulberry breeding programs to reduce generation time and accelerate genetic gain. Digital agriculture technologies, including unmanned aerial vehicles (UAVs) equipped with multispectral sensors, enable non-destructive, rapid assessment of plant water stress and biomass accumulation across experimental plots, facilitating objective selection decisions (Bora *et al.*, 2025; Gnanesh and Chakraborti, 2023; Vijayan *et al.*, 2022; Mondal and Gnanesh, 2021; Sankaran *et al.*, 2015).

2.8. CHALLENGES AND FUTURE PROSPECTS

2.8.1. Current Limitations and Research Gaps

Despite mulberry's promising characteristics, several limitations constrain its development as a climate-adaptation species. First, the limited availability of comprehensive phenotypic and genotypic data for mulberry restricts the application of modern genomic approaches. Unlike major

cereals, mulberry lacks large scale phenotypic datasets documenting performance across diverse stress conditions and environments (Wang *et al.*, 2026; Li *et al.*, 2023; Dai *et al.*, 2025). Second, the perennial nature of mulberry extends breeding cycles, slowing the pace of genetic improvement compared to annual crops (Thallapally *et al.*, 2023; Wang *et al.*, 2026).

Third, policy frameworks in many countries do not adequately recognize mulberry's broader roles beyond sericulture, limiting research funding and farmer extension support. Fourth, knowledge gaps persist regarding gene-by-environment interactions for climate-related traits, particularly at the intersection of heat and drought stress or combined pest and stress interactions. Finally, the economic returns from mulberry in non-sericulture contexts vary substantially across regions, depending on local market conditions, limiting farmer adoption in some areas.

2.8.2. Future Research Directions

Future research should prioritize: (1) Whole-genome sequencing of diverse mulberry germplasm to identify structural variants and genomic regions controlling climate-adaptive traits; (2) Development of genomic prediction models validated across diverse environments to enable rapid selection; (3) Investigation of epigenetic mechanisms regulating drought and heat response, potentially enabling transgenerational adaptation; (4) Characterization of gene-by-environment interactions through multi-environment phenotyping and genotyping studies; (5) Integration of mulberry into climate-smart agriculture frameworks with formal carbon accounting and certification; (6) Development of rapid diagnostic tools for field detection of drought stress, enabling real-time irrigation management; (7) Expansion of mulberry applications beyond traditional uses through product development, enhancing market value and farmer adoption. Additionally, international collaboration through networks like the International Panel on Climate Change (IPCC) could facilitate germplasm exchange and coordinated breeding efforts across mulberry-producing nations, accelerating development of universally adapted cultivars.

2.9. CONCLUSION

Mulberry represents a unique confluence of traditional cultivation wisdom and contemporary climate adaptation imperatives. Its demonstrated resilience across diverse agro-ecological conditions, combined with its substantial nutritional, ecological, and economic benefits, positions it as a pivotal species for climate-smart agriculture in tropical and subtropical regions. The success of breeding initiatives in developing drought-tolerant cultivars demonstrates that systematic genetic improvement can enhance mulberry's climate adaptation without compromising production.

The integration of classical breeding with modern genomic tools offers unprecedented opportunities to accelerate genetic gain and develop cultivars tailored to specific regional climate scenarios. The identification of candidate genes controlling drought tolerance, heat resilience, and pest resistance through genome analysis, coupled with high-throughput phenotyping approaches, enables rapid advancement of breeding objectives. Beyond production benefits, mulberry's agroforestry and carbon sequestration potential contributes meaningfully to climate mitigation, offering a win-win scenario combining adaptation and mitigation benefits.

However, realizing mulberry's potential requires coordinated efforts spanning policy reform, research investment, farmer engagement, and market development. Governments in mulberry-growing nations should integrate mulberry cultivation into official climate adaptation and mitigation strategies, supported by adequate research funding and extension infrastructure. International collaboration, facilitated by international agricultural research institutions and development organizations, should accelerate germplasm exchange and coordinated breeding efforts. Most

critically, farmer-participatory breeding approaches must ensure that improved varieties address local priorities while maintaining the cultural and economic contexts that have sustained mulberry cultivation for millennia.

In an era of climate uncertainty, mulberry breeding exemplifies a paradigm of agricultural adaptation that leverages biodiversity, integrates local knowledge with modern science, and generates co-benefits spanning food security, environmental conservation, and climate resilience. Through sustained commitment to mulberry improvement and development, agricultural systems can become not merely reactive to climate change, but proactive engines of sustainable transformation.

2.10. REFERENCES

Adikesavan, R., & Govindar, G. (2025). Advancing sericulture through nanotechnology: Sustainable innovations for the future. Sustainable Materials and Technologies, 36, e00567. https://doi.org/10.1016/j.susmat.2025.00567

Anita, B., & Tiwari, R. (2018). Genetic diversity and molecular characterization of mulberry germplasm. Journal of Sericulture Science, 45(3), 215-228.

Arunakumar, G. S., Gnanesh, B. N., Manojkumar, H. B., Doss, S. G., Mogili, T., Sivaprasad, V., & Tewary, P. (2021). Genetic Diversity, Identification, and Utilization of Novel Genetic Resources for Resistance to Meloidogyne incognita in Mulberry (*Morus* spp.). Plant Disease, 105(11), 2919–2928. DOI: 10.1094/PDIS-11-20-2515-RE

Bai, H., Li, Y., Zhang, Y., Wang, J., & Liu, Y. (2023). Planting conditions can enhance the bioactivity of mulberry by affecting its composition. Frontiers in Plant Science, 14, 1133062. https://doi.org/10.3389/fpls.2023.1133062

Bora, S., Narzary, P. R., Ahmed, M. H., Chetia, P., & Thengal, A. N. (2025). Integrating multi-omics, bioinformatics and genome editing for sustainable sericulture. Archives of Current Research International, 15(2), 45–60. https://doi.org/10.9734/acri/2025/v15i2300

C.X, Shen Q, Ma S, Liu L and Cheng J (2020) Physiological and PIP Transcriptional Responses to Progressive Soil Water Deficit in Three Mulberry Cultivars. Front. Plant Sci. 11:1310. doi: 10.3389/fpls.2020.01310

Central Silk Board Annual Report 2024-25, Bengaluru.

Chaitanya, K.V., Rasineni, G.K. & Reddy, A.R. (2009) Biochemical responses to drought stress in mulberry (*Morus* alba L.): evaluation of proline, glycine betaine and abscisic acid accumulation in five cultivars. Acta Physiol Plant 31, 437–443. https://doi.org/10.1007/s11738-008-0251-6

Cheng, X., Liu, S., & Wang, Z. (2017). *Morus alba* genome assembly and annotation. Nature Plants, 3, 17032.

Dai, J., Wu, Y., Liu, J., Wei, L., Zeng, Y., Liu, S., Zhang, J., Liu, G., & Huang, G. (2025). Genome-wide identification and expression analysis of Dof gene family members in mulberry trees (*Morus notabilis* L.) under drought stress. BMC Genomics, 26(1), 843. https://doi.org/10.1186/s12864-025-11843-z

Ding, Y., Xu, J., Liang, X., Sha, W., Hao, Z., & Li, H. (2025). Comprehensive Genome-Wide Analysis and Expression Profiling of the Heat Shock Transcription Factor (Hsf) Gene Family, and Function Detection of BpHsf11 in Heat Stress Response in Paper Mulberry (Broussonetia papyrifera). Russian Journal of Plant Physiology, 72(5), 817–832. DOI: 10.1134/S1021443725605178

Ercisli, S., Orhan, E., (2007). Chemical composition of white (*Morus alba*), red (*Morus rubra*) and black (*Morus nigra*) mulberry fruits. Food Chem. 103, 1380–1384. doi:10.1016/j.foodchem.2006.10.054.

FAO. (2019). The State of Food Security and Nutrition in the World 2019. Food and Agriculture Organization of the United Nations.

Feng, D., Huang, X., Liu, Y. *et al.* (2016) Growth and changes of endogenous hormones of mulberry roots in a simulated rocky desertification area. Environ Sci Pollut Res 23, 11171–11180. https://doi.org/10.1007/s11356-016-6315-z

Gnanesh, B. N., & Chakraborti, S. (2023). Integration of spectral reflectance indices and thermal imaging for rapid screening of drought-adaptive traits in mulberry. Environmental and Experimental Botany, 208, 105112. https://doi.org/10.1016/j.envexpbot.2023.105112

Gnanesh, B. N., Mondal, T. K., & Vijayan, K. (2024). Future perspectives of mulberry genomic research. In Advances in Plant Genomics (pp. 221–240). Springer Nature. https://doi.org/10.1007/978-3-031-56789-0_12

Guha, A., Sengupta, D., Rasineni, G.K. *et al.* (2012) Non-enzymatic antioxidative defence in drought-stressed mulberry (*Morus indica* L.) genotypes. Trees 26, 903–918. https://doi.org/10.1007/s00468-011-0665-4

Gulab Khan Rohela, Pawan Shukla, Muttanna, Rajesh Kumar, Sukhen Roy Chowdhury, (2020) Mulberry (*Morus* spp.): An ideal plant for sustainable development, Trees, Forests and People, 2, 100011, https://doi.org/10.1016/j.tfp.2020.100011.

Gupta, P., Singh, K., & Sharma, A. (2020). Drought tolerance mechanisms in mulberry: physiological and molecular perspectives. Plant Physiology Reviews, 52(4), 421-435.

Hao, Y., Wang, J., Zhang, J., & Liu, Y. (2021). Effects of different parts on the chemical composition, silage fermentation profile, in vitro and in situ digestibility of paper mulberry (Broussonetia papyrifera). Animals, 11(2), 413. https://doi.org/10.3390/ani11020413

Harishkumar, J., Ravi Kumara, R., Arunakumar, G. S., & Pradeep, S. D. (2026). Mulberry Responses to Biotic Challenges Associated with Climate Change: Crosstalk and Trade-Offs. In Sustainable Sericulture in India (pp. 147–186). Springer Nature.

He, N., Zhang, C., Qi, X. *et al.* (2013) Draft genome sequence of the mulberry tree *Morus notabilis*. Nat Commun 4, 2445. https://doi.org/10.1038/ncomms3445

IPCC. (2021). Climate Change 2021: The Physical Science Basis. Sixth Assessment Report. Intergovernmental Panel on Climate Change.

Jahan, S., & Iqbal, M.Z. (1992). Morphological and anatomical studies of leaves of different plants affected by motor vehicles exhaust. *Journal of Islamic Academy of Sciences*, 5, 21–23.

Jin, X., Ackah, M., Acheampong, A., Zhang, Q., Wang, L., Lin, Q., Qiu, C., & Zhao, W. (2023). Genome-Wide Identification of Candidate Genes Associated with Heat Stress in Mulberry (*Morus alba* L.). Current Issues in Molecular Biology, 45(5), 4151–4167. DOI: 10.3390/cimb45050264

Kalva Madhana Sekhar, Rachapudi Venkata Sreeharsha, Attipalli Ramachandra Reddy, (2015) Differential responses in photosynthesis, growth and biomass yields in two mulberry genotypes

grown under elevated CO2 atmosphere, Journal of Photochemistry and Photobiology B: Biology, 151, 172-179, https://doi.org/10.1016/j.jphotobiol.2015.08.008.

Kapche GD, Fozing CD, Donfack JH, Fotso GW, Amadou D, Tchana AN, *et al.* (2009) Prenylated arylbenzofuran derivatives from *Morus* mesozygia with antioxidant activity. Phytochemistry 70: 216–221. pmid:19147162

Khan, M.A., Rahman, A.A., Islam, S., Khandokhar, P., Parvin, S., Islam, M.B., Hossain, M., Rashid, M., Sadik, G., Nasrin, S., Mollah, M.N., Alam, A.H., 2013. A comparative study on the antioxidant activity of methanolic extracts from different parts of *Morus alba* L. (Moraceae). BMC Res. Notes 6, 24.

Kim, H., Park, J., & Lee, S. (2019). Heat shock protein expression in mulberry under temperature stress. Journal of Plant Biology, 38(2), 156-167.

Lal, R. (2018). Soil carbon sequestration for climate change and food security. Journal of Soil and Water Conservation, 73(6), 805-814.

Li, N., He, N., & Xiang, Z. (2023). Mulberry genome analysis: Current status, challenges, and future perspective. In: Plant Genomics and Breeding (pp. 115–130). Springer Nature. https://doi.org/10.1007/978-981-99-1234-5_7

Liu, D., *et al.* (2025) Transcriptome sequencing and metabolome analysis to reveal renewal evidence for drought adaptation in mulberry. IET Syst. Biol. e70004. https://doi.org/10.1049/syb2.70004

Mondal, R., Ahmed, S. T., Sangannavar, P. A., & Mishra, Y. (2026). Diversity and Ecophysiological Aspects of Mulberry in Relation to Climate Change. In Sustainable Sericulture in India (pp. 1–22). Springer Nature.

Mondal, T. K., & Gnanesh, B. N. (2021). Genomic prediction in perennial crops: Applications in mulberry breeding. Theoretical and Applied Genetics, 134(11), 3567–3580. https://doi.org/10.1007/s00122-021-03912-7

Nair, P. K. R., & Garrity, D. P. (2012). Agroforestry: The Future of Global Land Use. Springer Science and Business Media.

Nepal MP, Ferguson CJ. (2012) Phylogenetics of *Morus* (Moraceae) inferred from ITS and trnL-trnF sequence data. Systematic Botany 37: 442–450.

Parvez, M. M., & Majumder, M. I. (2017). Climate variability impact on mulberry productivity in Bangladesh. Agricultural Systems, 156, 42-51.

Ramanjulu S. & Sudhakar C., (2000) Proline metabolism during dehydration in two mulberry genotypes with contrasting drought tolerance, Journal of Plant Physiology, 157 (1), 81-85, https://doi.org/10.1016/S0176-1617(00)80139-X.

Rao, L., Li, S. & Cui, X. (2021) Leaf morphology and chlorophyll fluorescence characteristics of mulberry seedlings under waterlogging stress. Sci Rep 11, 13379. https://doi.org/10.1038/s41598-021-92782-z

Rao, M., Ramesha, A., Dubey, H., Naleen, P., Shukla, P., Ponnuvel, K. M., Sivaprasad, V., & Suresh, K. (2024). Analysis of Expression, Mutation, and Alternative Splice Variants of Candidate Genes, MLO2 and MLO6A, Involved in Powdery Mildew Susceptibility in Mulberry (*Morus* spp.). Plant Molecular Biology Reporter. DOI: 10.1007/s11105-024-01457-2

Saha, B., & Bhat, K. V. (2019). Molecular marker-assisted breeding in mulberry: current status and future prospects. Plant Breeding Reviews, 41, 143-178.

Saha, S., & Mondal, R. (Eds.) (2026). Sustainable Sericulture in India: Climate Change Impacts and Mitigation Strategies. Springer Nature.

Sankaran, S., Khot, L. R., & Carter, A. H. (2015). Unmanned aerial system-based multispectral sensing for crop monitoring: A review. Computers and Electronics in Agriculture, 116, 200–211. https://doi.org/10.1016/j.compag.2015.05.016

Sarkar, T., Mogili, T., Sivaprasad, V., 2017. Improvement of abiotic stress adaptive traits in Mulberry (*Morus* spp.): an update on biotechnological interventions. 3 Biotech 7(3), 214.

Singh, R., Kumar, A., & Verma, S. (2018). Osmolyte accumulation and antioxidant response in drought-tolerant mulberry cultivars. Acta Physiologiae Plantarum, 40(5), 89.

Srivastava S, Kapoor R, Thathola A, Srivastava RP (2006). Nutritional quality of leaves of some genotypes of mulberry (*Morus* alba). Int J Food Sci Nutr. Aug-Sep;57(5-6):305-13. doi: 10.1080/09637480600801837. PMID: 17135021.

Thallapally, M., Sarkar, T., & Gnanesh, B. N. (2023). Mulberry breeding for higher leaf productivity. In: The Mulberry Genome (pp. 57–114). Springer Nature. https://doi.org/10.1007/978-981-99-1234-5_3

Thimmanaik, S., Kumar, S.G., Kumari, G.J. *et al.* (2002) Photosynthesis and the Enzymes of Photosynthetic Carbon Reduction Cycle in Mulberry During Water Stress and Recovery. Photosynthetica 40, 233–236. https://doi.org/10.1023/A:1021397708318

Thompson, L. C., & Olesen, J. E. (2016). Climate change adaptation and livestock production. Global Food Security, 9, 11-20.

van Brummelen, J., *et al.* (2017). Mulberry-based agroforestry systems for climate change adaptation in the Hindu Kush Himalayas. Mountain Research and Development, 37(4), 479-490.

Vaya, H., & Rossi, J. (2016). Multi-strata mulberry systems and carbon sequestration. Environmental Management, 58(3), 412-425.

Vijayan, K., & Tikader, A. (2020). Advances in mulberry breeding for drought tolerance: Role of phenomics and genomics. Indian Journal of Genetics and Plant Breeding, 80(2), 123–132. https://doi.org/10.31742/IJGPB.80.2.123

Vijayan, K., Chakraborti, S., & Gnanesh, B. N. (2022). High-throughput phenotyping for mulberry improvement: Integrating physiological traits with genomic selection. Plant Physiology Reports, 27(3), 415–428. https://doi.org/10.1007/s40502-022-00678-9

Vijayan, K., Gnanesh, B.N., Shabnam, A.A., Sangannavar, P.A., Sarkar, T., Weiguo, Z. (2022). Genomic Designing for Abiotic Stress Resistance in Mulberry (*Morus* spp.). In: Kole, C. (eds) Genomic Designing for Abiotic Stress Resistant Technical Crops. Springer, Cham. https://doi.org/10.1007/978-3-031-05706-9_7

Wang, Y., Yang, C., Li, X., Liu, R., Huang, S., & Zhou, Y. (2026). *Genomics-driven mulberry breeding for improving agronomic traits and circular utilization value.* Biology, 15(8), 628. https://doi.org/10.3390/biology15080628

Xing, L., Zhang, D., & Li, Y. (2018). Water-use efficiency traits in mulberry germplasm: implications for semi-arid agriculture. Euphytica, 214(8), 162.

Yang, L.; Li, C.; Gao, H.; Hong, Z.; He, Y.; Huang, L. (2026) Mulberry Drought Diagnosis: Integrating Proximal Sensing and Metabolomics for Remote Monitoring. Plants 2026, 15, 741. https://doi.org/10.3390/plants15050741

Zhang, L., Wang, Y., & Chen, H. (2023). Ultrasonic assisted extraction of mulberry leaf protein: Kinetic model, structural and functional properties, in vitro digestion. Process Biochemistry, 128, 1–10. https://doi.org/10.1016/j.procbio.2023.06.004

CHAPTER 3: MANAGING SOIL HEALTH FOR CLIMATE RESILIENCE AND MULBERRY PRODUCTIVITY

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3.1. INTRODUCTION

Mulberry (genus: *Morus*) is usually grown as a perennial tree or shrub which is an economically important plant for successful cocoon production (Padhan *et al.*, 2023). As the unique food plant for the domesticated silkworm *Bombyx mori* L., the mulberry plant is widely grown in Asia, Europe, North and South America, and Africa. It is cultivated extensively for silkworm rearing in East, Central and South Asia which are the major silk producing areas of the world. A few species of mulberry are also valued for their edible fruit (*M. alba* and *M. laevigata*), and timber (*M. laevigata* and *M. serrata*). Mulberry is being considered as a unique plant as it is widely distributed across the globe with better adaptability under diversified climates, soil conditions and altitudes varying from sea level to 4000 m above mean sea level (Ercisli and Orhan, 2007; Khan *et al.*, 2013; Sarkar *et al.*, 2017). It thrives under various climatic conditions ranging from temperate to tropic (Srivastava *et al.*, 2003). Mulberry plant flourishes well in soils which are flat, deep, fertile, well drained, loamy and porous with good moisture holding capacity. The optimum pH required for mulberry plantation is 6.5-6.8 (Choudhury and Giridhar, 1987)

In India, mulberry cultivation is spreading to different parts of the country with varied agro-climatic conditions and hence, different cultivation methods have been followed by the farmers. At present mulberry is being cultivated as a low bush (with a comparatively closer spacing) as well as high bush plantation (with wider spacing). In many parts of Southern India where assured irrigation is available, mulberry is being cultivated as bush type with 5 crop schedules. The quality of mulberry leaf has a predominant role in determining the quality of silk production. Therefore, many technologies have been developed to sustain the productivity of mulberry leaf and to achieve higher silk production.

In the recent past, climate change has become one of the most critical challenges affecting global agriculture and allied sectors. Increasing atmospheric carbon dioxide (CO_2) concentration, rising temperatures, erratic rainfall patterns, drought, floods, and soil degradation are significantly influencing crop productivity and ecosystem sustainability. Sericulture, an agro-based rural industry, is highly climate-sensitive because mulberry requires optimal environmental conditions for sustained leaf production and quality. Since mulberry leaf quality directly determines silkworm growth and cocoon yield, climate-induced changes in soil and plant health severely affect silk productivity. According to Ortiz-Bobea *et al.* (2021), anthropogenic climate change has already reduced global agricultural productivity by approximately 21% since 1961, particularly in tropical and subtropical regions where sericulture is extensively practiced. Additionally, mulberry cultivation is severely constrained by several insect pests, mites, and nematodes whose occurrence and severity are strongly influenced by climatic factors. In recent decades, global climate change has significantly affected pest population dynamics in agricultural ecosystems, including mulberry-based sericulture systems (Bale *et al.,* 2002). Moreover, climate change largely affects the morpho-physiological aspects of mulberry besides altering the biochemical constituents of leaf. It is noteworthy to mention that climate induced physiological and biochemical changes in mulberry

leaf affect the performance of silkworm breed as a cascading effect. This chapter highlights the effect of climate change on soil health, mulberry productivity, physiological changes in mulberry, pest dynamics and their mitigation strategies for achieving climate resilience in sericulture.

3.2. IMPACT OF CLIMATE CHANGE ON SOIL HEALTH AND MULBERRY PRODUCTIVITY

3.2.1 Soil health

Soil health refers to the ability of soil to function as a living system that sustains biological productivity, maintains environmental quality and promotes plant and animal health. Climate change affects soil health through alterations in temperature, precipitation, organic matter decomposition, nutrient cycling, microbial activity, and erosion processes. Rising temperatures accelerate decomposition of soil organic matter, leading to depletion of soil organic carbon (SOC), which is essential for maintaining soil fertility, aggregation and water-holding capacity (Lal, 2015). Increased atmospheric temperatures also intensify evapotranspiration, resulting in soil moisture deficits and drought stress. Reduced soil moisture negatively affects nutrient solubility and microbial activities, thereby limiting nutrient availability to mulberry plants.

Extreme rainfall events associated with climate change increase soil erosion, nutrient runoff and leaching losses. Nitrogen and potassium losses are particularly severe under heavy rainfall conditions, reducing soil fertility and mulberry productivity. Zhang *et al.* (2026) reported that climate-induced disruptions in nitrogen cycling significantly affect nitrogen uptake efficiency in mulberry, thereby influencing leaf protein content and nutritional quality. Soil microbial communities are highly sensitive to climate variability. Elevated temperatures and drought conditions reduce microbial biomass and enzymatic activity, leading to poor nutrient mineralization and reduced soil fertility (Fierer *et al.,* 2003). In mulberry ecosystems, healthy microbial populations are essential for nutrient transformation, root growth and soil structural stability. Long-term soil degradation may therefore adversely affect sustainable sericulture production.

Another important consequence of climate change is soil salinization. Increased evaporation and improper irrigation practices under warmer climates cause salt accumulation in agricultural soils. Vijayan *et al.* (2011) observed that salinity stress in mulberry disrupts ionic balance, impairs nutrient uptake and reduces chlorophyll synthesis, resulting in lower biomass production and leaf quality. Mulberry plantations also play an important ecological role in carbon sequestration and restoration of degraded lands. Recent studies demonstrated that sustainable mulberry cultivation improves soil organic carbon storage and enhances soil ecological functions (Feng *et al.,* 2026). Kaushal *et al.* (2024) reported that adoption of a mulberry-based agroforestry system with canopy management practices system could improve soil fertility and productivity besides reducing soil degradation. Further, the mulberry under pollarding combined with turmeric could enhance SOC stock and SOC sequestration rates by 23.3% and 107.4%, respectively, over fallow and sole turmeric. Similarly, Yadav *et al.* (2020) suggested that reduced tillage with mulching and drip irrigation increased the carbon sequestration potential of mulberry as well carbon stock and rate of C sequestration in soil. Cultivating tree mulberry with proper nutrient management practices significantly increases total organic carbon and stabilizes carbon in passive, long-term soil pools (Padhan *et al.*, 2025). However, these benefits may decline if climate-induced soil degradation continues without proper soil conservation measures.

3.2.2 Mulberry Productivity

Mulberry productivity is highly dependent on environmental parameters such as temperature, humidity, soil moisture, solar radiation, and nutrient availability. Climate change influences mulberry growth at morphological, physiological, biochemical, and molecular levels.

(a) Temperature Stress:

Temperature is one of the most important environmental factors regulating mulberry growth and leaf quality. Optimum growth of mulberry occurs under moderate temperatures; however, excessive heat stress negatively affects physiological processes including photosynthesis, respiration, and transpiration. High temperatures reduce chlorophyll content and photosynthetic efficiency by damaging photosynthetic pigments and chloroplast structures (Ashrith *et al.*, 2025). Heat stress also increases respiration rates, resulting in depletion of stored carbohydrates required for growth and leaf development. Elevated temperatures accelerate leaf senescence and reduce leaf moisture content, thereby lowering leaf palatability and nutritional quality for silkworm feeding. At the cellular level, heat stress induces excessive production of reactive oxygen species (ROS), causing oxidative damage to proteins, lipids, and nucleic acids. Mulberry plants activate antioxidant defence mechanisms involving enzymes such as superoxide dismutase, catalase, and peroxidase to counter oxidative stress (Feng *et al.*, 2026). However, prolonged exposure to high temperature exceeds the plant's adaptive capacity and significantly reduces biomass accumulation and leaf yield.

(b) Drought Stress

Drought is one of the most severe abiotic stresses affecting mulberry cultivation under changing climatic conditions. Water deficit reduces cell expansion, shoot growth, leaf area development, and overall biomass production. Guha *et al.* (2010) reported that drought stress substantially decreases leaf yield and photosynthetic rate in mulberry due to stomatal closure and reduced carbon assimilation.

Water stress also alters biochemical composition of mulberry leaves by reducing protein content and increasing accumulation of stress metabolites such as proline and soluble sugars. Since silkworm growth depends heavily on leaf nutritional quality, drought-induced changes adversely affect cocoon yield and silk quality. Interestingly, elevated atmospheric CO_2 may partially mitigate drought stress effects in mulberry plants. Studies conducted under elevated CO_2 conditions showed improved water-use efficiency, enhanced photosynthesis, and better antioxidant activity in mulberry seedlings exposed to drought stress (Feng *et al.,* 2026). Nevertheless, severe and prolonged drought conditions continue to remain a major threat to sustainable mulberry cultivation.

(c) Salinity Stress:

Climate change-induced salinity has become increasingly important in irrigated agricultural regions. Salt stress affects mulberry growth through osmotic stress, ion toxicity, and nutrient imbalance. Excess sodium and chloride ions interfere with potassium and calcium uptake, impairing metabolic and physiological processes. According to Vijayan *et al.* (2011), salinity stress reduces shoot elongation, leaf area, chlorophyll synthesis, and photosynthetic efficiency in mulberry plants. Salt stress additionally increases oxidative damage and membrane instability, thereby reducing plant vigor and productivity. Development of salt-tolerant mulberry varieties through breeding and biotechnological approaches has therefore gained importance in recent years.

3.3. IMPACTS OF CLIMATE CHANGE ON PHYSIOLOGICAL ASPECTS OF MULBERRY

Mulberry leaf quality is significantly influenced by various environmental and climatic factors such as rainfall, temperature, relative humidity, soil pH, nutrient availability, soil organic carbon etc.

Environmental extremes caused by climate changes affects largely on plant's morpho-physiological aspects and it also stimulates the occurrence of various biotic and abiotic stresses in plants (Thornton *et al.,* 2014) followed by the generation of Reactive Oxygen Species (ROS) in the cells. Climate change causes a negative impact on the leaf yield and quality in mulberry by altering the plants' physio-biochemical process and also alters the population and growth of beneficial microorganisms exist in the rhizosphere. These changes will lead to reduce the nutrients availability and quantity in the soil. In recent years, due to frequent climate changes, an enhanced temperature and CO_2 levels in the atmosphere has been observed and this rise in temperature causes altered enzyme function within a leaf (Timm *et al.*, 2019) and triggers changes in developmental growth stage that are tightly coupled with crop yield (Ruiz-Vera *et al.*, 2018; Zhu *et al.,* 2018). Furthermore, the amount of water vapour in air at saturation increases exponentially with temperature, raising the vapour pressure deficit (VPD), and driving more potential water loss from plants (Novick *et al.*, 2016; Grossiord *et al.*, 2020). The result of these broad crop physiological responses to temperature means that any shifts in long-term mean annual temperature and extreme temperature events will be likely to have significant impacts on plant productivity. Increased temperature causes alteration in physiological processes in plant system especially it leads to the decline in the substrate specificity of photosynthetic enzyme Rubisco especially in C_3 plants. Stomatal conductance can change under temperature stress, and stomatal density and size can be altered if a plant develops under hotter conditions. Photosynthate allocation from sources to sinks is impacted by heat stress through differential expression and activity of enzymes involved in sucrose transport and metabolism, as well as phloem structural changes. At the whole-plant scale, leaf interactions create temperature gradients, and heat stress impairs plant development processes (Moore *et al.,* 2021).

A study by Chaitanya *et al.* (2001) reported that exposure of high temperature (40 °C) for 120, 240 and 360 minutes in plant growth chamber markedly reduced the activities of ribulose-1,5-biphosphate (RuBP) carboxylase and sucrose phosphate synthase in mulberry. Increased leaf temperature affected sugar metabolism through reductions in leaf starch content and sucrose-starch balance while total soluble protein content decreased under heat, total amino acid content increased. A reduction in foliar nitrogen (30%) and nucleic acid was also observed. SDS-PAGE of leaf proteins showed the accumulation of two new polypeptides (68 and 85 kDa) in the high temperature treated leaves. Decrease in leaf yield (22-37%) was observed in V1, G2, G4, MR2 and S36 mulberry varieties when exposed to 40 °C temperature (Kumar *et al.*, 2022).

Changes in average photosynthetic rates in response to translocation were mainly associated with those in leaf stomatal conductance and photosynthetic capacity (RuBP carboxylation, RuBP regeneration capacity). Effects of elevated levels of CO_2 on increasing photosynthesis, growth, and biomass of plants have been well documented as a fertilizing effect (Ainsworth and Long, 2005). However, it is unknown whether CO_2-induced stimulation of plant growth and biomass accumulation will be sustained or whether limited nitrogen (N) availability constrains greater plant growth in a CO_2-enriched world (Reich *et al.* 2006). The majority of plant species shows an increase in growth and yield under rising CO_2 mainly due to increased photosynthesis rate (Carlisle *et al.* 2012). While the long-term exposure of plants to elevated CO_2 may reduce photosynthetic capacity introducing photosynthetic acclimation for most C_3 plants (Long *et al.* 2004) because of limitation of nitrogen (N) supply (Seneweera *et al.* 2002; Sanz-Sáez *et al.* 2010), insufficient capacity of sink organs (Aranjuelo *et al.* 2011; Ruizvera *et al.* 2017), and downregulation of photosynthetic genes by carbohydrates (Vicente *et al.* 2017). In *Morus alba* var. Gui-sang-you 62, elevated CO_2 (710 ppm) leaf nitrogen and protein content was decreased by 5-6% (Shi *et al.*, 2021a). In addition, leaf biomass of *Morus multicaulis* Perr. var. QiangSang-1 and NongSang-14 under elevated CO_2 (710

ppm) was enhanced by 30% and 26% whereas leaf nitrogen concentration was reduced by 20% and 18% in both the varieties (Shi *et al.*, 2021b). These results indicated that mulberry leaf nutrient content in response to elevated temperature and CO_2 varied with varieties. The depletion of leaf nitrogen and protein concentrations in mulberry leaves would certainly affect silkworm growth and ultimately quality and quantity of cocoons. Silkworm may feed more quantity of leaves to balance nutrition that may result in increased life cycle (Neelaboina *et al.*, 2018). Varieties with higher leaf yield and physiological efficiency has high photosynthetic rate, more chlorophylls, high leaf moisture content, more number of shoots and leaves per plant, shoot length, specific leaf weight etc. for higher biomass accumulation. All these parameters may vary among the varieties under abiotic stress conditions such as elevated CO_2, high temperature, drought/moisture stress, soil alkalinity, water logging etc. Hence, the screening of varieties for climate resilient traits and abiotic stress tolerance is a priority aspect for sustainable crop production under climate change scenario.

3.4. IMPACT OF CHANGING CLIMATE ON PEST DYNAMICS IN MULBERRY AND MITIGATION STRATEGIES

Climate plays a major role in regulating insect development, survival, reproduction, dispersal, and seasonal abundance. Increasing temperature accelerates insect metabolism and shortens developmental duration, thereby increasing the number of generations per year. Similarly, drought stress and erratic rainfall alter host plant physiology and create favorable conditions for several sap-feeding pests and mites (Sharma, 2014). Consequently, changing climatic conditions are expected to intensify pest outbreaks, alter pest distribution, and reduce the effectiveness of conventional pest management strategies in mulberry cultivation.

3.4.1. Major Mulberry Pests and Climate Influence

Among the important pests of mulberry, thrips (*Pseudodendrothrips mori*), mealybugs (*Maconellicoccus hirsutus, Paracoccus marginatus*), whiteflies (*Dialeuropora decempuncta*), broad mite (*Polyphagotarsonemus latus*), and leaf roller (*Diaphania pulverulentalis*) are economically significant. Their population dynamics are highly sensitive to climatic fluctuations.

Thrips are among the most destructive sap-feeding pests in mulberry ecosystems. Both nymphs and adults feed on leaf sap causing curling, bronzing, and drying of leaves. High temperature and low relative humidity favor rapid multiplication of thrips populations. Under climate warming scenarios, thrips may exhibit increased reproductive rates, shortened life cycles, and prolonged seasonal activity. Similar observations were reported by Rahmathulla *et al.* (2015), who demonstrated strong correlations between temperature and seasonal pest incidence in mulberry fields.

Mealybugs and whiteflies are expected to become increasingly problematic under changing climatic conditions. Elevated temperature and prolonged dry periods enhance survival, reproduction, and dispersal efficiency of these sap-feeding insects. Climate-induced stress in mulberry plants weakens host defensive capacity and increases susceptibility to pest infestation. Variations in temperature and humidity also influence seasonal abundance and outbreak patterns of mulberry sap-feeding pests (Rahmathulla, 2012; Sakthivel *et al.*, 2019; 1990; Bale *et al.*, 2002).

Broad mite, is an important mite pest of mulberry causing curling, crinkling, bronzing, and deformation of leaves, ultimately reducing leaf yield and quality for silkworm feeding. The biology and population development of *P. latus* are strongly influenced by temperature and relative humidity. Studies have shown that developmental rate and reproductive performance of the broad mite vary significantly with temperature-humidity regimes, indicating the importance of climatic factors in its population dynamics (Jones and Brown, 1983; Luypaert *et al.*, 2014).

Defoliators such as leaf rollers are favored by humid conditions and moderate temperatures. Increased rainfall and humidity during monsoon seasons enhance larval survival and feeding activity. Climate variability may disrupt synchronization between pest emergence and natural enemy activity, thereby increasing the risk of sudden pest outbreaks (Rahmathulla, 2012).

3.4.2. Impact of Climate Change on Pest Population Dynamics in Mulberry

Climate change has emerged as a major factor influencing pest incidence and population dynamics in mulberry ecosystems. Variations in temperature, rainfall, relative humidity, and atmospheric carbon dioxide (CO_2) significantly affect the survival, development, reproduction, distribution, and seasonal abundance of mulberry pests. Continuous changes in climatic conditions have altered the ecological balance within mulberry agroecosystems, resulting in the emergence of new pests and increased severity of existing pest problems (Tripathi *et al.*, 2017).

Rising temperature accelerates insect metabolism and developmental rate, thereby increasing pest multiplication and the number of generations per year. Important mulberry pests such as thrips (*Pseudodendrothrips mori*), pink mealybug (*Maconellicoccus hirsutus*), whiteflies, mites, and leaf webber (*Diaphania pulverulentalis*) are greatly influenced by climatic fluctuations. High temperature and prolonged dry conditions generally favor sap-feeding pests and mites, whereas humid conditions and irregular rainfall patterns may enhance the incidence of defoliators and disease-associated pests (Tripathi *et al.*, 2017).

Climate change also indirectly affects pest dynamics through alterations in mulberry plant physiology and nutritional quality. Elevated atmospheric CO_2 can modify carbon-to-nitrogen ratio, leaf moisture, and secondary metabolite composition, thereby influencing insect feeding behavior, survival, and fecundity. In addition, climatic stress weakens plant defense mechanisms, making mulberry plants more susceptible to pest infestation.

Erratic rainfall and extreme weather events further disrupt the interactions among pests, predators, parasitoids, and microbial communities. Natural enemies are highly sensitive to environmental fluctuations, and their reduced efficiency under changing climate conditions may lead to frequent pest outbreaks. Such ecological disturbances increase dependence on chemical pesticides and pose serious challenges to sustainable sericulture production.

Overall, changing climatic conditions are expected to intensify pest problems in mulberry cultivation, affecting both leaf yield and quality. Therefore, understanding climate-driven pest population dynamics is essential for developing climate-resilient and sustainable pest management strategies for mulberry-based sericulture systems.

3.4.3. Climate-Resilient Pest Management Strategies in Mulberry

Climate change-induced variations in temperature, rainfall, humidity, and atmospheric CO_2 have increased the incidence and severity of several mulberry pests, necessitating the adoption of climate-resilient pest management strategies. Cultural practices such as timely pruning, field sanitation, balanced fertilization, optimum irrigation, and removal of infested plant parts play an important role in minimizing pest buildup under changing climatic conditions. Excessive nitrogen fertilization should be avoided, as it promotes succulent growth favorable for sap-feeding pests like thrips, mealybugs, whiteflies, and mites. Regular pest surveillance, monitoring of weather parameters, and climate-based forecasting systems are essential for early detection and timely management of pest outbreaks in mulberry ecosystems.

Integrated Pest Management (IPM) provides a sustainable and eco-friendly approach for managing mulberry pests under climate stress conditions. Conservation and augmentation of natural enemies such as ladybird beetles, chrysopids, spiders, and parasitoids help maintain ecological balance and naturally suppress pest populations. Emerging approaches such as semiochemical-based pest management, including the use of pheromones, kairomones, herbivore-induced plant volatiles, and microbial volatiles, offer promising alternatives for monitoring, attraction, repellence, and behavioral manipulation of mulberry pests. Mechanical methods such as yellow sticky traps and destruction of heavily infested plant parts further aid in pest reduction. Chemical pesticides should be used judiciously and only when pest populations exceed economic threshold levels, ensuring minimal residue toxicity to silkworms. Thus, integration of cultural, biological, behavioral, mechanical, and need-based chemical approaches is essential for developing climate-resilient and sustainable pest management strategies in mulberry cultivation.

3.4.4. Leaf Quality Degradation With A Cascading Effect On Silkworms

Intensifying temperature fluctuations, more frequent heat waves causing prolonged droughts, excessive rainfall and flooding, and increased incidents of pests and diseases have all adverse impact on mulberry leaf quality and yield which are essential for rearing healthy silkworms and the sustainability of the silk industry (Dandin *et al.,* 2003). The sole source of food for *Bombyx mori* is mulberry leaves, and any changes to the quality or quantity of mulberry leaves will directly find adverse effects on silkworm growth and development. Scientific literature indicates that the rise in temperature and other stresses on mulberry caused by global climate change can significantly reduce the chlorophyll content required for photosynthesis and protein content. The major component of silk is protein and hence changes in protein content directly effects the silk quantity and quality. One of the results of climate change is low sprouting which negatively affects the silkworm rearing by delaying in the brushing. Feeding low quality and quantity of mulberry leaves will reduce the economically important parameters like cocoon weight, shell weight, cocoon yield, shell percentage, survival and ultimately silk quantity and quantity. Increased incidents of pests and diseases due to climate change is one of the main concerns for silkworm rearing as it adversely impacts on mulberry leaf quality and yield (Qadri *et al.*, 1999a & 1999b) and feeding of such infected leaves to silkworm prolongs larval duration inviting silkworm diseases (Noamani *et al.,* 1970, Umesh kumar et al 1993). Monir *et al.* (2017) fed mulberry leaves infected with different levels of powdery mildew from 2nd instar silkworms to till spinning and observed that the larval duration was increased by two days when disease infected leaves were used for feeding. Higher larval weight, larval length, single cocoon weight, single shell weight, shell percentage, ERR by number and weight were witnessed in control and all were decreased with the level of infection while none of the silkworms survived till 5th instar when leaves with highest level of infection were fed. The experiment confirmed that reduction in quality and yield during rearing was proportional to the level of disease incidence in the leaves used for feeding. Feeding of powdery mildew affected leaves in the fifth instar silkworms resulted in 100 percent mortality. Earlier study (Krishnaswami *et al.*, 1973) also suggests that feeding unsuitable leaves is the main factor for causing flacherie and grasserie diseases as the infected leaves lack antibacterial and antiviral substances. Therefore, it is important to feed silkworms with disease free healthy mulberry leaves to obtain optimum production levels.

The quality of mulberry leaves plays a predominant role on health and growth of silkworm. Silkworms fed with nutritionally deficient mulberry leaves experience oxidative stress and reduced protein synthesis, adversely affecting their health and development (Peng *et al.,* 2023). Insufficient nutrition leads to adverse changes in metabolic processes, reducing the amount of silk fluid

synthesized in the silk glands. This results in thinner cocoons with less silk content (Bekkamov, 2023).

3.4.5. Mitigation And Adaptation Strategies

Global climatic changes have significant implications for sericulture by affecting the lifecycle, physiology, and population dynamics of the mulberry silkworm, *Bombyx mori*. Addressing these challenges requires a combination of mitigation and adaptation strategies. Mitigation strategies focus on reducing the underlying causes of climate change, especially greenhouse gas emissions, while adaptation strategies aim to minimize the adverse impacts already being experienced by ecosystems and agricultural systems.

To reduce the impacts of global warming on mulberry silkworm rearing, several practical approaches can be adopted. One important strategy is climate smart sericulture, where rearing houses are equipped with environmental control systems to maintain optimum temperature and humidity conditions. Such controlled environments help stabilize larval growth, cocoon formation, and survival rates despite external climatic fluctuations. Another effective approach is selective breeding and genetic improvement. Breeding programs can develop thermotolerant silkworm breeds capable of withstanding elevated temperatures and environmental stress. Selecting strains with improved resilience, better feed conversion efficiency, and stable silk productivity under changing climatic conditions can enhance the sustainability of sericulture.

In addition, climate monitoring and early warning systems play a crucial role in adaptive management. Continuous monitoring of temperature, humidity, and weather anomalies enables sericulturists to anticipate heat waves or extreme climatic events and take preventive measures in advance. Early warning systems can assist farmers in adjusting feeding schedules, ventilation practices, and disease management protocols to protect silkworm crops (Guha *et al.*, 2026; Laxmi and Singh, 2022).

3.5. CLIMATE-SMART MANAGEMENT PRACTICES FOR SUSTAINABLE MULBERRY CULTIVATION

Sustainability in sericulture may be achieved by adopting climate smart crop management practices under the changing climatic conditions. Integrating soil, water, nutrient and crop management practices can help in maximising mulberry productivity besides restoring the ecological resilience.

3.5.1. Precision nutrient and water management

Balanced fertilization to mulberry can sustain the productivity besides restoring the soil health. Coupling the application of chemical fertilizers and organic manures based on soil test value could improve the soil fertility and maximise productivity. Additionally, the use of microbial biofertilizers such as nitrogen fixers, phosphate solubilizers, potassium mobilizers etc. could enhance nutrient uptake, reduce synthetic fertilizer reliance, and lower nitrous oxide emissions. Increasing the carbon sequestration potential of soils through smart crop management practices could be one of the options to restore soil health and improve soil quality and resilience. The adoption of minimum tillage rather than deep tillage can protect the soil structure and improve the carbon hoarding capacity of soils. Mulberry cultivation with tree type plantation can be followed to enhance the soil carbon storage potential. Padhan *et al.* (2025) reported that suitable nutrient management practices in tree mulberry cultivation can allocate the carbon more towards the passive pool thereby improving the recalcitrant carbon in soils.

Similarly, drip irrigation in mulberry can improve the water use efficiency and can save 40% of the water as compared to furrow/flood irrigation. Of late, drip fertigation strategies can increase the water and nutrient use efficiency vis-à-vis improving the crop productivity. Mahesh *et al.* (2020) reported that low-cost drip fertigation (LCDF) could reduce water requirement by 24% resulting in increased WUE (61%) and NUE (63%) in mulberry. Moreover, fertigation at 75% RD could be the optimal quantum for sustainable mulberry leaf production and could be one of the climate-smart-sericulture option for economically poor and marginal stakeholders. Shiraishi *et al.* (2025) reported that drip fertigation can enhances agricultural sustainability by improving nutrient use efficiency, reducing greenhouse gas emissions, and minimizing nitrogen leaching. Notably, drip fertigation reduced reactive nitrogen losses by 21–33% (Fu et al, 2026). In recent years, IoT based drip fertigation system is gaining importance which can be employed for mulberry cultivation so as to reduce the water foot print and simultaneously scheduling real-time irrigation for maximizing productivity.

3.5.2. Resilient varietal selection and diversifying mulberry cultivation system

Breeding and adopting climate-resilient cultivars form the foundation of climate-smart sericulture. Cultivars must be selected for high water-use efficiency (WUE), drought tolerance, and resistance to emerging pests and diseases triggered by rising temperatures. Similarly, diversifying the mulberry cultivation by integrating intercropping with short-duration legumes could improve resource-use efficiency and enhance soil fertility. Exploring the potential of mulberry based integrated farming systems (mulberry+ livestock, mulberry+ horticultural crops) and agro-forestry systems (mulberry+ turmeric, mulberry+ cauliflower-pea) could help in enhancing the climate resilience.

3.6. CONCLUSION

The catastrophic effect of climate change on soil health and mulberry productivity directly threatens the sustainability of sericulture. Rising temperatures, erratic rainfall, and prolonged droughts accelerate soil organic matter depletion, increase salinity, and disrupt beneficial microbial communities. Such depletion of soil organic matter (referred as store house of nutrients)/ decline soil fertility fail to provide essential nutrients, resulting in poor mulberry leaf yield and compromised nutritional quality. Poor quality mulberry leaf when fed to silkworm automatically cripples their performance and cocoon quality. Thus, mitigation strategies to be prioritized for achieving sustainability in mulberry sericulture. Adopting climate smart sericulture practices such as conservation tillage (to protect soil carbon), integrated nutrient management, IoT based irrigation/ fertigation scheduling, integrated farming system approach, temperature and humidity-controlled mechanism during silkworm rearing etc. may be useful to combat the climate change induced ill effects. Future efforts must focus on the breeding of climate resilient mulberry cultivars vis-à-vis silkworm breeds to achieve sustainability in mulberry sericulture.

3.7. REFERENCES

Ainsworth EA, Long SP (2005) What have we learned from 15 years of free-air CO2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO2. New Phytol 165:351–372

Aranjuelo I, Cabrera-Bosquet L, Morcuende R et al (2011) Does ear C sink strength contribute to overcoming photosynthetic acclimation of wheat plants exposed to elevated CO2? J Exp Bot 62(11):3957–3969

Ashrith S, Pavithra MR, Harish Reddy C (2025) Climate change and its impact on sericulture: A brief review. Int J Adv Biochem Res 9(8):5283–5288

Bale JS, Masters GJ, Hodkinson ID et al (2002) Herbivory in global climate change research: Direct effects of rising temperature on insect herbivores. Glob Change Biol 8:1–16

Bekkamov C (2023) Effect of feeding mulberry silkworms with leaves of different cultivars and hybrids on silk gland activity and yield of cultivated cocoons. E3S Web Conf 389:03088

Carlisle E, Myers S, Raboy V, Bloom A (2012) The effects of inorganic nitrogen form and CO2 concentration on wheat yield and nutrient accumulation and distribution. Front Plant Sci 3(4):195

Chaitanya KV, Sundar D, Reddy R (2001) Mulberry leaf metabolism under high temperature stress. Biol Plant 44(3):379–384

Chaudhary PC, Giridhar K (1987) Mulberry cultivation. In: Jolly MS (ed) Appropriate sericulture techniques. CSRTI, Mysore, pp 17–34

Dandin SB, Jayaswal J, Giridhar K (2003) Handbook of sericulture technologies. Central Silk Board, Bangalore, pp 76–86

Ercisli S, Orhan E (2007) Chemical composition of white (*Morus alba*), red (*Morus rubra*) and black (*Morus nigra*) mulberry fruits. Food Chem 103:1380–1384.

Feng L, Fu R, Bu L (2026) Therapeutic potential of mulberry and its resilience to abiotic and biotic stresses. Int J Mol Sci 27(7):2934

Fierer N, Schimel JP, Holden PA (2003) Variations in microbial community composition through two soil depth profiles. Soil Biol Biochem 35:167–176

Fu H, Huang Y, Chen L, Wang X, Li T, Mi X, He G (2026) Drip fertigation: A potential triple-win strategy for improving crop yields, reducing water use, and enhancing eco-economic benefits. Eur J Agron 178:128149. doi:10.1016/j.eja.2026.128149

Grossiord C, Buckley TN, Cernusak LA et al (2020) Plant responses to rising vapor pressure deficit. New Phytol 226:1550–1566

Guha A, Rasineni GK, Reddy AR (2010) Drought tolerance in mulberry (*Morus* spp.): A physiological approach with insights into growth dynamics and leaf yield production. Exp Agric 46:471–488

Guha A, Reddy AR (2013) Leaf functional traits and stem-wood characteristics influencing biomass productivity of mulberry (*Morus* spp. L.) genotypes grown in short rotation coppice system. Bioenerg Res 6:547–563

Guha A, Shukla P, Prakash H et al (2026) Mulberry improvement in the scenario of climate change conditions: current progress and future prospects. In: Saha S, Mondal R (eds) Sustainable sericulture in India. Springer. doi.org

Jones VP, Brown RD (1983) Reproductive responses of the broad mite, *Polyphagotarsonemus latus* (Acari: Tarsonemidae), to constant temperature-humidity regimes. Ann Entomol Soc Am 76(3):466–469

Kaushal R, Kumar A, Mandal D, Tomar JMS, Jinger D, Islam S, Panwar P, Jayaprakash J, Uthappa AR, Singhal V, Barh A, Madhu M (2024) Mulberry based agroforestry system and canopy management practices to combat soil erosion and enhancing carbon sequestration in degraded lands of Himalayan foothills. Environ Sustain Indic 24:100467

Khan MA, Miah MA, Ahmed SU, Islam MS (2013) Ecological and environmental importance of mulberry: A review. Bangladesh J Environ Sci 24:52–57

Krishnaswami S, Narasimhanna MN, Surayanarayan SK, Kumaraji S (1973) Manual on sericulture. II. Silkworm rearing. FAO Agric Serv Bull AGS 22:1–131

Kumar SR, Swathiga G, Ramamoorthy R, Vijayalakshmi D (2022) Effects of high temperature stress on physiological and yield parameters of mulberry varieties. Res Biotica 4(2):58–61

Lal R (2015) Restoring soil quality to mitigate soil degradation. Sustainability 7:5875–5895

Long SP, Ainsworth EA, Rogers A, Ort DR (2004) Rising atmospheric carbon dioxide: Plants face the future. Annu Rev Plant Biol 55(1):591–628

Mahesh R, Anil P, Chakravarty D, Sivaprasad V (2022) Improved mulberry productivity and resource efficiency through low-cost drip fertigation. Arch Agron Soil Sci 68(6):749–763

Monir S, Mandal NC, Pappachan A, Dutta SK (2017) Study on feeding of powdery mildew infected mulberry leaves in silkworm rearing and its bioassay. Biosci Disc 8(1):20–23

Moore CE, Meacham-Hensold K, Lemonnier P et al (2021) The effect of increasing temperature on crop photosynthesis: from enzymes to ecosystems. J Exp Bot 72(8):2822–2844

Neelaboina BK, Khan GA, Kumar S et al (2018) Impact of climate change on agriculture and sericulture. J Entomol Zool Stud 6(5):426–429

Noamani MKR, Mukherjee PK, Krishnaswami S (1970) Studies on the effect of feeding multivoltine silkworm (*Bombyx mori* L.) larvae with mildew effected leaves. Indian J Seric 9:4–52

Novick KA, Ficklin DL, Stoy PC et al (2016) The increasing importance of atmospheric demand for ecosystem water and carbon fluxes. Nat Clim Chang 6(11):1023–1027

Ortiz-Bobea A, Ault TR, Carrillo CM et al (2021) Anthropogenic climate change has slowed global agricultural productivity growth. Nat Clim Chang 11:306–312

Peng M, Wang G, Zu S (2023) Cold-stored mulberry leaves affect antioxidant system and silk proteins of silkworm (*Bombyx mori*) larva. J Sci Food Agric 103(15):7673–7682

Qadri SMH, Gangwar SK, Pratheesh Kumar PM et al (1999a) Crop loss assessment due to leaf spot disease of mulberry. Indian J Seric 38(1):35–39

Qadri SMH, Pratheesh Kumar PM, Gangwar SK et al (1999b) Crop loss assessment due to powdery mildew in mulberry. Bull Seric Res 9:31–35

Rahmathulla VK, Sathyanarayana K, Angadi BS (2015) Influence of abiotic factors on population dynamics of major insect pests of mulberry. Pak J Biol Sci 18(5):215–223

Ram RL, Maji C, Bindroo BB (2016) Impact of climate change on sustainable sericultural development in India. Int J Agric Innov Res 4(6):2319–1473

Reich PB, Hobbie SE, Lee T et al (2006) Nitrogen limitation constrains sustainability of ecosystem response to CO2. Nature 440(7086):922–925

Sakthivel N, Narendra Kumar JB, Dhahira Beevi N et al (2019) Mulberry pests: current status and management practices. Central Sericultural Research & Training Institute, Central Silk Board, Government of India, Mysuru

Sanz-Sáez A, Erice G, Aranjuelo I et al (2010) Photosynthetic downregulation under elevated CO2 exposure can be prevented by nitrogen supply in nodulated alfalfa. J Plant Physiol 167(18):1558–1565

Sarkar T, Mogili T, Sivaprasad V (2017) Improvement of abiotic stress adaptive traits in mulberry (*Morus* spp.): An update on biotechnological interventions. J Crop Sci Biotechnol 20(3):215–225

Seneweera SP, Ghannoum O, Conroy JP et al (2002) Changes in source-sink relations during development influence photosynthetic acclimation of rice to free air CO2 enrichment (face). Funct Plant Biol 29(8):947–956

Shi S, Qui Y, Won M et al (2021a) Daytime, not nighttime, elevated atmospheric carbon dioxide exposure improves plant growth and leaf quality of mulberry (*Morus alba* L.) seedlings. Front Plant Sci 11:609031

Shi S, Xu X, Dong X et al (2021b) Photosynthetic acclimation and growth responses to elevated CO2 associate with leaf nitrogen and phosphorus concentrations in mulberry (*Morus multicaulis* Perr.). Forests 12:660

Shiraishi, W.; Nishimura, S.; Maeda, M.; Ueno, H. Drip Fertigation in Greenhouse Eggplant Cultivation: Reducing N2O Emissions and Nitrate Leaching. Nitrogen 2025, 6, 116. https://doi.org/10.3390/ nitrogen6040116

Srivastava S, Kapoor R, Thathola A, Srivastava RP (2003) Mulberry (*Morus alba*) leaves as human food: a new dimension of sericulture. Int J Food Sci Nutr 54(6):411–416.

Thornton PK, Ericksen PJ, Herrero M, Challinor AJ (2014) Climate variability and vulnerability to climate change: A review. Glob Change Biol 20:3313–3328

Timm S, Woitschach F, Heise C et al (2019) Faster removal of 2-phosphoglycolate through photorespiration improves abiotic stress tolerance of *Arabidopsis*. Plants 8:563

Tripathi VK, Tiwari AK, Singh P (2017) The effects of climate change on the mulberry insect fauna in India's temperate and subtropical regions. JournalNX 3(11):58–66

Umesh Kumar NN, Sharma DD, Shree MP (1993) Effect of feeding fungus infected leaves on commercial characters of silkworm (*Bombyx mori* L.). Indian J Seric 32(1):107–109

Vicente R, Perez P, Martınez-Carrasco R, Morcuende R (2017) Improved responses to elevated CO2 in durum wheat at a low nitrate supply associated with the upregulation of photosynthetic genes and the activation of nitrate assimilation. Plant Sci 260:119–128

Vijaya Laxmi R, Kunvar Dileep Pratap Singh (2022) The impact of global warming on the mulberry insect's lifecycle and population dynamics. Int J Res Publ Rev 3(12):2867–2870

Vijayan K, Chakraborti SP, Ghosh PD (2011) Enhancement of stress tolerance in mulberry. Sci Hortic 129:511–519

Zhang F, Peng S, Chen B et al (2026) Advances in nitrogen uptake preference and physiological and ecological mechanisms in mulberry. Nitrogen 7(1):33

Zhu P, Jin Z, Zhuang Q et al (2018) The important but weakening maize yield benefit of grain filling prolongation in the US Midwest. Glob Change Biol 24:4718–4730.

CHAPTER 4: CLIMATE-RESILIENT MULBERRY IMPROVEMENT THROUGH BIOTECHNOLOGICAL INTERVENTIONS FOR SUSTAINABLE SERICULTURE

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4.1. INTRODUCTION

Mulberry (*Morus spp.*) is a fast-growing important economical crop belonging to family Moraceae. It is a hardy plant found in nearly all types of agricultural environments. It thrives globally, with distribution ranging from tropical to subarctic zones. Mulberry trees can survive in temperatures from 40°C to -40°C and in soils with pH levels between 4.5 and 9. Primarily it includes *M. alba* L., *M. indica* L., *M. multicaulis* Perr, *M. notabilis* C. K. Schn, *M. rubra* L., *M. australis, M. cathayana* Hemsl, *M. rubra* L., *M. atropurpurea* Roxb, *M. nigra* L., *M. serrata* Roxb and *M. laevigata* Wall, *M. latifolia* Poir (Vijayan *et al.*, 2023). It is the only food source for silkworm, *B. mori.* Therefore, the silkworm growth, cocoon quality and silk yield depend on the quality and nutritional composition of mulberry leaf. The mulberry cultivation supports millions of farmers and industries (Baciu *et al.,* 2023; Ghosh *et al.,* 2017). The plant products like mulberry fruits, tea and herbal medicines are used widely, plant including leaves, fruits, roots, bark and twigs are rich in bioactive compounds like flavonoids, anthocyanins, alkaloids, vitamins and phenolic compounds that has antioxidant, antidiabetic, anticancer, anti-inflammatory and antimicrobial properties (Rahman and Islam, 2021).

Climate changes such as drought, high temperature, irregular rainfall, salinity, increased pest and disease prevalence negatively affect mulberry growth and leaf quality (Jian *et al.,* 2012). It greatly affects mulberry cultivation by reducing plant growth, leaf yield, photosynthesis, and nutritive value, and by increasing fungal attack and waterlogging. This further affects silkworm growth and yield and finally harms the sericulture industry (Kaushik *et al.,* 2025).

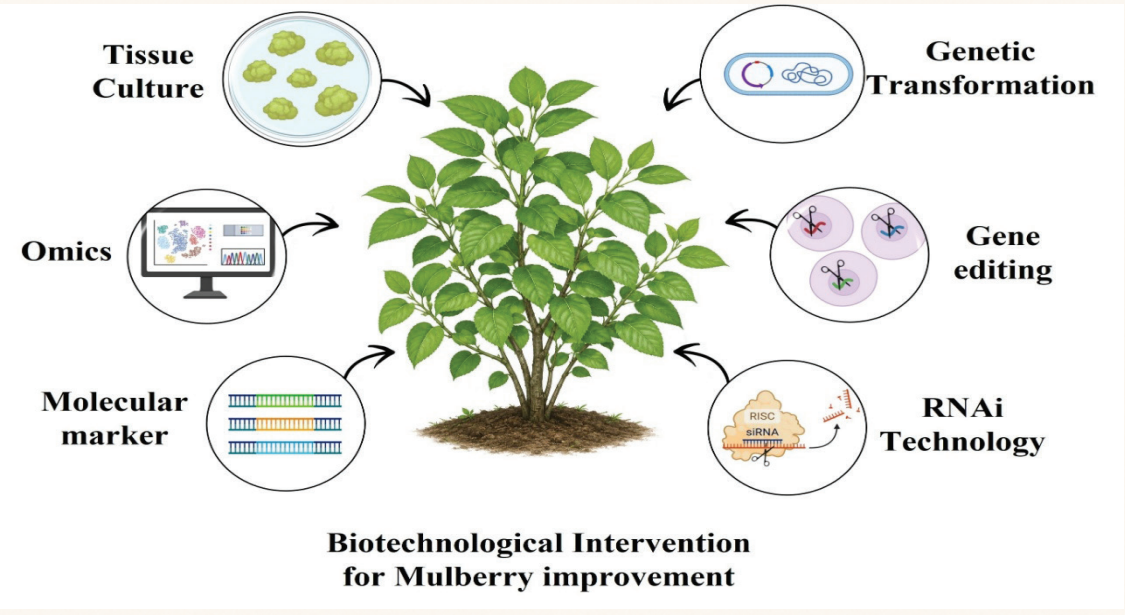


Figure 1: Overview of Biotechnological Interventions for mulberry improvement

To overcome these challenges, biotechnological interventions are needed to develop climate-resilient mulberry varieties for sustainable sericulture under changing environmental conditions.

Biotechnology has become an important tool for improving mulberry and maintaining stable silk production. By combining traditional breeding methods with modern biotechnological approaches such as marker-assisted breeding, tissue culture, genetic transformation, omics, RNAi technology, gene pyramiding, and genome editing, researchers are developing high-yielding mulberry varieties with improved drought tolerance, heat resistance, and resistance to pests and diseases (Fig. 1).

4.2. CLIMATE CHANGE AND ITS IMPACT ON MULBERRY

Climate change is the major environmental challenge affecting the global sericulture industry. High atmospheric temperature, CO_2 concentration, irregular rainfall, drought and floods have influenced mulberry cultivation and sericulture industry. Mulberry is very sensitive to environmental changes, which affect the physiological and biochemical processes. Also, various beneficial microorganisms are impacted by climate change resulting in poor soil quality (Bhat *et al.,* 2024; Manzoor and Qayoom, 2024).

4.2.1. Heat stress

High atmospheric temperatures at 40 ºC and above can affect growth and development of mulberry by reducing photosynthesis efficiency, increased respiration, leaf moisture reduction and finally decreases leaf yield (Chaitanya *et al.,* 2001; Guha *et al.,* 2026).

4.2.2. CO_2 Concentration

Due to increased concentration of greenhouse gases, the atmospheric CO_2 level increased by 20 percent from 1990. Although it has a positive effect on C3 plants but with long-term exposure may affect the photosynthesis (Woodward, 2002).

4.2.3. Irregular rainfall

The major consequences of climate change which affects soil moisture, poor water uptake, water logging and flooding and soil erosion. Which further affects the nutritional efficiency and increases the pest and disease incidence and finally the plant faces the physiological stress (Ramegowda *et al.,* 2012).

4.2.4. Drought

It usually occurs when water availability is reduces such as low rainfall, prolonged dry periods, high temperature, and increased evaporation causing declined ground water availability. These changes can cause plant to reduce growth, drying and wilting of the leaves, reduced photosynthesis and transpiration, decreased chlorophyll content and oxidative stress (Sun *et al.*, 2023).

4.3. BIOTECHNOLOGICAL TOOLS FOR MULBERRY IMPROVEMENT

The plant biotechnology has given important tools for mulberry improvement such as tissue culture, molecular marker assisted selection, genetic transformation, genome editing, RNA interference and omics technologies. Together these biotechnological interventions play an important role in improving mulberry varieties and make sure sustainable sericulture under changing climatic conditions (Guha *et al.,* 2026).

4.3.1. Tissue culture

Tissue culture technology is an important biotechnological tool used in propagation and improvement of mulberry plants which involves the growth of healthy, high yielding stress tolerant plant. Major tissue culture techniques involve micropropagation, meristem culture, callus culture, somatic embryogenesis, anther and pollen culture and *in vitro* germplasm conservation. These techniques

help in selection of stress tolerant line and regenerated into whole plants, production of disease-free plants and faster breeding (Vijayan *et al.,* 2011). Overall, these techniques play an important role in climate resilient mulberry improvement.

4.3.2. Marker-Assisted Selection

Marker assisted selection (MAS) is a breeding technology used to select high quality plants during breeding. Instead of visible characters MAS allows to identify useful genes at DNA level. Which helps in the selection of plant with heat and drought tolerance, salinity and disease resistance with high nutritional quality. Molecular marker technologies can be used in generation of genetic linkage maps, selection of breeds with specific characters within large progeny, selection of parents for new breeding programs, to study of quantitative traits loci (QTLs)**.** There are major types of molecular markers used in mulberry that includes RAPD, ISSR, AFLP, SSR and SNP (Venkateswarlu *et al.,* 2005).

Random Amplified Polymorphic DNA markers (RAPD) are mainly PCR based which uses random primers, to amplify random site of DNA. It is mainly used for identification of stress-tolerant genotypes, mutant detection and germplasm conservation. Inter Simple Sequence Repeat markers (ISSR) helps in analysis of stress-tolerant genotypes, conserving adaptive genetic resources and improving breeding efficiency. Amplified Fragment Length Polymorphism (AFLP) help in assess genetic diversity and support in marker assisted breeding.

Simple Sequence Repeats (SSR) are useful in identifying stress-tolerant genotypes, construct linkage maps and detect QTLs for mulberry improvement. Single Nucleotide Polymorphism (SNP) play a major role in construction high resolution genetic maps and QTLs associated with resistant genomic locus (Vijayan *et al.,* 2014). SSR markers are used for genetic characterization and diversification research in mulberry (*Morus alba*) germplasm. SSR markers, which are commonly used for genetic characterization, have identified 68 distinct alleles across 37 mulberry genotypes using SSR-based profiling (Garcia-Gómez *et al.,* 2019). The genetic relationships and fruit characteristics of mulberries for early selection was investigated using ISSR marker (Dönmez *et al.,* 2023).

4.3.3. Genetic Transformation

Genetic transformation is a modern biotechnological tool used in introducing a foreign or modified gene into the plant genome to improve desirable traits. In mulberry, it plays an important role to develop improved varieties of mulberry plant with stress tolerance, disease resistance and increased productivity.

The methods include direct and indirect transformation in which direct transfer includes 2 types physical and chemical, physical methods are electroporation, biolistic/particle bombardment, microinjection, vacuum in-filtration, silicon-carbide whisker mediated, ultrasound mediated, laser microbeams and shock wave mediated. Chemical methods include calcium phosphate coprecipitation, liposome mediated, Polyethylene Glycol (PEG) mediated, Diethyl amino ethyl (DEAE) dextran mediated. The indirect transformation includes, agrobacterium mediated (*Agrobacterium tumefaciens, Agrobacterium rhizogenic*) and Vector/virus mediated transfer (Tripathi and Shukla, 2024). Among all, Agrobacterium mediated transformation is commonly used for generating genetically modified plants including mulberry. For instance, the barley *HVA1* gene, encodes a group 3 LEA protein, was introduced into mulberry (*Morus indica*) through agrobacterium-mediated transformation. The resultant transformed mulberry plants exhibited tolerance to drought and salinity stress (Lal *et al.,* 2008). The *AtSHN1* gene from *Arabidopsis thaliana*, known for regulating wax biosynthesis, was introduced into Indian mulberry (*Morus indica*), resulting in transgenic plants with increased

leaf surface wax content. This modification led to reduced post-harvest water loss and improved moisture retention (Sajeevan *et al.,* 2017). In addition, Co-expression of *AtDREB2A* and *AtSHN1* in transgenic mulberry showed tolerance to salinity as well as drought stress (Sarkar *et al.,* 2025). Furthermore, Sarkar et al (2024) observed enhance photosynthesis and improve tolerance to drought and salinity in transgenic mulberry overexpressing the phosphoenol pyruvate carboxylase (PEPC) gene from *Flaveria trinervia* (Sarkar *et al.*, 2024). These are important techniques involved in the genetic transformation that helps in the improvement climate resilient mulberry.

The successful application of Agrobacterium-mediated transformation demonstrates the potential of biotechnology to overcome the limitations of traditional breeding methods, enabling the rapid development of high-quality mulberry varieties. As these genetic improvements continue to evolve, they offer significant implications for the sericulture industry and broader agricultural practices, paving the way for more resilient and productive crops in the face of changing environmental conditions.

4.3.4. Genome Editing

Genome editing is an advanced molecular biotechnological tool used to modify specific genes within genome of an organism. Genome editing does target insertion, deletion or modification of DNA sequences at specific gene locations. The major genome editing tools are Clustered Regulatory Interspaced Short Palindromic Repeats (CRISPR)/ CRISPR Associated Nuclease 9 (Cas 9), Transcription Activator-Like Effector Nucleases (TALENs), and Zinc finger nucleases (ZFNs) etc (Mohanta *et al.,* 2017). Among these, CRISPR/Cas 9 is one of the most popular and efficient tools in genome editing where the guide RNA identifies the target DNA and Cas 9 protein acts as a molecular scissor and cuts the DNA at specific loci. And the natural DNA repair system repairs the cut which leads to desired genetic modification. These tools are essential for improving mulberry under climate change conditions.

4.3.5. RNAi Technology

RNA interference (RNAi) technology is also an advanced molecular biotechnical tool in gene silencing. It is basically a cellular mechanism in which double stranded RNA (dsRNA) suppresses the expression of target specific genes. It has become an important strategy for plant protection. It contributes by silencing genes involved stress susceptibility, pest and disease. While enhancing drought tolerance, heat resistance and salinity adaptation including plant defence mechanism (Liu *et al.,* 2021). It contributes sustainable mulberry cultivation and resilient sericulture under changing climate conditions.

4.3.6. Omics

Omics approach is an advanced high throughput technology used to study structure, function and interaction of biological molecules. It helps in understanding the genetic makeup, stress tolerance and quality traits. It includes genomics, transcriptomics, proteomics and metabolomics. The genomics involves whole genome sequencing, and identification of molecular markers like SSRs and SNPs. Transcriptomics examines the expression pattern of specific drought and salt stress genes in mulberry by RNA sequencing, microarray analysis and differential gene expression studies. Transcriptomic analysis of heat-stressed mulberry plants reveals key pathways and transcription factors involved in heat response, including valine, leucine, and isoleucine degradation, starch and sucrose metabolism, and plant hormone signalling. The identification of specific differentially expressed genes (DEGs) and transcription factors such as AP2/ERF, WRKYs, NACs and HSF highlight the complex regulatory networks in play. These findings provide valuable insights for

developing heat-tolerant mulberry varieties and contribute to broader studies on plant stress resilience *(Jin et al.,* 2023).

Proteomics also plays an important role in understanding plant growth and development and how it can be modulated under different stress conditions by identifying stress responsive proteins, defence related proteins and enzyme activities. Proteomic study carried out by Liu et al (2019) have provided the first comprehensive physiological profile of mulberry's adaptation to these salt and drought stresses. Key findings include changes in the root-to-shoot ratio, increased electrolyte leakage, and reduced water content. Proteins involved in essential processes such as carbon metabolism, photosynthesis, ROS defence, and hormone metabolism were differentially expressed, indicating that these pathways work in synergy to mediate mulberry's stress response. This understanding is essential for future genetic engineering and breeding efforts aimed at enhancing crop productivity and resilience under combined stress conditions (Liu *et al.,* 2019).

Metabolomics studies enable the understanding of biochemical process in plants and its reaction towards the changing environment. overall theses omics techniques serve as a key role in the development of stress tolerant mulberry varieties for changing climatic conditions (Guha *et al.,* 2026). Recent metabolomics studies on mulberry variety Yu-711 under drought stress have uncovered significant alterations in several metabolite classes, including lipids, carbohydrates, polyphenols, and amino acids. These changes suggest that mulberry activates protective mechanisms to cope with water deficiency. For instance, the plant ramps up the biosynthesis of structural lipids to maintain the integrity of cell and chloroplast membranes, while increasing the production of antioxidants to scavenge reactive oxygen species (ROS), which are harmful byproducts of stress. These findings highlight the importance of metabolomics in understanding how mulberry adapts to drought, providing a foundation for future efforts to improve the plant's resilience through metabolic engineering (Ackah *et al.*, 2021).

These approaches help in understanding the stress occurring to the mulberry plant and try to overcome it. They have greatly enhanced the scope and efficiency of mulberry improvement under changing climatic conditions. By identifying important genes that are involved in abiotic stress to the plants and incorporating or editing the genes to make it resistant to such environment and produce quality yield. Such improvements are important for the sustainable sericulture productivity and farmer livelihoods.

4.4. FUTURE PERSPECTIVES

The future mulberry improvement should focus on advanced biotechnological tools including conventional breeding approaches to develop climate-resilient mulberry plants. Progress in biotechnological tools like genomics, gene editing etc may provide new opportunities for improving the mulberry varieties. And advanced technologies like CRISPR/Cas plays a major role in targeted gene modification of genes involved in stress tolerance etc. Likewise, incorporation of omics technology like genomics, transcriptomics, proteomics and metabolomics help to understand stress responsive mechanism. RNAi based technologies also provide pest and disease management during climate change conditions to mulberry. Further research should include conservation and stress tolerant species for breeding. And integration of high-throughput bioinformatics and machine learning may improve efficient selection of mulberry varieties. Furthermore, development of environmentally sustainable cultivation practices along with climate-smart biotechnology will be essential to ensure stable mulberry production, improved silkworm productivity and sustainable sericulture under future climate change scenarios.

4.5. CONCLUSION

Climate change has been raised as a serious crises affecting mulberry cultivation and its productivity by increased temperature, drought, irregular rainfall and salinity. These changes pose a negative effect on plant physiology, leaf yield and nutritional quality ultimately silkworm growth and silk production. So, the development of climate resilient mulberry is very essential. Biotechnological tools such as mentioned in the chapter has significantly improves the efficiency of mulberry varieties. These technologies help in identification, selection and editing of particular stress responsive genes. Modern biotechnology including breeding offers good potential for stress tolerant mulberry varieties. Overall, biotechnological tools provide solutions for mulberry improvement during changing climate condition.

4.6. REFERENCE:

Ackah, M., Shi, Y., Wu, M., Wang, L., Guo, P., Guo, L., Jin, X., Li, S., Zhang, Q., Qiu, C., 2021. Metabolomics response to drought stress in *Morus alba* L. variety Yu-711. Plants 10, 1636.

Baciu, E.-D., Baci, G.-M., Moise, A.R., Dezmirean, D.S., 2023. A status review on the importance of mulberry (*Morus* spp.) and prospects towards its cultivation in a controlled environment. Horticulturae 9, 444.

Bhat, M.R., Radha, P., Faruk, A.A., Vas, M., Brahma, D., Bora, N.R., Bharathi, K.M., Garai, I., 2024. Climate change and its impact on sericulture. International Journal of Zoology and Applied Biosciences 9, 13–25.

Chaitanya, K.V., Sundar, D., Ramachandra Reddy, A., 2001. Mulberry Leaf Metabolism under High Temperature Stress. Biologia plant. 44, 379–384. https://doi.org/10.1023/A:1012446811036

Dönmez, D., Karaat, F.E., Aka Kaçar, Y., Şimşek, Ö., 2023. Molecular characterization and association of ISSR markers with some fruit properties of *Morus alba* L. genotypes in Southeastern Türkiye. Genet Resour Crop Evol 70, 2129–2142. https://doi.org/10.1007/s10722-023-01563-2

Garcia-Gómez, B., Gonzalez-Alvarez, H., Martinez-Mora, C., Cenis, L.J., Pérez-Hernández, C.D.M., Martinez-Zubiaur, Y., Martínez-Gómez, P., 2019. The molecular characterization of an extended mulberry germplasm by SSR markers. Genetika 51, 389–403.

Ghosh, A., Gangopadhyay, D., Chowdhury, T., 2017. Economical and environmental importance of mulberry: a review. International Journal of Plant and Environment 3, 51–58.

Guha, A., Shukla, P., Prakash, H., Ramesha, A., Dubey, H., Moorthy, S.M., 2026. Mulberry Improvement in the Scenario of Climate Change Conditions: Current Progress and Future Prospects, in: Saha, S., Mondal, R. (Eds.), Sustainable Sericulture in India. Springer Nature Switzerland, Cham, pp. 23–49. https://doi.org/10.1007/978-3-032-13890-3_2

Jian, Q., Ningjia, H., Yong, W., Zhonghuai, X., 2012. Ecological issues of mulberry and sustainable development. Journal of Resources and Ecology 3, 330–339.

Jin, X., Ackah, M., Acheampong, A., Zhang, Q., Wang, L., Lin, Q., Qiu, C., Zhao, W., 2023. Genome-wide identification of candidate genes associated with heat stress in mulberry (Morus alba L.). Current Issues in Molecular Biology 45, 4151–4167.

Kaushik, A., Borah, G., Saikia, S., Kaushiki, B., Phukan, T., 2025. Climate-resilient sericulture: Strategies for sustainable silk production in a changing climate. Int. J. Adv. Biochem. Res 9, 891–897.

Lal, S., Gulyani, V., Khurana, P., 2008. Overexpression of HVA1 gene from barley generates tolerance to salinity and water stress in transgenic mulberry (*Morus indica*). Transgenic Res 17, 651–663. https://doi.org/10.1007/s11248-007-9145-4

Liu, S., Geng, S., Li, A., Mao, Y., Mao, L., 2021. RNAi technology for plant protection and its application in wheat. Abiotech 2, 365–374.

Liu, Y., Ji, D., Turgeon, R., Chen, J., Lin, T., Huang, J., Luo, J., Zhu, Y., Zhang, C., Lv, Z., 2019. Physiological and proteomic responses of mulberry trees (*Morus alba*. L.) to combined salt and drought stress. International journal of molecular sciences 20, 2486.

Manzoor, S., Qayoom, K., 2024. Environmental importance of mulberry: A review. Journal of Experimental Agriculture International 46, 95–105.

Mohanta, T.K., Bashir, T., Hashem, A., Abd_Allah, E.F., Bae, H., 2017. Genome editing tools in plants. Genes 8, 399.

Rahman, M.S., Islam, S.M.S., 2021. Studies on food, health and environmental perspectives in mulberry (*Morus* spp.)–A review. Journal of Bio-Science 163–179.

Ramegowda, G.K., Illahi, I., Mittal, V., Akhter, I., Dhar, A., Khan, M.A., 2012. Influence of weather on the incidence and severity of lesser mulberry Pyralid and mulberry Looper in Kashmir, India. J Entomol 9, 422–428.

Sajeevan, R.S., Nataraja, K.N., Shivashankara, K.S., Pallavi, N., Gurumurthy, D.S., Shivanna, M.B., 2017. Expression of Arabidopsis SHN1 in Indian mulberry (*Morus indica* L.) increases leaf surface wax content and reduces post-harvest water loss. Frontiers in Plant Science 8, 418.

Sarkar, T., Nataraja, K.N., F., L.K., Sajeevan, R.S., Dhanyalakshmi, K.H., Doss, S.G., Raghunath, M.K., Sivaprasad, V., 2025. Co-expression of *AtDREB2A* and *AtSHN1* in transgenic mulberry (*Morus* spp.) confers tolerance to drought and salinity and reduces post-harvest water loss. Plant Growth Regul 105, 773–786. https://doi.org/10.1007/s10725-025-01306-6

Sarkar, T., Ravindra, K.N., Sidhu, G.K., Doss, S.G., Raghunath, M.K., Gayathri, T., Ramesha, A., Raghavendra, A.S., Sivaprasad, V., Mogili, T., Arunakumar, G.S., 2024. Overexpression of phosphoenol pyruvate carboxylase gene of *Flaveria trinervia* in transgenic mulberry (*Morus* spp.) leads to improved photosynthesis rate and tolerance to drought and salinity stresses. Plant Cell Tiss Organ Cult 156, 26. https://doi.org/10.1007/s11240-023-02646-9

Sun, Z., Yin, Y., Zhu, W., Zhou, Y., 2023. Morphological, physiological, and biochemical composition of mulberry (*Morus* spp.) under drought stress. Forests 14, 949.

Tripathi, A., Shukla, S., 2024. Methods of genetic transformation: major emphasis to crop plants. Journal of microbiology, biotechnology and food sciences 13, e10276–e10276.

Venkateswarlu, M., Saratchandra, B., Surendranath, B., Vijayan, K., Rajeurs, S., 2005. Strategies for genome mapping and marker assisted selection in mulberry. J Cytol Genet 5, 111–24.

Vijayan, K., Gnanesh, B.N., Tikader, A., 2023. Botanical Features and Economic Significance of Mulberry, in: Gnanesh, B.N., Vijayan, K. (Eds.), The Mulberry Genome, Compendium of Plant Genomes. Springer International Publishing, Cham, pp. 1–11. https://doi.org/10.1007/978-3-031-28478-6_1

Vijayan, K., Raju, P.J., Tikader, A., Saratchnadra, B., 2014. Biotechnology of mulberry (*Morus* L.)-An appraisal. Emir. J. Food Agric 26, 418–442.

Vijayan, K., Tikader, A., da Silva, J.A.T., 2011. Application of tissue culture techniques for propagation and crop improvement in mulberry (*Morus* spp.). Tree For Sci Biotechnol 5, 1–13.

Woodward, F.I., 2002. Potential impacts of global elevated CO2 concentrations on plants. Current Opinion in Plant Biology 5, 207–211.

CHAPTER 5: CLIMATE CHANGE AND ADAPTATION FOR SUB-TROPICAL MULBERRY SERICULTURE

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5.1. INTRODUCTION

Sericulture is an important agro-based industry that integrates mulberry cultivation, silkworm rearing, silk reeling, and silk weaving into a sustainable production system. In countries such as India, sericulture contributes significantly to rural employment generation, livelihood security, women empowerment, and socio-economic development (Ssemugenze *et al.,* 2021). The industry provides direct and indirect employment opportunities to millions of small and marginal farmers, particularly in resource-constrained and climatically vulnerable regions. Owing to its low initial investment requirement and high employment potential, sericulture has emerged as an important component of sustainable rural development and agro-based entrepreneurship. The mulberry silkworm, *Bombyx mori*, is a completely domesticated and highly climate-sensitive insect species. Its growth, development, metabolism, cocoon formation, and silk productivity are strongly influenced by environmental parameters such as temperature, relative humidity, photoperiod, and air quality (MR, A. K., 2025). Optimum silkworm growth generally requires a narrow range of environmental conditions; therefore, even slight fluctuations in climatic variables can adversely affect larval health, feed conversion efficiency, cocoon yield, and filament quality. Since silkworms are monophagous insects dependent exclusively on mulberry leaves for nutrition, the quality and nutritional composition of mulberry foliage also play a decisive role in cocoon productivity and silk quality. Sub-tropical regions, where a major portion of mulberry sericulture is practiced, are characterized by moderate to high temperatures, seasonal rainfall patterns, variable humidity, and diverse agro-climatic conditions. However, the increasing intensity of climate change and climate variability has emerged as a major challenge to sustainable sericulture production systems. Rising atmospheric temperatures, irregular precipitation patterns, prolonged drought periods, unseasonal rainfall, floods, heat waves, and other extreme climatic events have significantly altered the ecological balance of sericulture ecosystems. These climatic abnormalities directly affect mulberry crop physiology by influencing photosynthesis, nutrient uptake, water-use efficiency, leaf moisture content, and biomass production. Consequently, deterioration in mulberry leaf yield and nutritional quality negatively impacts silkworm growth and cocoon characteristics.

High temperature stress and low relative humidity during silkworm rearing often result in reduced larval appetite, increased susceptibility to diseases, shortened larval duration, improper moulting, and higher mortality rates. Similarly, excessive humidity and poor ventilation create favourable conditions for the outbreak and spread of silkworm diseases caused by pathogens such as fungi, bacteria, viruses, and microsporidia. Climatic stress also affects cocoon shell ratio, filament length, denier, reelability, and raw silk recovery, thereby reducing the economic returns of farmers and the silk industry. In addition, climate-induced changes in pest and disease dynamics in mulberry fields further aggravate production instability in sub-tropical sericulture regions (Kaushik *et al.,* 2025).

The sustainability and resilience of sericulture under changing climatic conditions therefore depend on the adoption of scientifically designed (climate-resilient management strategies. These include

the development of heat- and drought-tolerant mulberry varieties, improved silkworm breeds with enhanced thermo-tolerance, efficient irrigation and water conservation techniques, precision nutrient management, integrated pest and disease management, protected rearing technologies, and climate-based advisory systems. Advanced approaches involving geospatial technologies, remote sensing, climate modelling, artificial intelligence, and decision-support systems can further strengthen climate risk assessment and adaptive management in sericulture.

Understanding the complex interaction between climate change and sericulture production systems is therefore essential for developing effective adaptation and mitigation strategies to ensure sustainable silk production, livelihood security, environmental stability, and long-term resilience of the sericulture sector in sub-tropical regions.

5.2. CLIMATE CHANGE SCENARIO IN SUB-TROPICAL REGIONS

Climate change refers to long-term alterations in climatic parameters including temperature, precipitation, relative humidity, wind dynamics, and atmospheric greenhouse gas concentrations. These changes may occur naturally over geological time scales; however, in recent decades, anthropogenic activities have become the primary drivers of climate variability and global warming. Rapid industrialization, deforestation, urban expansion, intensive agricultural practices, and large-scale combustion of fossil fuels have significantly increased the concentration of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) in the atmosphere. The enhanced greenhouse effect resulting from these emissions has accelerated global warming, disturbed ecological balance, and intensified environmental degradation across terrestrial and aquatic ecosystems (Morales, J. A., 2022).

Climate change has emerged as one of the most critical environmental challenges affecting agriculture and allied sectors worldwide. Sub-tropical regions, which are highly dependent on climate-sensitive agricultural activities, are increasingly experiencing substantial alterations in weather and climatic patterns (Fluteau, F., 2003). These regions are particularly vulnerable due to their dependence on monsoon rainfall, high population pressure, and limited adaptive capacity. Major climatic changes observed in sub-tropical regions include:

- Gradual increase in mean atmospheric temperature and frequency of heat waves
- Erratic and uneven distribution of rainfall leading to droughts and floods
- Prolonged dry spells and declining soil moisture availability
- Increased occurrence of extreme weather events such as cyclones, storms, and heavy precipitation
- Fluctuations in relative humidity affecting crop and insect physiology
- Seasonal shifts in monsoon onset and withdrawal patterns
- Enhanced evapotranspiration resulting in water stress conditions
- Increased incidence of pests, pathogens, and invasive species due to altered ecological conditions

These climatic abnormalities have profound impacts on agricultural productivity, soil health, biodiversity, water resources, and agro-based industries such as sericulture. In mulberry-based sericulture systems, climatic stress affects both mulberry cultivation and silkworm rearing by altering plant physiological processes, leaf nutritional quality, and silkworm metabolic activities. Elevated temperatures and moisture stress reduce mulberry leaf yield and impair nutrient composition, while unsuitable rearing conditions adversely influence silkworm growth, cocoon formation, disease resistance, and silk quality. Furthermore, climate change affects carbon cycling,

soil microbial activity, and nutrient dynamics, thereby influencing long-term sustainability of agricultural ecosystems. The combined effect of abiotic and biotic stresses under changing climatic conditions poses serious threats to rural livelihoods, food security, and sustainable silk production in sub-tropical regions. Therefore, scientific assessment of climate variability and development of climate-resilient technologies are essential to minimize the adverse impacts of climate change and ensure sustainable agricultural and sericultural production systems.

5.2.1. Rise in Temperature

A continuous rise in atmospheric temperature has been observed in many mulberry sericulture-growing regions under sub-tropical climatic conditions. Elevated temperature adversely affects both mulberry cultivation and silkworm rearing by disturbing physiological and biochemical processes. In mulberry plants, high temperature accelerates evapotranspiration, reduces soil moisture availability, and induces moisture stress, leading to reduced leaf yield, poor leaf succulence, and deterioration in nutritional quality. Photosynthetic efficiency, chlorophyll stability, and nutrient uptake are also negatively influenced under heat stress conditions.

In silkworm rearing, elevated temperature disrupts larval metabolism, feeding behaviour, digestion, and growth (Kumar *et al.*, 2024). The mulberry silkworm, *Bombyx mori*, requires optimum environmental conditions for proper development; therefore, excessive heat causes reduced feed intake, shortened larval duration, improper moulting, reduced cocoon weight, poor shell ratio, and decline in silk quality. Prolonged exposure to high temperature also increases larval mortality and susceptibility to diseases.

5.2.2. Erratic Rainfall Distribution

Rainfall distribution in sericulture-growing regions has become increasingly irregular and unpredictable due to climate change. Delayed monsoon onset, uneven seasonal rainfall, prolonged dry spells, and sudden heavy precipitation events create severe constraints in mulberry cultivation. Insufficient rainfall and drought conditions reduce soil moisture availability, impair nutrient transport, and suppress mulberry leaf production, while excessive rainfall and waterlogging damage root systems, reduce aeration, and increase the incidence of root diseases.Erratic rainfall also affects irrigation scheduling, intercultural operations, and leaf harvesting practices in mulberry gardens. Poor-quality mulberry leaves produced under moisture stress conditions adversely affect silkworm nutrition, larval growth, cocoon formation, and filament quality. In addition, excessive moisture during the silkworm rearing season increases humidity inside rearing houses, thereby creating favourable conditions for pathogen development and disease outbreaks.

5.2.3. Increased Frequency of Extreme Weather Events

The frequency and intensity of extreme climatic events such as heat waves, cyclones, thunderstorms, droughts, and flash floods have increased considerably in recent years. These events cause severe damage to mulberry-based sericulture ecosystems. Strong winds, heavy rainfall, and floods destroy mulberry plantations, cause soil erosion, nutrient losses, lodging of plants, and reduction in leaf biomass production. Drought conditions further aggravate moisture stress and decrease mulberry productivity (Bekkamov, C., & Samatova, S., 2023).

Extreme weather conditions also create unsuitable environmental conditions for silkworm rearing. Sudden fluctuations in temperature and humidity adversely affect larval physiology, moulting process, cocoon spinning behaviour, and silk synthesis. Heat waves and poor ventilation during rearing may induce thermal stress, resulting in poor cocoon quality and increased larval mortality.

Similarly, excessive moisture and unhygienic conditions following floods or storms promote the spread of silkworm diseases caused by fungal, bacterial, viral, and microsporidian pathogens.

5.2.4. Changes in Relative Humidity

Relative humidity is one of the most critical environmental factors influencing the growth and development of silkworms. Climate change-induced fluctuations in humidity levels significantly affect silkworm physiology, disease incidence, cocoon productivity, and silk quality. Very high humidity inside rearing houses creates favourable conditions for fungal pathogens and increases the occurrence of diseases such as muscardine, leading to substantial crop losses. Excessive humidity also affects larval respiration, feeding efficiency, and cocoon spinning (Kumar *et al.*, 2024).Conversely, low relative humidity causes rapid moisture loss from silkworm body tissues, resulting in dehydration, reduced feeding activity, weak larval growth, and poor cocoon formation. Dry environmental conditions also reduce mulberry leaf moisture content, thereby decreasing leaf palatability and nutritional efficiency for silkworms. Frequent fluctuations in humidity during different larval stages disturb normal physiological activities and reduce overall rearing performance and silk productivity.

Table 1. Climatic Factors and Their Effects on Mulberry Sericulture

Climatic Factor	Impact on Mulberry	Impact on Silkworm
High Temperature	Reduced leaf quality and moisture	Heat stress and reduced cocoon quality
Drought	Reduced leaf yield	Insufficient feed availability
Flooding	Root damage and nutrient loss	Increased disease incidence
Humidity Fluctuation	Leaf disease incidence	Poor moulting and larval mortality

5.3. IMPORTANCE OF CLIMATIC FACTORS IN MULBERRY SERICULTURE

Climatic factors play a crucial role in determining the productivity, sustainability, and economic viability of mulberry sericulture. Since both mulberry plants and silkworms are highly sensitive to environmental conditions, variations in climatic parameters directly influence mulberry growth, leaf nutritional quality, silkworm physiology, cocoon characteristics, and raw silk production. Environmental conditions regulate several physiological, biochemical, and metabolic processes involved in plant growth and insect development. Therefore, maintaining favourable climatic conditions is essential for achieving higher cocoon yield, improved silk quality, and successful silkworm crop performance.

5.3.1. Temperature

Temperature is one of the most critical environmental factors governing mulberry cultivation and silkworm rearing. Mulberry plants generally exhibit optimum growth and leaf production within a temperature range of approximately 24–28°C. Suitable temperature conditions enhance photosynthetic activity, nutrient absorption, enzymatic reactions, and vegetative growth, resulting in increased leaf biomass and better leaf nutritional quality. However, exposure to elevated temperatures induces heat stress, accelerates evapotranspiration, reduces soil moisture availability, and adversely affects leaf moisture content and protein synthesis (Bhat, *et al.*, 2024).

In silkworm rearing, the mulberry silkworm, *Bombyx mori*, requires specific temperature conditions during different larval instars for proper growth, moulting, and cocoon formation. Temperature directly regulates larval metabolism, digestion, feeding efficiency, respiration, and silk protein

synthesis. High temperature stress reduces feed intake, impairs silk gland development, shortens larval duration, and decreases cocoon shell ratio and filament quality. Extreme temperature fluctuations may also increase larval mortality and disease susceptibility, thereby reducing overall cocoon productivity.

5.3.2. Relative Humidity

Relative humidity is another important climatic parameter influencing both mulberry physiology and silkworm health. In mulberry plants, humidity affects transpiration rate, stomatal conductance, water-use efficiency, and leaf succulence. Adequate humidity maintains leaf tenderness and moisture content, which are essential for silkworm nutrition and palatability.

During silkworm rearing, optimum relative humidity is necessary for proper larval growth, feeding, moulting, and cocoon spinning. Different larval stages require specific humidity levels to maintain normal physiological activities and successful moulting processes. High humidity conditions favour the proliferation of fungal and bacterial pathogens, increasing the incidence of diseases such as muscardine and flacherie. Conversely, low humidity causes dehydration, reduced feeding activity, poor larval growth, and defective cocoon formation. Sudden fluctuations in humidity disturb silkworm metabolism and negatively affect cocoon yield and silk quality.

5.3.3. Rainfall

Rainfall is a major climatic factor regulating soil moisture availability, nutrient dynamics, and mulberry productivity. Adequate and well-distributed rainfall supports healthy vegetative growth, root development, and continuous leaf production in mulberry plantations. Sufficient soil moisture improves nutrient uptake, leaf succulence, and photosynthetic efficiency, thereby enhancing leaf yield and nutritional quality (Ashaq *et al.*, 2025).

However, insufficient rainfall and prolonged drought conditions reduce soil moisture content, suppress mulberry growth, and decrease leaf biomass production. Water stress also lowers protein content and moisture levels in mulberry leaves, adversely affecting silkworm feeding and cocoon development. On the other hand, excessive rainfall and waterlogging create anaerobic soil conditions that damage root systems, reduce nutrient absorption, and increase the incidence of root rot and other fungal diseases. Irregular rainfall patterns further complicate irrigation scheduling and mulberry crop management practices in sericulture-growing regions.

5.3.4. Solar Radiation

Solar radiation is essential for photosynthesis, energy transfer, and biomass accumulation in mulberry plants. Adequate sunlight enhances chlorophyll activity, carbohydrate synthesis, and leaf development, thereby improving mulberry leaf yield and nutritional quality. Proper solar radiation also supports balanced plant growth and increases the synthesis of proteins and other metabolites required for silkworm nutrition.

However, excessive solar radiation and prolonged exposure to intense sunlight may increase leaf temperature, moisture loss, and transpiration rates, resulting in leaf scorching, reduced succulence, and decline in leaf quality (Zhao *et al.*, 2022). Heat stress associated with excessive radiation may also reduce photosynthetic efficiency and overall mulberry productivity. In sericulture systems, poor-quality leaves produced under excessive solar stress negatively affect silkworm feeding behaviour, larval growth, cocoon formation, and silk filament characteristics. Therefore, balanced solar exposure is essential for maintaining sustainable mulberry growth and efficient silkworm rearing.

5.4. IMPACT OF CLIMATE CHANGE ON MULBERRY CULTIVATION

Climate change directly affects mulberry cultivation through alterations in environmental and soil conditions.

5.4.1. Effect of High Temperature on Mulberry Growth

Elevated temperatures increase transpiration and evapotranspiration rates, leading to rapid soil moisture depletion. Heat stress reduces chlorophyll synthesis, photosynthetic efficiency, and leaf moisture content. As a result, mulberry leaves become coarse, less succulent, and nutritionally inferior for silkworm feeding. High temperatures also affect root activity and nutrient uptake, thereby reducing biomass production and leaf yield. Prolonged exposure to heat stress may result in reduced shoot growth and premature leaf senescence.

5.4.2. Drought Stress and Water Scarcity

Drought conditions are becoming increasingly common in sub-tropical regions. Water stress reduces cell expansion, photosynthesis, and leaf area development in mulberry plants. Reduced soil moisture availability also affects microbial activity and nutrient mineralization. Under severe drought conditions, mulberry leaf yield declines significantly, affecting silkworm feeding and cocoon production. Rainfed sericulture systems are particularly vulnerable to prolonged dry spells.

5.4.3. Flooding and Waterlogging

Excessive rainfall and flooding create anaerobic conditions in the root zone, reducing oxygen availability for root respiration. Waterlogging damages root tissues, decreases nutrient absorption, and promotes root diseases (Zhao *et al.*, 2022). Flood-affected mulberry fields often show yellowing of leaves, stunted growth, and reduced productivity. Soil erosion and nutrient leaching further deteriorate soil fertility.

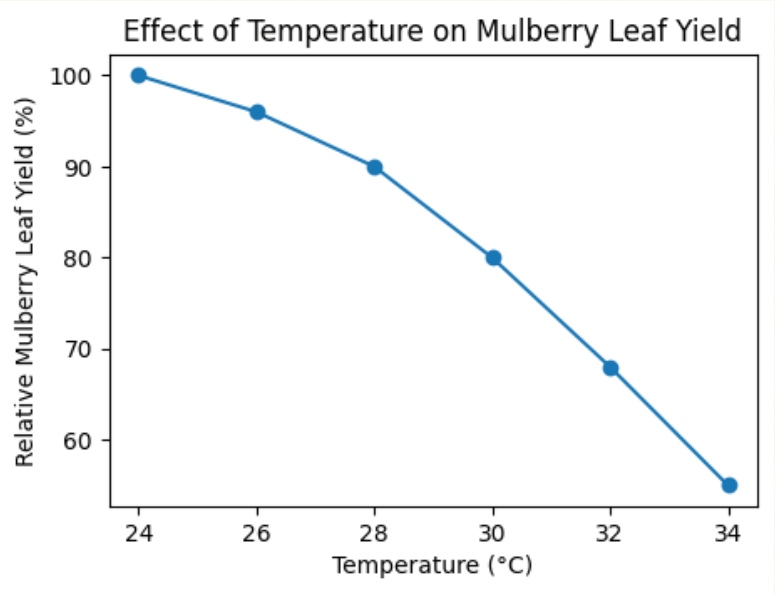
5.4.4. Soil Degradation under Climate Change

Climate change accelerates soil degradation processes including erosion, salinity, nutrient depletion, and organic matter loss. Increased temperature enhances organic carbon decomposition, leading to reduced soil carbon stocks. Declining soil fertility negatively affects mulberry productivity and sustainability. Soil degradation also reduces water-holding capacity and increases vulnerability to drought.

5.4.5. Pest and Disease Incidence

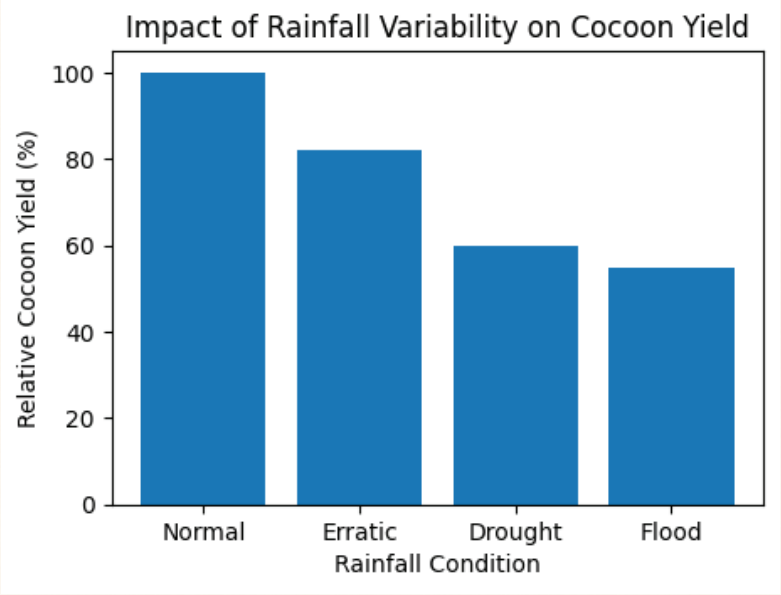
Changing climatic conditions favor the proliferation and spread of insect pests and pathogens. Higher temperature and humidity create suitable environments for diseases such as powdery mildew, leaf spot, tukra disease, and root rot. Climate change may also alter pest life cycles, increase pest survival rates, and expand their geographical distribution (Yadav, N., & Upadhyay, R. K. 2023).

Chart 1. Effect of Temperature on Mulberry Leaf Yield



The chart indicates that increasing temperature beyond optimum conditions significantly reduces mulberry leaf yield due to heat stress and increased evapotranspiration.

Chart 2. Impact of Rainfall Variability on Cocoon Yield



Erratic rainfall, drought, and flooding conditions adversely affect cocoon productivity through poor mulberry growth and unfavorable silkworm rearing conditions.

5.5. IMPACT OF CLIMATE CHANGE ON SILKWORM REARING

Silkworms are highly sensitive to environmental conditions, making silkworm rearing extremely vulnerable to climatic fluctuations.

5.5.1. Heat Stress in Silkworms

Elevated temperatures increase silkworm metabolic activity and respiration rate. Excess heat reduces feeding efficiency, digestion, and nutrient assimilation. Heat-stressed larvae often exhibit poor growth, weak immunity, and reduced cocoon quality.Severe heat stress may increase larval mortality and reduce silk production efficiency.

5.5.2. Humidity Imbalance

Improper humidity during rearing adversely affects moulting and cocoon spinning. Low humidity causes dehydration and poor larval growth, whereas excessively high humidity favors microbial infection and fungal diseases. Maintaining optimum humidity is therefore essential for healthy silkworm development.

5.5.3. Increased Disease Incidence

Climate variability enhances the occurrence of silkworm diseases such as:

- Pebrine
- Grasserie
- Flacherie
- Muscardine

Fluctuating environmental conditions weaken larval immunity and promote pathogen multiplication.

5.5.4. Decline in Cocoon and Silk Quality

Climatic stress affects silk gland development and silk protein synthesis. Consequently, cocoon shell weight, filament length, reelability, and silk strength decline under unfavorable climatic conditions. Poor-quality cocoons reduce market value and economic returns to farmers.

5.6. VULNERABILITY OF SUB-TROPICAL SERICULTURE SYSTEMS

The vulnerability of sericulture systems depends upon climatic exposure, sensitivity of biological components, and adaptive capacity of farmers (Bhat, M. R. *et al.*, 2024) .Small and marginal farmers practicing traditional sericulture are more vulnerable because of:

- Limited irrigation facilities
- Low financial resources
- Lack of climate-resilient technologies
- Inadequate access to weather information
- Dependence on rainfed agriculture

Regions with fragile ecosystems and poor infrastructure are particularly susceptible to climate-induced losses.

5.7. ADAPTATION STRATEGIES FOR CLIMATE-RESILIENT SERICULTURE

Adaptation strategies are necessary to minimize climate-induced risks and sustain sericulture productivity.

Table 2. Adaptation Strategies for Climate-Resilient Sericulture

Adaptation Strategy	Purpose	Expected Benefit
Drip Irrigation	Efficient water use	Reduced drought stress

Adaptation Strategy	Purpose	Expected Benefit
Mulching	Soil moisture conservation	Improved leaf productivity
Protected Rearing House	Environmental control	Reduced larval mortality
Climate-Resilient Varieties	Stress tolerance	Stable productivity
Agroforestry	Carbon sequestration	Improved ecosystem stability

5.7.1. Development of Climate-Resilient Mulberry Varieties

Scientific breeding programmes should focus on developing mulberry varieties with:

- Drought tolerance
- Heat tolerance
- Pest and disease resistance
- High water-use efficiency
- Improved nutrient-use efficiency

Climate-resilient varieties can maintain productivity under adverse environmental conditions.

5.7.2. Water Management Strategies

Efficient water management practices are essential for sustaining mulberry cultivation under changing climatic conditions (Nandan, M., & Ashwini, T. R., 2026).

Important measures include:

- Drip irrigation
- Sprinkler irrigation
- Rainwater harvesting
- Farm ponds
- Mulching
- Micro-irrigation systems

These practices improve water-use efficiency and reduce drought stress.

5.7.3. Soil Health Management

Improvement of soil health enhances resilience against climate stress. Integrated soil management practices include:

- Application of farmyard manure
- Vermicompost addition
- Green manuring
- Biofertilizer application
- Conservation tillage
- Crop residue recycling

Improved soil organic carbon enhances water retention and nutrient availability.

5.7.4. Protected Silkworm Rearing

Scientific rearing houses with environmental control systems help maintain optimum temperature and humidity during silkworm rearing.

Low-cost technologies such as:

- Ventilation systems
- Humidifiers
- Cooling devices
- Insulated rearing houses

can significantly reduce climate-induced mortality.

5.7.5. Integrated Pest and Disease Management

Integrated approaches combining biological, cultural, and chemical methods are essential for climate-resilient sericulture.

These include:

- Use of disease-free layings
- Biological control agents
- Resistant varieties
- Hygienic rearing practices
- Botanical pesticides

5.7.6. Agroforestry and Carbon Sequestration

Mulberry-based agroforestry systems improve biodiversity conservation, soil health, and carbon sequestration. Trees regulate microclimate, reduce soil erosion, and improve ecological stability.

Sericulture systems therefore contribute not only to adaptation but also to climate change mitigation.

5.7.7. Climate Information and Digital Advisory Services

Modern technologies such as GIS, remote sensing, artificial intelligence, and weather forecasting systems can support climate-smart sericulture management (Ashaq *et al.*, 2025).

Digital advisory systems help farmers in:

- Irrigation scheduling
- Pest forecasting
- Drought monitoring
- Crop planning
- Risk assessment

5.8. ROLE OF GIS AND REMOTE SENSING IN CLIMATE ADAPTATION

Geospatial technologies are increasingly important for climate-resilient sericulture planning and management.

Remote sensing and GIS applications support:

- Climatic zoning
- Soil mapping
- Drought assessment
- Land suitability analysis
- Carbon stock estimation
- Monitoring of mulberry plantations

These technologies help policymakers and researchers identify vulnerable regions and implement targeted adaptation strategies.

5.9. CLIMATE CHANGE MITIGATION THROUGH SERICULTURE

Mulberry sericulture contributes to environmental sustainability and climate mitigation through carbon sequestration and ecological conservation.

Mulberry plantations act as perennial vegetation systems capable of storing atmospheric carbon in:

- Above-ground biomass
- Root biomass
- Soil organic matter

Adoption of sustainable land management practices further enhances carbon storage and reduces greenhouse gas emissions.

5.10. POLICY SUPPORT AND INSTITUTIONAL INTERVENTIONS

Climate-resilient sericulture requires strong institutional and policy support.

Important interventions include:

- Farmer training programmes
- Climate-smart sericulture policies
- Crop insurance schemes
- Research and development support
- Irrigation infrastructure development
- Weather-based advisory services

Collaboration among research institutions, government agencies, and farmers is essential for long-term sustainability.

5.11. FUTURE RESEARCH PRIORITIES

Future research in climate-resilient sericulture should focus on developing stress-tolerant mulberry varieties and resilient races of *Bombyx mori* capable of withstanding heat stress, drought, fluctuating humidity, and emerging diseases under sub-tropical climatic conditions. Studies on carbon sequestration potential in mulberry-based agroforestry systems are essential to evaluate their role in climate change mitigation, enhancement of soil organic carbon, and ecosystem sustainability. Research should also emphasize precision sericulture through integration of advanced technologies such as Internet of Things (IoT), Geographic Information Systems (GIS), remote sensing, artificial intelligence, and sensor-based environmental monitoring systems for real-time decision support, disease forecasting, irrigation scheduling, and climate advisory services. Furthermore, detailed investigation of soil–plant–atmosphere interactions is necessary to understand climate-induced changes in soil microbial activity, nutrient cycling, carbon dynamics, water-use efficiency, and mulberry physiological responses. Such multidisciplinary approaches will support the development of climate-smart sericulture systems capable of improving productivity, resource-use efficiency, environmental sustainability, and livelihood security of sericulture.

5.12. CONCLUSION

Climate change has farmers under changing climatic scenarios, emerged as a major environmental and socio-economic challenge threatening the sustainability of sub-tropical mulberry sericulture

systems. Increasing atmospheric temperatures, irregular rainfall distribution, prolonged droughts, floods, heat waves, and frequent extreme weather events have significantly disrupted the ecological balance required for efficient mulberry cultivation and silkworm rearing. These climatic stresses adversely influence mulberry plant growth, leaf yield, leaf nutritional quality, soil moisture dynamics, and overall plantation productivity. Simultaneously, fluctuating environmental conditions negatively affect the physiology, metabolism, immunity, and rearing performance of the mulberry silkworm, *Bombyx mori*, resulting in reduced cocoon yield, inferior silk quality, higher disease incidence, and increased larval mortality.Climate-induced alterations in pest and pathogen dynamics further aggravate production instability in sericulture ecosystems. Elevated temperature and humidity conditions create favourable environments for the proliferation of fungal, bacterial, viral, and microsporidian diseases affecting both mulberry plants and silkworms. Moreover, declining water availability, soil degradation, nutrient imbalance, and loss of biodiversity under changing climatic conditions directly threaten the livelihood security of sericulture farmers, particularly small and marginal rural households dependent on silk production for income generation.Despite these challenges, adoption of scientifically designed climate adaptation and mitigation strategies can substantially improve the resilience and long-term sustainability of sericulture systems. Development and dissemination of climate-resilient mulberry varieties possessing tolerance to heat, drought, and moisture stress can help maintain stable leaf productivity under adverse environmental conditions. Similarly, breeding and utilization of thermo-tolerant and disease-resistant silkworm races can improve crop stability and cocoon performance under fluctuating climatic environments. Efficient water management practices such as drip irrigation, rainwater harvesting, mulching, micro-irrigation systems, and moisture conservation techniques are essential for sustaining mulberry productivity under water-scarce conditions. Improvement of soil health through integrated nutrient management, organic amendments, biofertilizers, carbon sequestration approaches, and conservation agriculture practices can enhance soil fertility, water retention capacity, and ecosystem resilience. Protected silkworm rearing technologies, environmental monitoring systems, and scientific disinfection practices can further reduce climatic stress and disease outbreaks during silkworm rearing. In addition, integration of agroforestry systems, precision agriculture, remote sensing, geographic information systems (GIS), climate modelling, and artificial intelligence-based decision support systems can provide real-time climatic information and improve adaptive management strategies in sericulture. Climate-smart advisory services and early warning systems can assist farmers in making timely decisions related to irrigation scheduling, disease management, crop protection, and rearing operations.

Therefore, sustainable development of sub-tropical mulberry sericulture under changing climatic conditions requires a multidisciplinary and farmer-centered approach involving scientific innovation, technological intervention, institutional support, and policy integration. Strengthening climate-resilient sericulture through advanced research, geospatial technologies, capacity building, and sustainable resource management will be essential for ensuring long-term silk productivity, environmental sustainability, and rural livelihood security in future climate scenarios.

5.13. REFERENCES:

Ashaq, M., Ayoub, O. B., Abhishek, G. J., & Pandey, A. (2025). Mulberry Cultivation. In *Sericulture* (pp. 54-82). CRC Press.

Bekkamov, C., & Samatova, S. (2023, March). Impact of temperature variations in worm containers and nutrition amount on silk glands and silk productivity. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1142, No. 1, p. 012065). IOP Publishing.

Bhat, M. R., Radha, P., Faruk, A. A., Vas, M., Brahma, D., Bora, N. R., ... & Garai, I. (2024). Climate change and its impact on sericulture. *International Journal of Zoology and Applied Biosciences*, *9*(4), 13-25.

Bhat, M. R., Radha, P., Faruk, A. A., Vas, M., Brahma, D., Bora, N. R., ... & Garai, I. (2024). Climate change and its impact on sericulture. *International Journal of Zoology and Applied Biosciences*, *9*(4), 13-25.

Fluteau, F. (2003). Earth dynamics and climate changes. *Comptes Rendus Geoscience*, *335*(1), 157-174.

Kaushik, A., Borah, G., Saikia, S., Kaushiki, B., & Phukan, T. (2025). Climate-resilient sericulture: Strategies for sustainable silk production in a changing climate. *Int. J. Adv. Biochem. Res*, *9*, 891-897.

Kumar, U. A., Parasuramudu, M., Nandhini, K., & Reddy, Y. P. (2024). Optimizing silkworm rearing: the impact of environmental factors and advanced technologies on silk quality and production. *Res Biotica*, *3*, 195-202.

Kumar, U. A., Parasuramudu, M., Nandhini, K., & Reddy, Y. P. (2024). Optimizing silkworm rearing: the impact of environmental factors and advanced technologies on silk quality and production. *Res Biotica*, *3*, 195-202.

Morales, J. A. (2022). Climate: climate variability and climate change. In *Coastal geology* (pp. 375-388). Cham: Springer Nature Switzerland.

MR, A. K. (2025). Climate change and its impact on sericulture: A brief review. *International Journal of Advanced Biochemistry Research*.

Nandan, M., & Ashwini, T. R. (2026). Sustainable Sericulture: Climate Change Adaptation, Challenges, and Mitigation Strategies. In *Sustainable Sericulture in India: Climate Change Impacts and Mitigation Strategies* (pp. 187-205). Cham: Springer Nature Switzerland.

Ssemugenze, B., Esimu, J., Nagasha, J., & Wandui Masiga, C. (2021). Sericulture: Agro-based industry for sustainable socio-economic development: A review.

Yadav, N., & Upadhyay, R. K. (2023). Global effect of climate change on seasonal cycles, vector population and rising challenges of communicable diseases: a review. *Journal of Atmospheric Science Research*, *6*(1).

Zhao, W., Zhao, H., Wang, H., & He, Y. (2022). Research progress on the relationship between leaf senescence and quality, yield and stress resistance in horticultural plants. *Frontiers in Plant Science*, *13*, 1044500.

CHAPTER 6: EMERGING CLIMATIC RISKS IN MULBERRY SERICULTURE

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6.1. INTRODUCTION

Climate change and agriculture are interrelated closely with each other, as changing climate conditions induce several biotic and abiotic stresses that adversely affects crop productivity. Presently, agricultural systems are experiencing rapid alterations driven by population growth, socioeconomic development, technological advancement and increasing demand for commodities including sericulture products. Further, these challenges become more complicated with the concerns for sustainable production facing global environmental challenges (Abebaw 2025). With the increase of global population about 10 billion by 2050 and beyond 11 billion by 2100, there is a need to rapidly increase the production to meet out the projected demand of the population. Limited agricultural land and natural resources together with climate change are the major challenges to fulfill the future population demand (FAO 2016; Popkin *et al.* 2012). Environmental pressures such as green house gases, aerosol pollution, alterations in land-use and ecological degradation along with socioeconomic constrains including shortage of labor and urban migration poses serious obstacles in enhancing the production. Climate change further aggravates these issues through changes in atmospheric circulation, variations in seasonal and regional rainfall patterns and increased occurrence and severity of extreme weather events (Bindoff *et al.* 2013).

Agricultural production systems are becoming increasingly susceptible to the adverse effects of climate change. The occurrence and intensity of extreme climatic events such as heat waves, droughts, and floods have increased considerably, posing serious threats to agricultural productivity and sustainability (Mina *et al.* 2019; Field *et al.* 2018). These climate-related disturbances affect the entire agricultural value chain, including production, processing, manufacturing, distribution, retailing, and waste management. Furthermore, climate-induced disruptions have significant socioeconomic implications, contributing to environmental stress, rising food prices, deteriorating public health, and reduced livelihood security (Maestre *et al.* 2012). In developing countries, these challenges may further intensify poverty, social inequality, migration, and social instability if appropriate climate-resilient measures and support mechanisms are not implemented effectively (Reckien *et al.* 2017).

6.1.1. Climate change

Climate change is primarily influenced by human activities that causes alteration in atmospheric greenhouse gases. Various industrial, agricultural, and domestic activities contribute substantially to global warming. Chlorofluorocarbons, released from appliances such as refrigerators and air conditioners, are highly potent greenhouse gases and are also responsible for depletion of the ozone layer (Bolaji *et al.* 2013). Agricultural practices involving excessive fertilizer application emit nitrous oxide, a greenhouse gas with a warming potential far greater than carbon dioxide (Fagodiya *et al.* 2019). Methane emissions originating from livestock production, landfill sites, and leakage from natural gas systems also contribute significantly to atmospheric warming. However, carbon dioxide released through the combustion of fossil fuels in industries, power generation, and transportation remains the major contributor to global climate change. The accumulation of these gases in the atmosphere traps solar radiation and increases global temperatures, resulting in major climatic disturbances.

Human-induced climate change has produced several adverse environmental and socioeconomic consequences, including increased occurrence of extreme weather events, reduced adaptability to environmental fluctuations, declining livelihood security, and deterioration in human well-being (Handmer *et al.* 2012). Major factors accelerating climate change include deforestation, intensive agricultural activities, and excessive dependence on fossil fuels. According to climate projections, the global average temperature may rise by approximately 1.0 to 5.8 °C by the end of the 21st century (Garedew 2023). Such climatic alterations pose serious challenges to climate-sensitive sectors such as sericulture, which depends heavily on stable environmental conditions for sustainable production.

6.1.2. Climate change in Indian scenario

India is considered one of the most climate-vulnerable nations in the world and continues to face severe impacts from climate extremes every year. During 2025, the country experienced extreme weather events on nearly 270 days between January and September, affecting approximately 9.47 million hectares of agricultural land and causing the loss of 4,064 human lives, according to the Centre for Science and Environment. The Climate Vulnerability Index published by Council on Energy, Environment and Water in 2021 identified Assam, Andhra Pradesh, Maharashtra, Karnataka, and Bihar among the most climate-sensitive states in the country. Furthermore, over 80% of the Indian population resides in districts that are highly vulnerable to extreme hydro-meteorological events and climate-related disasters (Mohanty *et al.* 2021).

In India, greenhouse gas emissions vary across different sectors, with waste management, industrial activities, and agriculture contributing substantially to total CO_2 equivalent emissions, accounting for approximately 58%, 22%, and 17%, respectively (Ramachandra 2012). The persistent rise in greenhouse gas concentration has contributed to an increase of nearly 0.5 °C in the country's average temperature over the last hundred years. Climate projections further suggest that, if emission levels continue unabated, average temperatures may increase by more than 2.0 °C in the coming decades (Sanjay *et al.* 2020).

Such climatic changes have serious implications for the sericulture sector, where stable environmental conditions are essential for successful silkworm rearing and silk production. Increasing temperatures and irregular climatic patterns are adversely affecting mulberry cultivation, silkworm growth, cocoon quality, and overall productivity (Sujatha *et al.* 2024). The growing disruption of favorable environmental conditions emphasizes the need for climate-resilient technologies and adaptive management practices to ensure the sustainability and long-term development of the sericulture industry.

6.2. IMPACT OF CLIMATE CHANGE ON SERICULTURE

Sericulture plays a crucial role in strengthening rural economies by providing sustainable livelihood opportunities while simultaneously conserving traditional knowledge, cultural heritage, and biodiversity. In many silk-producing countries, the sector supports rural populations through employment generation, particularly benefiting women, small farmers, and economically weaker communities, while also promoting household- and cottage-based enterprises. In addition to its economic contribution, sericulture possesses significant cultural importance, as silk production and weaving are deeply associated with regional customs, rituals, and traditional craftsmanship. This combination of economic utility and cultural relevance has enabled sericulture to remain a sustainable and resilient occupation over generations despite changes in agricultural practices and industrial development (Attri *et al.* 2024; Sharma and Kapoor 2020; Zhan and Walker 2018).

From an economic perspective, sericulture contributes substantially to rural income generation and regional economic development in silk-producing areas, thereby supporting broader sustainable development objectives. Its close association with indigenous traditions and artisanal practices further enhances its social and cultural significance by preserving community identities and heritage skills (Attri *et al.* 2024; Grześkowiak *et al.* 2022). However, the sector is increasingly facing serious challenges due to climate variability and long-term climate change. In recent decades, global silk production, once relatively stable, has shown increasing fluctuations as rising temperatures, irregular rainfall patterns, and frequent extreme weather events disrupt mulberry cultivation and silkworm rearing systems (Manzoor and Qayoom 2024; Sujatha *et al.* 2024).

The severity of these impacts varies across regions because different sericulture zones are exposed to distinct climatic stresses. Certain regions experience prolonged drought and heat stress, whereas others are affected by excessive rainfall, flooding, and increased incidence of pests and diseases. These climate-related disturbances adversely influence mulberry growth, silkworm health, cocoon productivity, and ultimately the quality and quantity of silk production (Fig. 1) (Bhat *et al.* 2024).



Figure.1 Impact of climate change on sericulture activities

In this scenario, the adoption of effective adaptation strategies has become essential for sustaining the sericulture sector under changing climatic conditions. Development of climate-resilient silkworm and mulberry varieties, improved cultivation practices, efficient pest and disease management systems, and the application of modern technologies provide important pathways for enhancing resilience and maintaining productivity. Simultaneously, traditional knowledge and indigenous practices continue to hold significant value and can effectively complement scientific and technological advancements. Therefore, an integrated approach that combines technological innovation with the preservation of cultural traditions will be critical for ensuring the long-term sustainability, resilience, and authenticity of sericulture systems.

6.3. IMPACT OF CLIMATE CHANGE ON SOIL, MULBERRY AND SILKWORM

It has become gradually clear that alterations in environmental conditions caused largely by climate change are adversely influencing agricultural productivity, including climate-sensitive sectors such as sericulture (Sujatha *et al.* 2024). Major climatic factors such as increasing temperatures, variations in humidity, erratic rainfall patterns, and the rising occurrence of extreme weather events have a direct impact on the growth, physiology, and productivity of host plants such as mulberry, which serve as the primary food source for silkworms (Gull *et al.* 2021; Chanotra and Angotra 2022).

Increased atmospheric CO_2 concentration, a major consequence of climate change, may positively influence C_3 plants such as mulberry by stimulating photosynthetic activity and enhancing water-use efficiency (Atumo *et al.* 2023). Nevertheless, these beneficial effects are often counterbalanced by other climate-related stresses, including rising temperatures, irregular precipitation patterns, and elevated tropospheric ozone levels. Ozone exposure is particularly harmful because it damages plant tissues and suppresses photosynthesis, thereby reducing the potential advantages associated with higher CO_2 concentrations.

Climate-induced temperature variations also affect the phenological behavior of mulberry plants. Elevated temperatures may induce early sprouting and altered growth patterns that do not coincide with the ideal silkworm rearing season. Such mismatches can lead to inadequate leaf availability during important larval stages, negatively influencing silkworm development, cocoon productivity, and silk quality (Rahmathulla 2012).

The effects of climate change on mulberry cultivation are diverse and highly complex, influencing multiple aspects such as soil fertility, plant physiology, and the occurrence of pests and diseases. The interaction of these environmental stress factors poses serious challenges to sustainable sericulture production. Therefore, there is an urgent need to adopt adaptive and climate-smart sericulture practices, including the development of resilient mulberry varieties and improved environmental management strategies, to ensure stable silk production under changing climatic conditions (Jhansilakshmi and Rao 2021).

6.3.1 Effect on soil properties

Climate change influences soil systems through both direct and indirect mechanisms. Direct impacts involve changes in soil temperature, moisture availability, and rates of organic matter decomposition, whereas indirect impacts occur through alterations in vegetation cover, cropping systems, and land management practices. These environmental changes affect soil microbial diversity, nutrient cycling processes, and the balance of soil organic matter, thereby reducing the soil's capacity to sustain plant growth and ecosystem functions (Costa *et al.* 2022).

6.3.1.1 Effect on physical properties

Soil physical properties provide the basic structural foundation that regulates the movement and availability of air, water, and nutrients within the soil environment. Characteristics such as soil texture, structure, porosity, bulk density, infiltration rate, and water-retention capacity play a vital role in plant development and soil biogeochemical functions. Climate change, through increasing temperatures, changing rainfall distribution, and more frequent extreme climatic events, has substantial effects on these physical soil attributes. Such alterations can influence soil fertility, increase susceptibility to erosion, and reduce the resilience and productivity of agricultural systems (Amundson *et al.* 2019).

Variations in precipitation patterns further disturb soil moisture dynamics. Prolonged drought conditions suppress microbial activity and slow nutrient mineralization processes, whereas excessive rainfall can result in nutrient loss through leaching and create waterlogged conditions. Together, these changes adversely affect soil quality and reduce its ability to support healthy crop growth.

In addition, rising atmospheric temperatures contribute to higher soil temperatures, especially in areas with limited vegetation cover. Increased soil warming accelerates the decomposition of organic matter and enhances evapotranspiration, resulting in reduced soil moisture and decreased aggregate stability. Extended exposure to high temperatures may also cause the development of compact and crusted soil surfaces, which hinder water infiltration and restrict soil aeration and gas exchange. In temperate and cold regions, increasing temperatures can induce thawing of permafrost layers, leading to the release of large amounts of stored carbon and significant alterations in soil structure. Similarly, in arid and semi-arid environments, elevated soil temperatures promote rapid drying, causing soil cracking and suppression of microbial activity. The combined influence of warming and moisture loss ultimately reduces soil porosity and water-retention capacity, both of which are essential indicators of healthy and productive soils (Mattoo 2023). Changes in soil moisture patterns influence the soil's ability to store and transport water efficiently, resulting in decreased hydraulic conductivity and reduced capacity to withstand climatic stress conditions.

6.3.1.2 Effect on chemical properties

Soil chemical properties also play a crucial role in determining soil fertility, nutrient availability, and the overall capacity of soil to sustain plant growth. Important chemical characteristics include soil pH, cation exchange capacity, electrical conductivity, nutrient status, and soil organic carbon content. These properties regulate the chemical conditions under which plants and soil micro-organisms function and interact. Climate change, driven by increasing temperatures, changing rainfall patterns, and elevated atmospheric carbon dioxide (CO_2) levels, can substantially influence these soil chemical processes. Such changes alter nutrient cycling, organic matter stability, and soil chemical balance, thereby affecting agricultural productivity as well as long-term environmental sustainability (Baveye *et al.* 2018).

Soil organic matter (SOM) is considered one of the key indicators of soil fertility because it serves as a major reservoir of nutrients, improves cation exchange capacity, and enhances the soil's ability to retain water. Climate change strongly influences SOM dynamics through variations in temperature and moisture conditions. Higher temperatures accelerate microbial decomposition of organic matter, resulting in increased CO_2 release and depletion of soil carbon reserves. Although decomposition processes release essential nutrients such as nitrogen and phosphorus, excessive mineralization under elevated temperatures may create nutrient imbalances and gradually reduce soil fertility over time. Climate change also influences nutrient availability by modifying biochemical processes, mineral weathering, and nutrient leaching dynamics. Among the essential nutrients, the cycles of nitrogen, phosphorus and potassium (K) are particularly affected under changing environmental conditions (Tarun *et al.* 2025).

In addition, changes in rainfall distribution also affect the accumulation and loss of soil carbon. Drought conditions reduce plant growth and limit the return of organic residues to the soil, whereas heavy rainfall events promote leaching of dissolved organic carbon. Together, these processes contribute to a decline in SOM levels, particularly in tropical and semi-arid regions. Reduced organic matter not only lowers soil fertility but also weakens soil structure and aggregation, increasing the susceptibility of soils to erosion and degradation (Tarun *et al.* 2025).

6.3.2 Effect on mulberry plants

Global climate change directly influences mulberry cultivation through variations in temperature, water availability, and atmospheric carbon dioxide concentration. The growth, physiology, and developmental processes of mulberry plants are closely regulated by environmental factors such as rainfall, temperature, relative humidity, and soil conditions. Alterations in these climatic parameters can significantly affect the activity and population dynamics of beneficial soil microorganisms, leading to deterioration in soil health and fertility, which ultimately hampers the growth and productivity of host plants.

Increasing atmospheric carbon dioxide (CO_2) concentrations along with rising temperatures have substantial effects on mulberry growth and its overall suitability for sericulture practices. Research findings indicate that elevated CO_2 (eCO_2) conditions can improve plant height, leaf production, chlorophyll concentration, and photosynthetic performance (Lavanya *et al.* 2017; Sekhar *et al.* 2015; Liu *et al.* 2019). For example, under elevated CO_2 conditions (550 ± 25 ppm), mulberry plants showed considerable improvement in growth parameters, including increased plant height reaching up to 93.74 cm and production of nearly 350 leaves per plant at 60 days after planting (Lavanya *et al.* 2017). Day time exposure to elevated CO_2 (710 ppm day and 460 ppm night time) produces more pronounced effects on mulberry growth, biomass accumulation, and leaf nutritional quality in comparison to night time exposure (410 ppm day and 760 ppm night time). Higher CO_2 concentrations promoted the synthesis of carbohydrates, proteins, amino acids, and several mineral nutrients in mulberry leaves. Nevertheless, the concentration of certain essential nutrients, including nitrogen, phosphorus, magnesium, iron, and zinc, declined under elevated CO_2 conditions. Although biomass and yield increased, the reduction in some key nutrients may negatively influence silkworm development and cocoon productivity (Shi *et al.* 2021a; Shi *et al.* 2021b). Elevated CO_2 levels were also found to enhance biomass accumulation, improve leaf nutritional quality, and increase water-use efficiency, particularly under drought stress conditions (Liu *et al.* 2019).

However, the combined influence of elevated CO_2 and higher temperatures produces variable responses. Although elevated CO_2 alone generally stimulates plant growth, its interaction with increased temperature may reduce the concentration of important nutritive compounds in mulberry leaves due to disturbances in essential mineral absorption and balance (Shi *et al.* 2021a). In addition, exposure to high temperature stress independently causes marked reductions in dry matter production, photosynthetic enzyme activity, and overall plant productivity (Chaitanya *et al.* 2001; Jiang *et al.* 2025). Differences in stress tolerance among mulberry genotypes have also been observed, with varieties such as V1 and S13 demonstrating relatively greater resilience under adverse environmental conditions (Sekhar *et al.* 2014; Lavanya *et al.* 2017).

Further, exposure to excessive heat can reduce photosynthetic activity, limit nutrient absorption, and induce water stress in mulberry plants (Shi *et al.* 2025). Such conditions often result in premature leaf senescence, restricted plant growth, and overall decline in plant health and vigor. As a consequence, the nutritional quality of mulberry leaves deteriorates, negatively influencing silkworm growth and silk productivity. Prolonged heat stress may also alter the biochemical composition of mulberry leaves, reducing their palatability and digestibility for silkworms (Hăbeanu *et al.* 2024). This lower feeding efficiency and ultimately affects both the quantity and quality of silk production. In addition, higher temperatures create favorable conditions for increased incidence of pests and diseases, posing further risks to mulberry cultivation and silkworm rearing systems (Sujatha *et al.* 2024). However, temperature fluctuations in hilly regions during autumn and spring have altered the dormancy and sprouting behavior of mulberry plants. Higher temperatures and increased

sunshine duration were found to promote early bud break and sprouting in mulberry varieties such as Goshoerami, Ichinose, SKM-31, SKM-27, Mandaliya, Zust, Kanva-2, and local mulberry types. In contrast, sprouting percentage showed a negative relationship with relative humidity, indicating that higher humidity levels may delay or reduce sprouting under changing climatic conditions (Mehraj *et al.* 2023).

Furthermore, excessive rainfall induced waterlogging condition significantly reduces leaf yield, chlorophyll content, photosynthetic efficiency, and nutrient metabolism in mulberry. However, mulberry genotypes such as S1 and Kolitha-3 showed comparatively better tolerance to flooding stress. Physiological traits like nitrate reductase activity, membrane stability, and ABA content were identified as important markers for selecting waterlogging-tolerant mulberry varieties. Conversely, excessive rainfall and prolonged waterlogged conditions increase the susceptibility of roots to fungal infections and adversely affect leaf quality, which subsequently reduces cocoon productivity and overall silkworm performance (Basu and Sil 2017). These observations emphasize the importance of identifying climate-tolerant mulberry genotypes and adopting adaptive cultivation strategies to sustain sericulture productivity under changing climatic scenarios.

6.3.3 Effect on silkworm rearing

Silkworms are ectothermic organisms that require a relatively narrow range of temperature and humidity for optimal growth and development. Any deviation from these favorable environmental conditions can quickly reduce their performance and productivity.

Temperature is one of the most important abiotic factors influencing silkworm growth, development, and cocoon productivity. High-quality cocoons are generally produced when silkworms are reared within an optimal temperature range of approximately 22–27 °C. Exposure of early instar larvae to moderately high temperatures may enhance their thermal tolerance, thereby improving survival and cocoon characteristics. Elevated temperatures tend to accelerate larval growth and shorten the larval duration, particularly during the late instars, whereas lower temperatures delay development and prolong the larval period. Several studies have reported that healthy silkworm development occurs best between 22 °C and 27 °C, while maximum productivity is achieved within a narrower range of 23–27 °C (Rahmathulla 2012). Temperatures below 20 °C or above 30 °C can negatively affect silkworm physiology, especially during the sensitive early larval stages. Under such stressful conditions, silkworms become more vulnerable to diseases and physiological stress, ultimately reducing cocoon yield and silk quality. Exposure to high temperatures often accelerates larval growth, but it generally results in lower larval weight, reduced cocoon and shell weight, and shorter filament length. Recent studies suggest that oxidative stress and activation of heat-shock responses play major roles in causing these effects (Ashraf and Qamar 2023; Sarkhel *et al.* 2017). The fourth and fifth instars are particularly sensitive because they represent the most critical stages for cocoon development and silk synthesis. In addition to temperature, environmental factors such as relative humidity, light conditions, and nutritional quality of feed strongly influence silkworm growth and phenotypic performance.

At the molecular level, elevated temperatures stimulate the expression of stress-responsive genes, including small heat-shock proteins and molecular chaperones, which help silkworms cope with thermal stress (Liu *et al.* 2024). These gene-level responses are closely associated with declines in economically important traits and may serve as useful markers in breeding programs aimed at developing heat-tolerant silkworm strains. In practical sericulture conditions, even brief heatwaves or sudden increases in humidity during later larval stages can increase susceptibility to diseases and

cause defects during reeling. This highlights the importance of maintaining suitable microclimatic conditions and promoting the use of thermotolerant silkworm breeds in vulnerable rearing regions.

6.3.4 Effect on pest and disease incidence

Climate change can substantially influence plant–pest interactions, resulting in important ecological and agricultural implications. Because these interactions are highly complex and continuously changing, precise predictions remain difficult; however, several common trends have been observed. Warmer conditions can accelerate insect development, increase feeding activity and metabolic demand, raise the number of generations produced within a season, and enable pests to expand into new geographical areas. Broad-scale studies across agricultural systems have predicted greater crop losses from insect herbivores with every degree of temperature increase, mainly due to enhanced pest multiplication and feeding intensity (Deutsch *et al.* 2018). Climate change can also prolong pest developmental periods, modify the timing of pest occurrence, and disrupt the synchrony between crop growth stages and pest life cycles, thereby increasing the threat of migratory pest outbreaks (Maqbool *et al.* 2019; Subedi *et al.* 2023). Furthermore, elevated temperatures may enhance plant vulnerability to certain diseases; for example, warmer conditions increased plant susceptibility to rust infections (Coakley *et al.* 1999).

In recent years, mulberry leaf productivity and quality have been considerably affected by various pests and diseases, largely due to intensive cultivation practices and indiscriminate use of nitrogen fertilizers and pesticides. Climate change is expected to further intensify these problems, particularly in temperate regions, by improving the winter survival capacity of insect pests. Since insect pests and their host plants respond differently to environmental factors such as temperature, atmospheric CO_2 concentration, and photoperiod, climatic changes may disturb the natural synchronization between pest life cycles and host plant development. Additionally, several predictive mathematical models indicate that increases in temperature within favorable ranges can accelerate pathogen growth and infection processes, thereby increasing the likelihood of plant disease outbreaks.

Recent research also indicates that extreme climatic events and shifts in seasonal patterns can disrupt the balance between pests and their natural enemies (Subedi *et al.* 2023; Skendžić *et al.* 2021). These climatic effects may lead to more frequent infestations of leaf-feeding and sap-sucking insects on host plants, increased prevalence of uzi fly and other parasitoids during warmer periods, and a higher occurrence of silkworm diseases such as muscardine and flacherie under fluctuating humidity conditions. These emerging challenges have highlighted the importance of advanced surveillance systems, early warning mechanisms, and molecular diagnostic approaches for effective pest and disease management in sericulture (Deepika *et al.* 2024).

6.3.5 Effects on Post cocoon activities

The quality, yield, and processing efficiency of cocoons play a crucial role in determining the economic success of the sericulture industry. Differences in cocoon shape and size, particularly in hybrid cocoons, directly influence filament thickness and the quality of reeled silk. Non-uniform and irregular cocoons often lead to several reeling problems, including frequent thread breakage, poor reelability, difficulty during cooking, reduced raw silk recovery, variation in denier, and inferior yarn neatness (Lord 2003). In addition, maintaining cocoon shell moisture below 20% is important for producing high-quality cocoons with better reeling performance (Akahane and Tsubouchi 1994).

Apart from genetic factors, several environmental conditions such as temperature, humidity, airflow, and related climatic parameters significantly influence the biological and commercial traits of

silkworms and cocoons. Seasonal variations, ambient temperature, and surrounding environmental conditions play an important role in determining cocoon quality and silk characteristics. Fluctuations in temperature can adversely affect cocoon formation by altering filament size and the quality of reeled silk threads. Changes in climatic conditions are also associated with variations in cocoon weight, shell weight, filament length, silk recovery, denier, and sericin content (Srivastava *et al.* 1998).

6.4. STRATEGIES AND INNOVATIVE APPROACHES FOR CLIMATE ADAPTION AND RESILIENCE

The increasing impact of climate change has become a serious concern for the sericulture sector, as fluctuations in temperature, irregular rainfall patterns, drought, flooding, and emerging pest and disease problems are adversely affecting mulberry cultivation and silkworm rearing. Because successful sericulture depends heavily on stable environmental conditions, climate-induced disturbances pose substantial risks to leaf production, silkworm health, cocoon yield, and silk quality. These challenges highlight the need for effective adaptation measures and resilient production systems capable of withstanding climatic stress (Fig. 2).



Figure. 2 Strategies and Innovative approaches for climate adaption

6.4.1. Breeding and biotechnological approaches

Breeding programs for mulberry and silkworms are increasingly emphasizing the development of traits that can withstand heat stress, drought conditions, and disease incidence without compromising cocoon productivity and silk filament quality. In mulberry improvement programs, genomics-assisted breeding and transcriptome-based trait identification are gaining importance for selecting climate-resilient genotypes. These advanced approaches facilitate the development of mulberry varieties possessing enhanced tolerance to drought and high temperatures along with improved leaf biomass and protein content, thereby ensuring consistent nutrition for silkworm

larvae under unstable climatic conditions (Ernst *et al.* 2025; Sivaprasad *et al.* 2024; Sujatha *et al.* 2024). Additionally, the application of molecular marker technologies and rapid clonal propagation methods has accelerated the multiplication and dissemination of superior mulberry genotypes, helping to bridge the gap between laboratory research and field-level adoption (Biswas and Kumar 2023).

In silkworm breeding, functional genomics and modern genome-editing technologies have created new possibilities for enhancing resilience against climatic stress. Genome-editing tools such as CRISPR/Cas9 have demonstrated potential in modifying genes associated with silkworm growth and silk synthesis, while advanced CRISPR/Cas12a systems provide greater editing precision and the ability to target multiple genes simultaneously (Dong *et al.* 2020; Ma *et al.* 2017). These technologies offer opportunities to develop silkworm hybrids with improved thermal tolerance, enhanced resistance to bacterial and viral diseases, and more efficient silk gland metabolism. Furthermore, genetic modifications involving antioxidant defense mechanisms and heat-shock proteins may strengthen silkworm adaptability against recurring heat stress and extreme temperature events (Liu *et al.* 2024; Sun *et al.* 2024).

However, successful application of these biotechnological innovations requires effective biosafety measures, appropriate regulatory frameworks, and efficient farmer-oriented distribution systems for disease-free layings (DFLs). Ensuring safe implementation, ecological sustainability, and equitable access to improved technologies will be essential for achieving climate-resilient and sustainable sericulture production systems.

6.4.2. Climate smart cultivation and rearing practices

Strengthening resilience at the farm level largely depends on the adoption of climate-smart cultivation and rearing practices. In mulberry cultivation, efficient water management approaches such as drip irrigation, regulated deficit irrigation, and partial root-zone irrigation help conserve water while sustaining leaf yield and quality. Practices like mulching, intercropping with leguminous plants, and application of organic manures improve soil moisture retention, regulate soil temperature, and enhance soil fertility, thereby increasing the ability of mulberry plantations to withstand climatic stress (Mahesh *et al.* 2022; Chai *et al.* 2016).

Recent agronomic studies have also highlighted the importance of location-specific pruning schedules that synchronize leaf production with favorable environmental conditions and minimize exposure to climatic stress periods. The use of protected nursery and propagation structures is another important strategy for safeguarding planting materials from extreme weather events (Altman and Farrell 2022).

In silkworm rearing, maintaining a stable microclimate within rearing houses is essential for ensuring healthy larval development. Proper regulation of temperature and humidity, adequate ventilation, and the use of shading systems help reduce thermal stress and maintain favorable rearing conditions. Adjusting rearing schedules to avoid periods of extreme heat, along with strict hygiene and disinfection measures, has proven effective in lowering larval mortality and minimizing the spread of diseases across rearing cycles (Kumar *et al.* 2024; Chen *et al.* 2023).

6.4.3. Integrated pest and disease management

The occurrence and severity of pests and diseases in sericulture are strongly influenced by climatic factors. Increasing temperatures and irregular rainfall patterns can promote the spread and survival of major pests such as uzi fly, mealybugs, and various fungal and bacterial pathogens. To address these emerging risks, integrated pest management approaches are increasingly incorporating

climate-responsive monitoring and surveillance methods, including light traps, pheromone traps, degree-day forecasting models, and ecological habitat management within mulberry plantations. Biological control remains an important component of sustainable pest management, with natural enemies such as *Nesolynx thymus* playing a key role in suppressing uzi fly populations. Chemical pesticides are recommended only when pest populations exceed economic threshold levels in order to minimize harm to beneficial organisms and maintain ecological balance (Bhat *et al.* 2024; Sujatha *et al.* 2024; Qadir *et al.* 2024).

Climate-induced heat stress also weakens silkworm immunity, increasing susceptibility to viral and bacterial diseases. Therefore, disease management strategies should include the use of high-quality DFLs, regular disinfection practices, proper sanitation, and maintenance of stable environmental conditions within rearing houses. Adoption of stress-tolerant silkworm breeds can further improve resistance against climate-related disease outbreaks. Collectively, these integrated approaches provide a comprehensive defense system that is particularly important under future climatic conditions where pest and disease outbreaks are expected to become more frequent and unpredictable (Sujatha *et al.* 2024; Sun *et al.* 2022).

6.5. CONCLUSION

The sericulture industry is increasingly vulnerable to the adverse effects of climate change, which disrupts the environmental balance essential for mulberry cultivation and silkworm growth. Climatic stresses such as rising temperatures, erratic rainfall, drought, flooding, and increasing pest and disease outbreaks negatively affect soil conditions, host plant productivity, silkworm physiology and cocoon production. Although elevated atmospheric CO_2 may stimulate mulberry growth under certain conditions, the associated nutrient imbalances and heat stress can reduce leaf nutritional quality and ultimately impair silkworm performance. Similarly, silkworms are highly sensitive to environmental fluctuations, making them prone to stress-related disorders, disease susceptibility, and reduced commercial productivity under unfavorable climatic conditions.

Climate change impacts on sericulture are complex and interconnected, involving plant physiology, soil processes, insect ecology, and farm management practices. Therefore, a comprehensive and adaptive approach is required to sustain sericulture under changing climatic scenarios. Strategies such as the development of stress-tolerant mulberry varieties and silkworm hybrids, efficient nutrient and water management, improved environmental regulation in rearing systems, and effective pest and disease monitoring are critical for enhancing resilience. Integration of scientific innovations with traditional sericultural knowledge can further strengthen sustainable production systems. Continued research, policy interventions, and farmer-oriented climate adaptation programs will play a vital role in ensuring the long-term sustainability and economic stability of the sericulture sector.

6.6. REFERENCES

Abebaw SE (2025) A global review of the impacts of climate change and variability on agricultural productivity and farmer's adaption strategies. Food Science & Nutrition, 13:e70260

Akahane T, Tsubouchi K (1994) Reelability and water content of cocoon layer during the spinning stage. J Sericult Sci Jpn 63(3):229–234

Altman GH, Farrell BD (2022) Sericulture as a sustainable agroindustry. Clean Circ Bioecon. 2:100011.

Amundson R, Berhe AA, Hopmans JW, Olson C, Sztein AE, Sparks DL (2019) Soil and human security in the 21st century. Science, 348(6235), 1261071. https://doi.org/10.1126/science.1261071

Ashraf H, Qamar A (2023) A review on heat stress altering the insect life history strategies and underlying mechanisms: special reference to an economically important Lepidoptera, *Bombyx mori* (Linnaeus, 1758) (Lepidoptera: Bombycidae). Lepidopterol. 51(202):339-357.

Attri K, Vakayil S, Shruthi G, Parmar S, Harika KR, Teja KS, et al (2024) Integrative approaches in sericulture from traditional practices to modern technologies sericulture and its contribution to biodiversity conservation. J Adv Biol Biotechnol. 27(8):480 490.

Atumo TT, Ayalew T (2023) Elevated carbon dioxide effect on radiation, nutrient and water use efficiency of C3 and C4 crops: a review. Heliyon. https://doi.org/10.2139/ssrn.4480351

Basu M, Sil SK (2017) A review on waterlogging and its effects in mulberry. Ad Plant Sci, 30(II):183-191

Baveye PC *et al.* (2018) Soil organic matter research and climate change: Looking beyond carbon. of Soil Science, European 69(2), Journal 219–229. https://doi.org/10.1111/ejss.12500

Bhat MR, Radha P, Faruk AA, Vas M, Brahma D, Bora NR, et al (2024) Climate change and its impact on sericulture. Int J Zool Appl Biosci. 9(4):13-25.

Bindoff NL, Stott PA, AchutaRao KM, Allen MR, Gillett N, Gutzler D, Hansingo K, Hegerl G, Hu Y, Jain S, Mokhov II, Overland J, Perlwitz J, Sebbari R, Zhang X (2013) Detection and attribution of climate change: from global to regional. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds) Climate change 2013, the physical science basis, contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

Biswas P, Kumar N (2023) Application of molecular markers for the assessment of genetic fidelity of in vitro raised plants: current status and future prospects. In: Molecular Marker Techniques: A Potential Approach of Crop Improvement. p. 233-256.

Bolaji BO, Huan Z (2013) Ozone depletion and global warming: case for the use of natural refrigerant-a review. Renew Sust Energ Rev 18(2013):49–54

Chai Q, Gan Y, Zhao C, Xu HL, Waskom RM, Niu Y, *et al.* (2016) Regulated deficit irrigation for crop production under drought stress. A review. Agron Sustain Dev. 36(1):3.

Chaitanya KV, Sundar D, Reddy AR (2001) Mulberry leaf metabolism under high temperature stress. Biol Plant 44:379–384

Chanotra S, Angotra J (2022) Implications of meteorological forecasting for accelerating the success rate in sericulture: new avenues in seri-industry: a review. Agric Rev 46(1):35–43

Chen Y, Zheng S, Li D, Tang Y, Xu Y (2023) A review of the research on temperature and humidity control systems in silkworm rooms. In: International Conference on Computer Engineering and Networks. Singapore: Springer Nature Singapore; p. 18-28.

Coakley SM, Scherm H, Chakraborty S (1999) Climate change and plant disease management. Annu Rev Phytopathol 37(1):399–426

Costa D, Sutter C, Shepherd A, Jarvie H, Wilson H, Elliott J, Macrae M (2022) Impact of climate change on catchment nutrient dynamics: Insights from around the world. Environmental Reviews, 31(1), 4–25. https://doi.org/10.1139/er 2022-0023

Deepika I, Ramesh KV, Kumar I, Singh A, Debnath R, Dubey H, *et al.* (2024) Molecular diagnostics in sericulture: a paradigm shift towards disease diagnosis in silkworms. Entomol Exp Appl. 172(5):372-382.

Deutsch CA, Tewksbury JJ, Tigchelaar M, Battisti DS, Merrill SC, Huey RB, *et al.* (2018) Increase in crop losses to insect pests in a warming climate. Science. 361(6405):916-919.

Dong Z, Qin Q, Hu Z, Zhang X, Miao J, Huang L, *et al.* (2020) CRISPR/Cas12a mediated genome editing enhances *Bombyx mori* resistance to BmNPV. Front Bioeng Biotechnol. 8:841.

Ernst L, Sayed HM, Hassanin A, Moegenburg R, Meents T, Lyu H, *et al.* (2025) Reverse prenylation in plants by non-canonical aromatic prenyltransferases. Plant J. 122(6):e70268.

Fagodiya RK, Pathak H, Bhatia A, Jain N, Gupta DK, Kumar A, Malyan SK, Dubey R, Radhakr ishanan S, Tomer R (2019) Nitrous oxide emission and mitigation from maize–wheat rotation in the upper Indo-Gangetic Plains. Carbon Manag 10(5):489–499

Field CB, Barros V, Stocker TF, Dahe Q, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner GK, Allen SK, Tignor M (2018) IPCC, 2012: summary for policymakers: managing the risks of extreme events and disasters to advance climate change adaptation. In: Planning for climate change 2018 Sep 18 (pp 111–128). Routledge

Food and Agriculture Organization of the United Nations (FAO) (2016) The state of food and agriculture: climate change, agriculture and food security. http://www.fao.org/3/a-i6030e.pdf

Garedew KF (2023) Litter and soil carbon stock potential of coffee agroforestry in Berbere District, Southeast Ethiopia: implications for climate change mitigation. https://doi.org/10.21203/rs.3. rs-3173721/v1

Grześkowiak J, Łochyńska M, Frankowski J (2022) Sericulture in terms of sustainable development in agriculture. Problemy Ekorozwoju. 17(2):210 217.

Gull A, Ramegowda GK, Illahi I (2021) Genetic appraisal of frost damage in mulberry germplasm accessions in temperate climate of Jammu and Kashmir, India. Electron J Plant Breed 12(1):104–108

Hăbeanu M, Gheorghe A, Dinita G, Mihalcea T (2024) An in-depth insight into the profile, mech anisms, functions, and transfer of essential amino acids from mulberry leaves to Silkworm *Bombyx mori* L. Pupae Fish Insects 15(5):332

Handmer J, Honda Y, Kundzewicz ZW, Arnell N, Benito G, Hatfield J, Mohamed IF, Peduzzi P, Wu S, Sherstyukov B, Takahashi K, Yan Z (2012) Changes in impacts of climate extremes: human systems and ecosystems. In: Field CB, Barros V, Stocker TF, Qin D, Dokken DJ, Ebi KL, Mastrandrea MD, Mach KJ, Plattner G-K, Allen SK, Tignor M, Midgley PM (eds) Managing the risks of extreme events and disasters to advance climate change adaptation, a special report of working Groups I and II of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp 231–290

Jhansilakshmi K, Rao AA (2021) Conservation of mulberry genetic resources to sustain sericulture under climate change. CRC Press, pp 225–245

Jiang X, Chen Q, Agathokleous E, Zhang J, Yang Z, Takin MP (2025) Effects of low-temperature stress during anthesis stage on dry matter accumulation and yield of winter wheat. Agronomy 15(4):761

Kumar UA, Parasuramudu M, Nandhini K, Reddy YP (2024) Optimizing silkworm rearing: the impact of environmental factors and advanced technologies on silk quality and production. Res Biotica. 3:195 202.

Lavanya C, Ashoka J, Sreenivasa AG, Sushila N, Beladhadi BV (2017) Effect of elevated carbon dioxide and temperature on growth, yield and quality parameters of mulberry. Entomol Ornithol Herpetol 6:1–3

Liu X, Zhang H, Wang J, Wu X, Ma S, Xu Z, Zhou T, Xu N, Tang X, An B (2019) Increased CO2 concentrations increasing water use efficiency and improvement PSII function of mulberry seedling leaves under drought stress. J Plant Interact 14(1):213–223

Liu Z, Li C, Yang W, Wu Q, Xiao W, Zhu Y, *et al.* (2024) The *Bombyx mori* singed gene is involved in the high temperature resistance. 15(4):264.

Lord PR (2003) Handbook of yarn production: technology, science and economics. Elsevie

Ma S, Liu Y, Liu Y, Chang J, Zhang T, Wang X, *et al.* (2017) An integrated CRISPR *Bombyx mori* genome editing system with improved efficiency and expanded target sites. Insect Biochem Mol Biol. 83:13-20.

Maestre FT, Salguero-Gómez R, Quero JL (2012) It is getting hotter in here: determining and projecting the impacts of global environmental change on drylands. Phil Trans R Soc B or Phil Trans B 367(1606):3062–3075

Mahesh R, Anil P, Debashish C, Sivaprasad V (2022) Improved mulberry productivity and resource efficiency through low-cost drip fertigation. Arch Agron Soil Sci. 68(6):749-763.

Manzoor S, Qayoom K (2024) Impact of climate change on sericulture. Asian Res J Agric. 17(3):107-113.

Maqbool S, Illahi I, Gull A, Rizvi G (2019) Pathogenesis of mulberry leaf spot in response to meteorological aspects of Kashmir, India. Arch Phytopathol Plant Prot 52(3–4):303–317

Mattoo R (2023) Microbial roles in the terrestrial and aquatic nitrogen cycle— implications in climate change. FEMS Microbiology Letters, 370, fnad061. https://doi.org/10.1093/femsle/fnad061

Mehraj S, Kamili AS, Ganie NA, Mir MR, Manzoor M, Sharma RK, Mir SA (2023) Correlation analysis between mulberry sprouting and weather parameters under changing climate scenario. Res J Chem Environ Sci, 11(1):1-4

Mina U, Kumar A, Chaturvedi AK, Kumar P (2021) Climate change and plant diversity: threats and opportunities. In: Climate Change and the Microbiome: Sustenance of the Ecosphere (pp 369–396). Cham: Springer International Publishing

Mohanty, Abinash, Shreya W (2021) Mapping India's Climate Vulnerability- A District Level Assessment. New Delhi: Council on Energy, Environment and Water

Popkin BM, Adair LS, Ng SW (2012) Global nutrition transition and the pandemic of obesity in developing countries. Nutr Rev 70(1):3–21

Qadir J, Islam T, Pavankumar S, Kant R, Aryan S (2024) Nesolynx thymus (Girault) as an effective biocontrol agent of Uzi fly, Exorista bombycis (Louis). Int J Theor Appl Sci. 16(1):93-98.

Rahmathulla VK (2012) Management of climatic factors for successful silkworm (*Bombyx mori* L.) crop and higher silk production: a review. Psyche A J Entomol (1):121234

Ramachandra TV (2012) Decentralised carbon footprint analysis for opting climate change mitigation strategies in India. Renew Sustain Energy Rev 16(8):5820–5833

Reckien D, Creutzig F, Fernandez B, Lwasa S, Tovar-Restrepo M, Mcevoy D, Satterthwaite D (2017) Climate change, equity and the sustainable development goals: an urban perspective. Environ Urban 29(1):159–182

Sanjay J, Revadekar JV, Ramarao MV, Borgaonkar H, Sengupta S, Kothawale DR, Patel J, Mahesh R, Ingle S, AchutaRao K, Srivastava AK (2020) Temperature changes in India. Assessment of climate change over the Indian region: a report of the Ministry of Earth Sciences (MoES), Government of India, pp 21–45

Sarkhel S, Shrivastava S, Pouranik M (2017) The effective influence of temperature on the varied characteristic of silkworm: a review. Asian J Exp Sci. 31(2):31-37.

Sekhar KM, Rachapudi VS, Mudalkar S, Reddy AR (2014) Persistent stimulation of photosynthesis in short rotation coppice mulberry under elevated CO_2 atmosphere. J Photochem Photobio B: Bio, 137:21-30

Sekhar KM, Sreeharsha RV, Reddy AR (2015) Differential responses in photosynthesis, growth and biomass yields in two mulberry genotypes grown under elevated CO2 atmosphere. J Photochem Photobiol B 151:172–179

Sharma K, Kapoor B (2020) Sericulture as a profit-based industry—a review. Indian J Pure Appl Biosci. 8(4):550-562.

Shi S, Li H, Wang X, Wang Z, Xu J, He X, Yang ZA (2025) Greater biomass production under elevated CO2 is attributed to physiological optimality, trade-offs in nutrient allocation, and oxidative defense in drought-stressed mulberry. Antioxidants 14(4):383

Shi S, Qiu Y, Wen M, Xu X, Dong X, Xu C, He X (2021a) Daytime, not nighttime, elevated atmospheric carbon dioxide exposure improves plant growth and leaf quality of mulberry (*Morus alba* L.) seedlings. Front Plant Sci 11:609031

Shi S, Xu X, Dong X, Xu C, Qui Y, He X (2021b) Photosynthetic acclimation and growth responses to elevated CO_2 associate with leaf nitrogen and phosphorus concentrations in mulberry (*Morus multicaulis* Perr.). Forests, 12:660

Sivaprasad V, Sangannavar PA, Lingaiah K (2024) An introduction to biotechnology driven advances for silkworm improvement and sustainable perspectives. In: Biotechnology for Silkworm Crop Enhancement: Tools and Applications. Singapore: Springer Nature Singapore; p. 1-20.

Skendžić S, Zovko M, Živković IP, Lešić V, Lemić D (2021) The impact of climate change on agricultural insect pests. Insects. 12(5):440.

Srivastava AK, Naqvi AH, Roy GC, Sinha BR (1998) Temporal variation in qualitative and quantita tive character of Antheraea mylitta Drury. In: Third international conference on Wild Silkmoths, Bhubaneswar Odisha, pp 54–56

Subedi B, Poudel A, Aryal S (2023) The impact of climate change on insect pest biology and ecology: implications for pest management strategies, crop production, and food security. J Agric Food Res. 14:100733.

Sujatha GS, Kumar GA, Teja KS, Devi DL, Rupali JS, Gautam SK (2024) A comprehensive review of the effect and mitigation of climate change on sericulture. Int J Environ Clim Change 14(7):776–788

Sun H, Chen J, Wang R, Liu D, Zhang N, Zhang T, *et al.* (2024) Genome-wide CRISPR screening reveals key genes and pathways associated with 20-hydroxyecdysone signal transduction in the silkworm (*Bombyx mori*). Insect Sci. 31(1):47-58.

Sun X, Yuan Q, Du B, Jin X, Huang X, Li Q, *et al.* (2022) Relationship between changes in intestinal microorganisms and effect of high temperature on the growth and development of *Bombyx mori* larvae. Int J Mol Sci. 23(18):10289.

Tarun KT, Thamizh VR, Rajeshwari C (2025) Impact of climate change on soil health and nutrient cycling: Implications for sustainable agriculture. Int J Environ Clim Change, 15(11):519-529

Zhan X, Walker S (2018) Value direction: moving crafts toward sustainability in the Yangtze River Delta, China. Sustainability (Basel). 10(4):1252.

CHAPTER 7: CLIMATE CHANGE IMPACTS AND ADAPTIVE STRATEGIES IN TEMPERATE SERICULTURE

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7.1. INTRODUCTION

Climate change has become an immediate production constraint for temperate sericulture rather than a distant environmental concern. In Himalayan temperate regions, especially Kashmir Valley, sericulture is built around a highly seasonal production calendar. Mulberry growth begins after winter dormancy, leaf availability must match silkworm brushing, and the short spring and autumn windows must be used efficiently to secure quality bivoltine cocoons. Any change in temperature, snowfall, rainfall timing, or humidity can disturb this biological timing and cause disproportionate losses.

The sensitivity of the system is amplified by the dependence of the region on snowpack and winter moisture. In temperate sericulture, winter is actually the preparatory phase that shapes spring sprouting, moisture recharge, egg diapause completion, and the nutritional quality of the first flush of mulberry leaves. Long-term analyses from the Kashmir Valley indicate a consistent warming trend in both maximum and minimum temperatures, with stronger warming in winter and post-monsoon periods. At the same time, snowfall dominance is declining and precipitation is becoming more irregular. These shifts weaken the climatic foundation on which bivoltine sericulture depends (Dar *et al.,* 2021; Arif *et al.,* 2025; Bhat *et al.,* 2025).

This chapter traces climate impacts through the full value chain. First, it describes the changing climate signals in temperate regions. Next, it explains how those signals alter mulberry physiology, leaf quality, and water relations. It then connects those plant-level changes to silkworm biology, cocoon quality, and silk reelability. Finally, it presents adaptive strategies that are already available or emerging for climate-resilient temperate sericulture.

7.2. CLIMATIC CHANGES IN TEMPERATE SERICULTURE REGIONS

7.2.1. Rising temperatures and winter warming

The most visible expression of climate change in temperate sericulture zones is warming. The Himalayan climate system is highly sensitive because regional hydrology depends strongly on snow and glacier meltwater. In the Kashmir Valley, long-term observations show a persistent warming trend over the past several decades, with measurable increases in both maximum and minimum temperatures. Comparative analyses across climatic periods have also shown warming at representative temperate stations such as Qazigund, while similar signals have been reported from Pahalgam, Gulmarg, and Kokarnag (Dar *et al.,* 2021; Bhat *et al.,* 2025; Shafiq *et al.,* 2024; Arif *et al.,* 2025).

In temperate sericulture, winter warming has emerged as a critical concern. During the winter months (December–March), mulberry plants accumulate moisture and nutritional reserves essential for the development of spring leaf biochemistry. However, rising winter temperatures can disrupt these physiological processes and induce premature breaking of dormancy in mulberry. As a result, mulberry sprouting may occur earlier than the conventional silkworm rearing schedule, creating

a mismatch between host plant phenology and silkworm requirements. Climatic variability in temperate regions can therefore lead to desynchronization between mulberry leaf availability and the hatching of cold-stored silkworm eggs. To maintain proper host plant–silkworm synchronization and ensure successful cocoon production, annual seed release should be regulated based on the actual sprouting status of mulberry rather than following fixed calendar schedules (Benchamin & Jolly, 1986; Rahmatulla, 2012).

7.2.2. Declining snowfall and changing snowmelt dynamics

In the Kashmir Valley, the decline in snowfall is more consequential for sericulture than a simple reduction in annual precipitation. Snow is a slow-release reservoir that sustains soil moisture through the dry transition into spring. Long-term records show that winter precipitation is weakening in its snowfall component, and snow water equivalent is negatively associated with rising temperature. Earlier snowmelt further shifts the timing of water availability away from the period when mulberry requires stable moisture for bud break, leaf expansion, and quality accumulation (Dad *et al.*, 2021; Gusain *et al.*, 2014; Bhat *et al.,* 2025).

As a consequence, soils dry earlier than before, and the first flush of mulberry may emerge under moisture stress. This directly affects leaf succulence, moisture retention, and nutrient concentration. Since bivoltine silkworms are reared on fresh mulberry leaves and are highly sensitive to feed quality, the changing snow regime becomes a major indirect driver of rearing instability.

7.2.3. Erratic precipitation and hydrological volatility

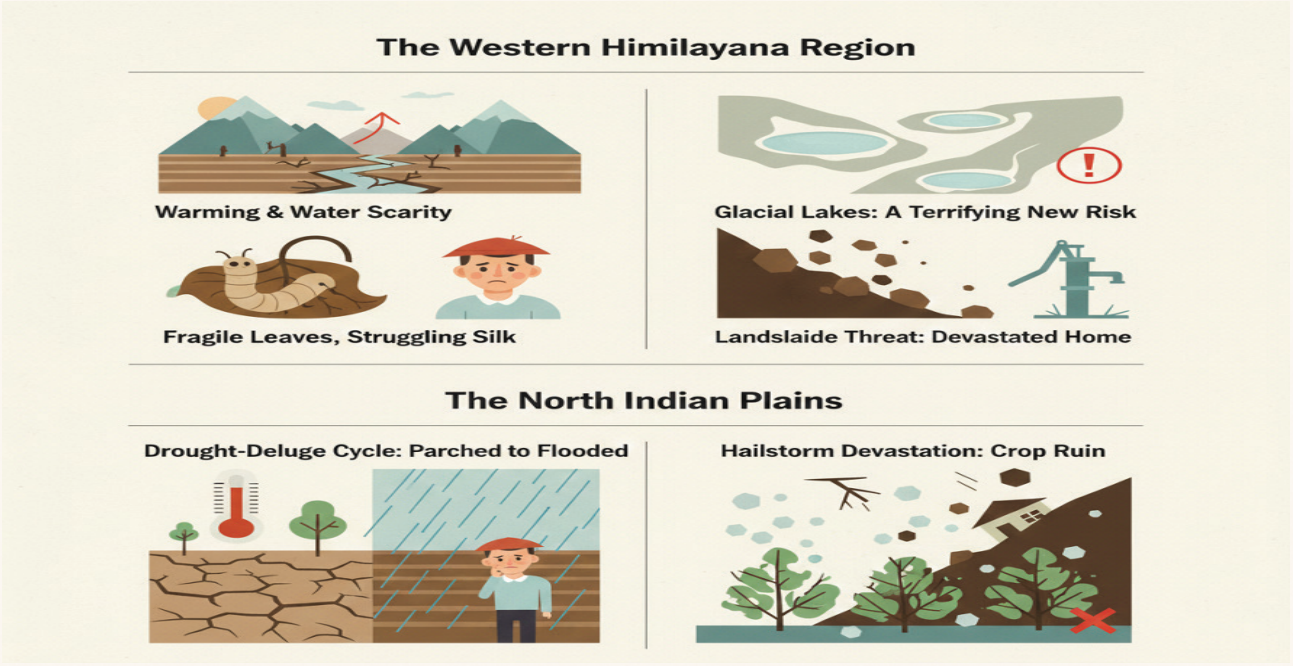
Total annual precipitation has not necessarily collapsed in a uniform way, but its distribution has become more erratic. Rainfall is increasingly characterized by higher intensity, shorter duration, and poor seasonal regularity. Such rainfall patterns are less useful for maintaining stable soil moisture and more likely to produce runoff, erosion, and surface damage. In temperate sericulture, this means that water arrives either too early, too late, or too violently to support steady mulberry growth (Arif *et al.*, 2025; Shafiq *et al.,* 2024).

The hydrological instability is also shaped by larger climate modes and the changing behavior of western disturbances. Historically, winter precipitation and snow accumulation were relatively dependable, but that dependability is weakening. For a production system built on sequential seasonal operations, this uncertainty is itself a major form of climate risk.

7.2.4. Acute climate events in the Himalayan temperate belt

Temperate sericulture is not threatened only by slow climatic drift. It is also exposed to acute, high-impact events such as cloudbursts, flash floods, landslides, hailstorms, and glacial lake outburst floods. These shocks are particularly damaging because they can destroy mulberry plantations, damage rearing houses, disrupt transport, and interrupt the collection and marketing chain in a single event. The fragile Himalayan terrain magnifies the impact of such disasters (Ahmed *et al.*, 2024; The Tribune, 2025).

In the temperate sericulture context, these events should not be treated as isolated disasters. They are part of a broader climate-risk pattern in which the production environment has become more volatile and less predictable. This volatility undermines the planning discipline that sericulture traditionally requires.



7.3. WHY TEMPERATE SERICULTURE IS ESPECIALLY VULNERABLE

Temperate sericulture is highly vulnerable because it depends on a tight biological synchronization between mulberry dormancy, leaf emergence, silkworm brushing, larval feeding, cocoon spinning, and seasonal temperature windows. The Kashmir Valley represents India's major contiguous temperate mulberry sericulture zone, and the system here is dominated by bivoltine production. Bivoltine silkworms produce superior silk but are less tolerant of climatic stress than multivoltine types.

The vulnerability profile is therefore double-edged. On the one hand, the region is exposed to warming winters, reduced snowfall, and erratic precipitation. On the other hand, the biology of the crop is narrow and highly season-dependent. A brief deviation in temperature or moisture can disturb dormancy break, leaf maturity, feeding quality, larval growth, and spinning behavior. This means that even small climatic shifts can create large production losses in temperate sericulture (Rahmatulla, 2012; Zaz *et al.,* 2019; Manzoor & Qayoom, 2024).

7.4. IMPACTS OF CLIMATE CHANGE ON MULBERRY IN TEMPERATE REGIONS

7.4.1. Altered dormancy, sprouting, and phenology

Mulberry is the primary host plant of silkworm and therefore the biological base of the entire industry. Climate stress alters the timing of dormancy break, bud burst, and leaf expansion. Warmer winters can prompt earlier sprouting, while later frost episodes can injure young shoots. The result is irregular phenology, which reduces the ability of farmers to align leaf availability with silkworm brushing schedules.

Phenological mismatch is one of the central climate risks in temperate sericulture. When mulberry sprouts too early, young leaves may be exposed to frost damage. When sprouting is delayed, rearing is forced onto older, less nutritious foliage. Either way, the biological synchrony that supports successful bivoltine rearing is weakened.

7.4.2. Decline in leaf yield and leaf quality

Mulberry leaves exposed to heat and water stress tend to become smaller, thinner, less succulent, and more fibrous. Premature senescence may set in, and the canopy can lose its capacity to sustain the biomass needed for multiple rearings. Acute events such as hailstorms can shred the canopy and cause instant crop loss. In the temperate zone, where seasonal leaf supply is already constrained, such physical damage is highly disruptive (Chaitanya *et al.,* 2001; The Times of India, 2019).

More important than visible leaf damage is the hidden nutritional decline. Heat stress reduces total soluble protein, lowers foliar nitrogen, and diminishes nucleic acid content. Moisture content and moisture retention capacity also decline. Even when leaves remain green, they may be physiologically unsuitable for robust silkworm growth. This is why climate change affects sericulture not only through leaf quantity but also through leaf quality.

7.4.3. Water stress and soil moisture instability

Temperate mulberry depends heavily on snow-derived and rainfall-derived soil moisture. When snowfall declines or spring snowmelt occurs too early, soil moisture recharge becomes insufficient. This creates water stress during the critical phase of leaf expansion. If irrigation is unavailable or poorly timed, mulberry growth slows, leaf quality deteriorates, and the crop becomes less suitable for chawki and later-age silkworm feeding.

The increasing unreliability of water availability makes climatic adaptation in mulberry cultivation a core issue for the survival of temperate sericulture.

7.5. IMPACTS OF CLIMATE CHANGE ON SILKWORM REARING

7.5.1. Thermal stress in bivoltine silkworms

Bombyx mori is a poikilothermic and highly domesticated insect whose development is tightly controlled by ambient conditions. Bivoltine silkworms, which are the backbone of temperate sericulture, perform best within a narrow temperature and humidity range. When temperatures rise above the optimum, larval weight declines, larval duration shortens, feed conversion becomes inefficient, and mortality increases. Breeds of temperate origin are more sensitive to heat than tropical multivoltine stocks (Sharma *et al.*, 2022; Thrilekha, 2024; Ashrith *et al.*, 2025).

Heat stress is especially damaging in the chawki stage because the young larvae are physiologically fragile and highly dependent on feed quality and environmental stability. A heat wave during this stage can permanently reduce reelability, raw silk percentage, and filament length even when later management is sound.

7.5.2. Humidity imbalance and disease amplification

Climate change does not affect silkworms through temperature alone. The alternating pattern of heat and humidity creates a disease-amplifying environment. High temperature weakens the larvae and reduces immunity, while sudden humid spells favor the spread of viral, bacterial, and fungal pathogens. Grasserie, flacherie, and muscardine are all more likely to appear under such conditions, particularly when poor ventilation and wet bed conditions persist (Sharma *et al.,* 2020; Hossain, 2017; Rabha *et al.,* 2025).

This interaction between climate stress and disease outbreak is one of the most destructive consequences of warming in temperate sericulture. It means that the farmer faces a disease-amplification loop in which heat stress weakens the insect, humidity favors pathogens, and crop loss accelerates.

7.5.3. Effects on cocoon spinning and post-cocoon quality

Even when larvae survive to spinning, climate stress continues to affect the commercial value of the crop. Stressed larvae produce thinner shells, irregular cocoons, and lower shell ratios. In unfavorable seasons, filament length and non-broken filament length decline, while reelability suffers because humidity alters the behavior of sericin during reeling. The end result is lower raw silk recovery and poorer yarn quality (Reddy *et al.*, 2003; Ueda, 1985; Kumar *et al.,* 2025).

The effect is cumulative. Poor leaf quality lowers larval nutrition, thermal stress shortens development, disease pressure rises, and cocoon quality drops. Climate change therefore reduces not just the quantity of cocoons but their commercial value at every post-harvest stage.

7.6. ADAPTIVE STRATEGIES FOR CLIMATE-RESILIENT TEMPERATE SERICULTURE (SHABNAM ET AL., 2025)

7.6.1. Climate-resilient mulberry varieties

The first adaptation priority is to strengthen the host plant. Mulberry varieties bred for temperate regions can buffer the effects of frost, moisture stress, and phenological instability. PPR-1 (Developed by Baksh *et al.*, 2016) is a particularly important temperate genotype. Compared with older varieties such as Goshoerami, it shows better frost tolerance, much higher rooting success, earlier spring sprouting, high leaf moisture, and superior moisture retention capacity.

These traits matter because they help the plant recover after winter, establish quickly in nursery conditions, and supply fresh leaves when silkworm rearing begins. Early sprouting can also function as a phenological escape mechanism, allowing the crop to be completed before the onset of peak summer heat.

Somatic hybrids such as SH2 and SH3 (Developed by Rohela *et al.,* 2019) add another layer of resilience by improving leaf yield and nutritional quality. Higher carbohydrate and protein levels in such hybrids provide a better food base for silkworms under stress. In a climate-stressed system, leaf nutrition is not a secondary issue; it is central to survival and productivity.



PPR-1



SH-2



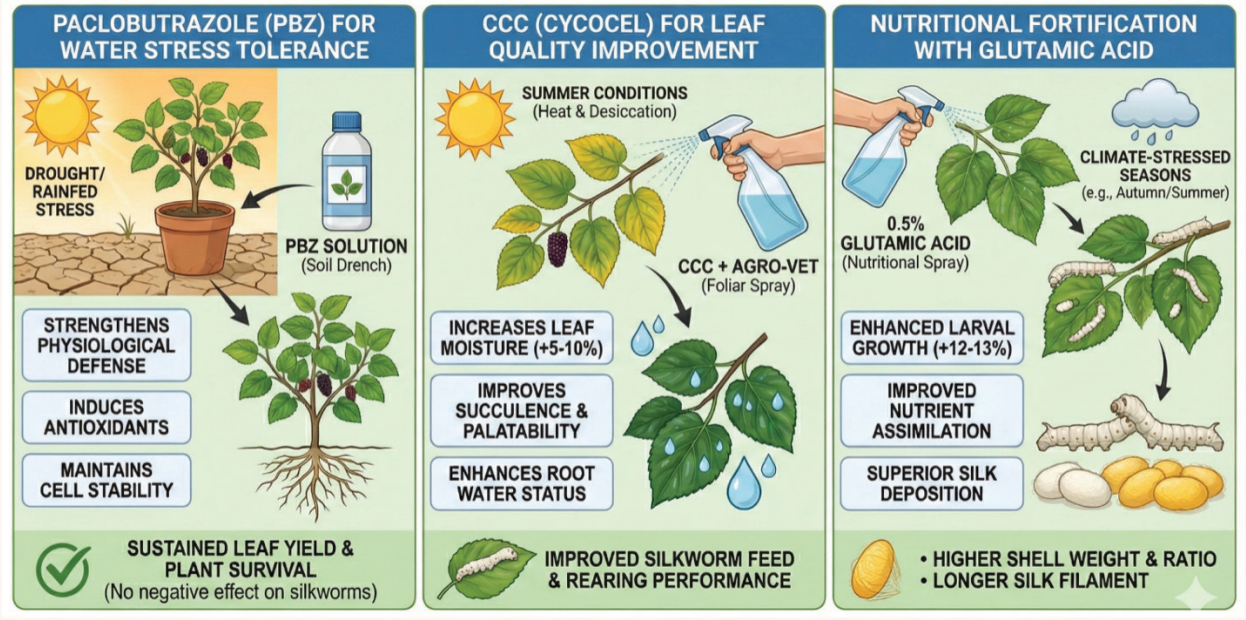
SH-3

7.6.2. Agronomic interventions for moisture and leaf quality management

Where varietal replacement is not immediately possible, agronomic interventions can reduce vulnerability in existing plantations. Paclobutrazole (Developed by Mohan *et al.*, 2014) has been shown to improve water stress tolerance by strengthening antioxidant defenses, reducing membrane damage, and improving biomass retention under drought-like conditions. It is therefore useful in areas where moisture deficits and unreliable irrigation have become more common.

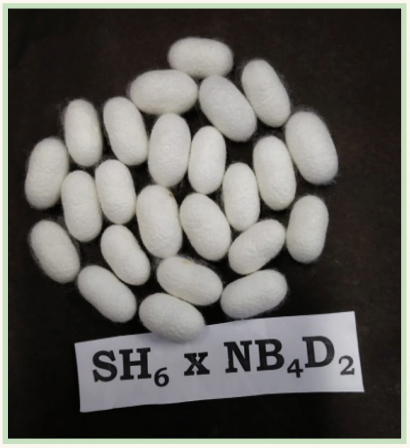
Cycocel (CCC) (Developed by Mohan *et al.*, 2008) is another useful intervention because it improves leaf moisture content, succulence, and root water status. Under warmer and drier conditions, leaves may lose quality rapidly after the spring crop; CCC helps reduce that loss and improves the suitability of leftover foliage for subsequent rearing.

Nutritional fortification of leaves with glutamic acid (Developed by Ravindra *et al.,* 2024) represents a different kind of intervention. By improving the nutritional value of the feed, it supports silkworm growth, shell weight, shell ratio, and filament length during seasons when climate stress reduces natural leaf quality. Such low-cost approaches are especially valuable for the autumn crop in Kashmir.



7.6.3. Climate-adaptive silkworm hybrids

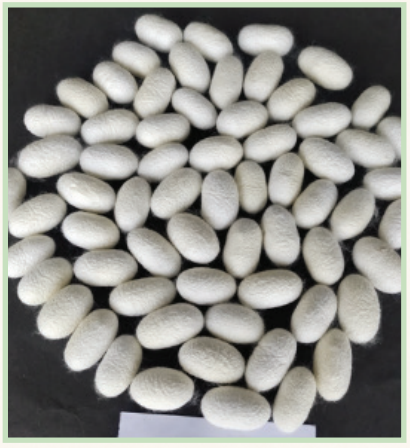
Silkworm breeding must also move in the direction of climate resilience. The long-standing bivoltine hybrid SH6 × NB4D2 has remained popular because of its stable performance under northern conditions, but climate change now requires hybrids that are better tuned to seasonal stress. Autumn-specific hybrids such as ASH-14 demonstrate how season-focused breeding can improve productivity under fluctuating temperature and humidity. Nutrigenetic hybrids (Developed by Murali *et al.*, 2024) such as CSR50 × BCon4, CSR50 × BCon1, and RSJ14 × BCon1 further indicate the value of improving nutrient conversion efficiency when leaf quality becomes unstable.



SH6 x NB4D2



ASH-14



CSR50 x BCon4



CSR50 x BCon1

These hybrids are important because climate stress often reduces leaf quality before it reduces leaf quantity. A hybrid that can convert limited or suboptimal nutrition into silk biomass more efficiently has a clear advantage in a warming temperate environment.

7.6.4. Climate-responsive water management

Water management is a cornerstone of adaptation. Mulberry is a high-water-demand crop, and the reliability of traditional irrigation is declining as snowpack decreases and rainfall becomes more erratic. Drip irrigation offers a practical answer because it delivers water directly to the root zone, reduces loss, and maintains leaf yield with much less water use than furrow irrigation. Rainwater harvesting through ponds, check dams, and jalkunds adds another buffer by capturing intense rainfall and storing it for dry periods.

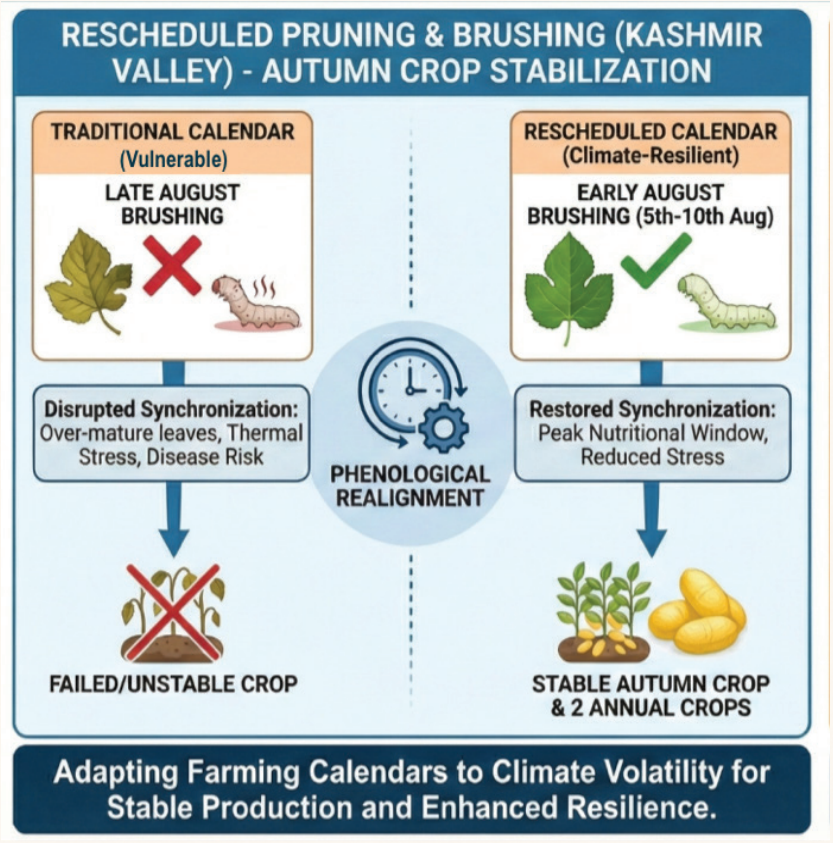
Together, micro-irrigation and rainwater harvesting help decouple mulberry productivity from unstable precipitation and shrinking cryospheric water sources. This transition from water-dependent to water-smart sericulture is central to future sustainability in temperate regions.

7.6.5. Rescheduled pruning and brushing calendars

Climate change is also altering the timing of operations. In Kashmir, the autumn crop is increasingly exposed to over-mature leaves because prolonged warmth accelerates leaf ageing while the traditional brushing calendar lags behind the plant's actual phenology. Rescheduled pruning and

brushing technology (Developed by Khan *et al.,* 2025) addresses this mismatch by advancing the autumn calendar so that silkworms are fed with physiologically young leaves of higher quality.

This is a low-cost but highly effective adaptation because it does not require major infrastructural change. It simply aligns the production schedule with the new climatic reality. In a region where the safe rearing window is getting narrower, phenological realignment can be as important as breeding.



7.6.6. Climate advisory services and protected rearing environments

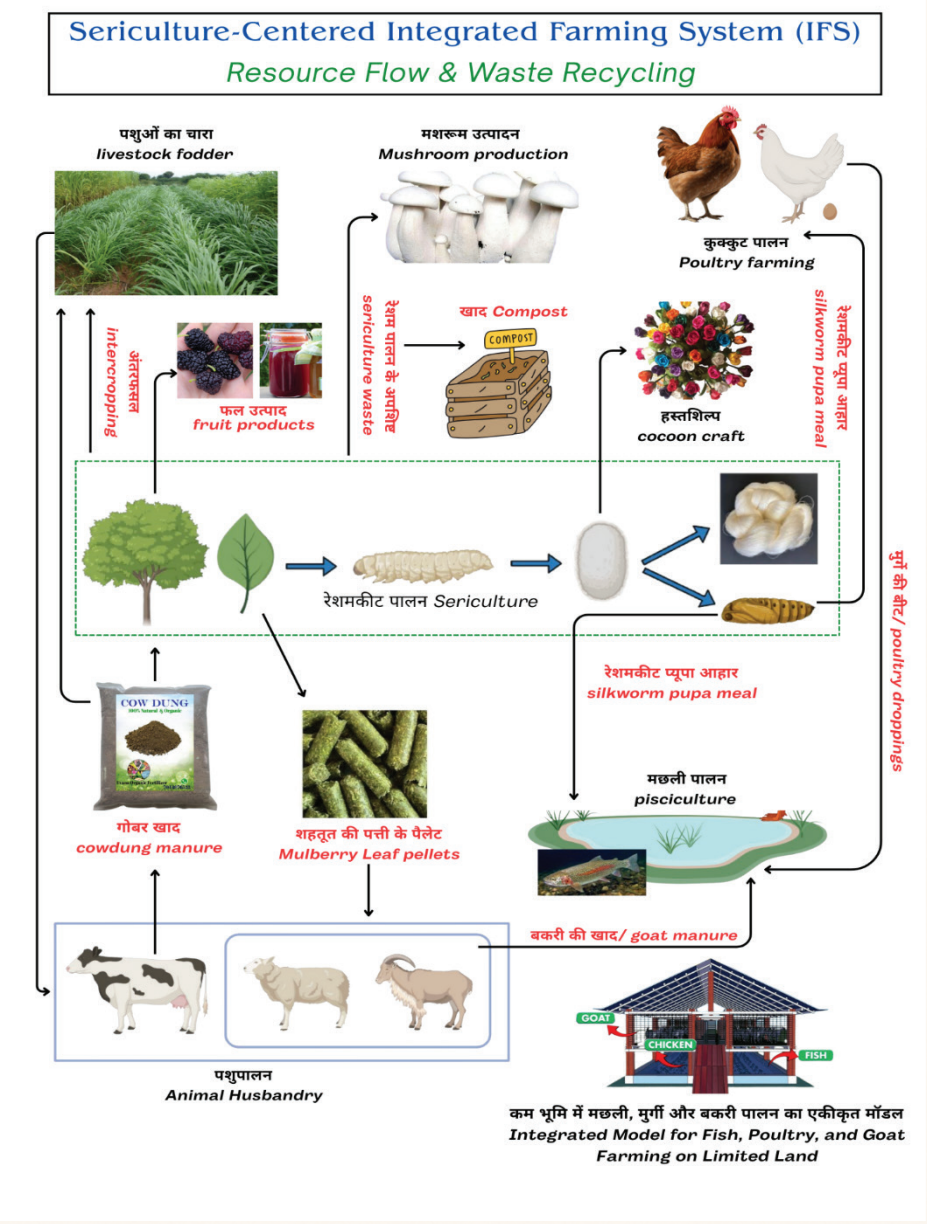
Weather-based advisories, early warning systems, and improved rearing-house ventilation are essential complements to biological and agronomic adaptation. Farmers need timely forecasts of heat spells, rainfall events, and humidity shifts so that brushing, feeding, and disease-prevention measures can be adjusted in advance. Rearing houses must also be designed or upgraded to reduce heat accumulation and maintain appropriate ventilation.

In the temperate context, adaptation should not be seen as a single technology but as a management system that combines climate information, planting decisions, rearing schedules, and infrastructure control.

7.7. ECONOMIC BUFFERING AND INTEGRATED RESILIENCE

7.7.1. Sericulture-centric integrated farming systems

Climate resilience in temperate sericulture is stronger when the enterprise is linked with other farm components. A sericulture-centric integrated farming system combines mulberry and silkworm rearing with livestock, poultry, fishery, apiculture, composting, vermicomposting, and intercrops.



Such integration improves nutrient cycling, creates multiple income streams, and reduces the risk that a climate shock in one component will destroy the whole farm economy.

Mulberry prunings can be used as fodder, livestock manure can return to the field as compost, poultry litter can support soil fertility, and fish-pond water can be used for irrigation. In this way, the farm becomes a circular and resilient production system rather than a single-point enterprise.

7.7.2. Seri-tourism as a livelihood support mechanism

In suitable locations, seri-tourism offers an additional buffer. A working sericulture unit can also function as an educational and experiential destination where visitors learn about mulberry cultivation, silkworm rearing, cocoon processing, and silk heritage. This can generate supplementary income through entry fees, guided tours, training visits, and related products. For temperate sericulture regions with strong cultural identity, this form of diversification can help stabilize livelihoods when climate conditions reduce the output of the core crop.

7.8. FUTURE PERSPECTIVES

The future of temperate sericulture will depend on whether the sector can adapt quickly enough to a warming and more variable climate. The main challenge is not just higher temperature; it is the loss of predictability. Mulberry growth, silkworm rearing, disease pressure, and post-cocoon quality must all be managed in a climate environment that no longer follows the old calendar. The response therefore has to be integrated.

Future priorities should include breeding for frost, drought, and heat tolerance; phenology-based scheduling; precision and digital sericulture tools; stronger climate advisories; and better integration of mulberry, silkworm, and farm-management research. The objective is not merely to maintain production in a changed climate but to build a system that can remain productive, profitable, and biologically synchronized under continued climatic stress.

7.9. CONCLUSION

Temperate sericulture is highly climate-sensitive, as its success depends on close matching of winter cold, spring moisture, mulberry dormancy, leaf quality, and bivoltine silkworm development. Climate change is disturbing all of these links through winter warming, snowfall decline, erratic precipitation, moisture stress, and extreme weather events. The result is reduced leaf yield, poorer nutritional quality, higher disease risk, unstable cocoon traits, and lower reelability.

At the same time, the chapter shows that adaptation is possible. Climate-resilient mulberry varieties, improved irrigation and rainwater harvesting, agronomic treatments, climate-adaptive silkworm hybrids, rescheduled pruning and brushing, advisory systems, and integrated farming approaches together provide a practical pathway for sustaining temperate sericulture. The future of the sector in the Kashmir Valley will depend on how rapidly these measures are adopted and combined into a coherent climate-smart production strategy.

7.10. REFERENCES

Ahmed, M., Lotus, S., Das, B., Bhat, F. A., Kichloo, A. H., & Singh, S. (2024). Extreme weather events induced mortalities in Jammu and Kashmir, India during 2010-2022. Mausam, 75(2), 395-406.

Arif, F. and Shukla, U. (2025). Analysis of climate change impacts: Temperature trends and escalation of extreme weather events. International Journal Of Research and Analytical Reviews (IJRAR), 12(2).

Ashrith, S., Pavithra, M.R., Harish, R. C., Jekinakatti. B., Kumar, A and Suhas BV. (2025). Climate change and its impact on sericulture. International Journal of Advanced Biochemistry Research, 9(8): 656-661.

Bhat, A. A., Dhondiram, P. D., Gupta, S. K., Kanga, S., Singh, S. K., Meraj, G.,... & Sajan, B. (2025). Snow Resources and Climatic Variability in Jammu and Kashmir, India. Climate, 13(2), 28.

Chaitanya, K. V., Sundar, D., & Reddy, A. R. (2001). Mulberry leaf metabolism under high temperature stress. Biologia Plantarum, 44(3), 379-384.

Dad, J. M., Muslim, M., Rashid, I., & Reshi, Z. A. (2021). Time series analysis of climate variability and trends in Kashmir Himalaya. Ecological Indicators, 126, 107690.

Dar, K.A., Ganie, A.H., Ganie N.A., Farhat, S., Sharma, R.K., Salib, S., Omaise, A., Rafique, A.A. and Parviz, S., 2021. Jammu and Kashmir Silk Industry: Problems and Prospects. *The Pharma Innovation Journal*,10(6), pp.369-371

Gusain, H. S., Mishra, V. D., & Bhutiyani, M. R. (2014). Winter temperature and snowfall trends in the cryospheric region of north-west Himalaya. Mausam, 65(3), 425-432.

Hossain, Z., Chakraborty, S., Gupta, S. K., Saha, A. K., & Bindroo, B. B. (2017). Silkworm disease incidence trends during the years 1992–2011 in the Murshidabad district of West Bengal, India. International Journal of Tropical Insect Science, 37(4), 259-270.

Khan, G. A., Rohela, G. K., Ahmad, H. R., Rai, K. K., & Singh, S. (2025). Rescheduling of Brushing and Pruning Dates for Stabilization of Second Commercial Mulberry Silkworm Crop in Kashmir Valley. Mysore Journal of Agricultural Sciences, 59(2).

Kumar, A., Singhal, N., Hore, N. and Tripathi, A. (2025). Impact of Seasonal Variations on Filament Length and Non-Broken Filament Length in Relation to Silk Reeling Performance. Preprints, 202503.0446.v1.

Manzoor, S. and Qayoom, K. (2024). Impact of Climate Change on Sericulture. Asian Research Journal of Agriculture, 17(3) 107–113.

Rabha, M., Ethungbeni, T. N., Rahul, K., Alam, K., & Maheswari, M. (2025). Temporal analysis of climatic factors influencing silkworm disease incidences in commercial sericulture crops of West Bengal, India (2018–2024). The Journal of Basic and Applied Zoology, 86(1), 65.

Rahmathulla, V. K. (2012). Management of climatic factors for successful silkworm (*Bombyx mori* L.) crop and higher silk production: a review. Psyche: A Journal of Entomology, 2012(1), 121234.

Reddy, P. L. N., Naik, S. S., Rao, M. S., & Reddy, N. S. (2003). Implications of high temperature and low humidity on cocoon economic traits in the silkworm, *Bombyx mori* L. Journal of Advanced Zoology, 24(1-2), 34-40.

Shabnam, A. A., Syam, S., Rohela, G. K., Khan, G. A., Satish, Y., & Singh, S. (2025). Sericulture technology descriptor for North and Northwest India. Central Sericultural Research and Training Institute, Central Silk Board, Govt of India.

Shafiq, M. U., Islam, Z. U., Fayaz, A., Mahmood, R., Ahmed, P., & Dimri, A. P. (2024). Spatio-temporal trends and variability in extreme temperature and precipitation indices in the Kashmir Valley, North Western Himalayas. Journal of Water and Climate Change, 15(8), 3867-3887.

Shafiq, M. U., Islam, Z. U., Fayaz, A., Mahmood, R., Ahmed, P., & Dimri, A. P. (2024). Spatio-temporal trends and variability in extreme temperature and precipitation indices in the Kashmir Valley, North Western Himalayas. Journal of Water and Climate Change, 15(8), 3867-3887.

Sharma, A., Chanotra, S., Gupta, R., & Kumar, R. (2020). Influence of climate change on cocoon crop loss under subtropical conditions. International Journal of Current Microbiology and Applied Sciences, 9(5), 167-171.

Sharma, P., Bali, K., Sharma, A., Gupta, RK., Singh, AK., Gupta, M. and Samnotra, RK. (2022). Effect of high temperature on commercial traits of silkworm, *Bombyx mori* L. The Pharma Innovation Journal, 11(12): 2870-2873.

The Times of India. (2019, April 17). Hail, gusty winds destroy 60% of Mahabaleshwar's mulberry crop.

The Tribune. (2025, August 6). Why effects of climate change are most deadly and seen in Himachal and Uttarakhand.

Thrilekha, D., Mala, H.P., Gowthami, B., Kumar DS, C. (2024). Influence of temperature on growth and development of bivoltine silkworm breeds and hybrids: A comprehensive review. International Journal of Research in Agronomy, 7(6): 590-597.

UEDA, S. (1985). Effects of Silkworm rearing and mounting conditions on cocoon reelability. JARQ, 19(2), 132-136.

Zaz, S. N., Romshoo, S. A., Krishnamoorthy, R. T., & Viswanadhapalli, Y. (2019). Analyses of temperature and precipitation in the Indian Jammu and Kashmir region for the 1980–2016 period: implications for remote influence and extreme events. Atmospheric Chemistry and Physics, 19(1), 15-37.

CHAPTER 8: CLIMATE CHANGE AND SOIL HEALTH INDICATORS: TRENDS, RESPONSES, AND SOIL SUSTAINABILITY CHALLENGES

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8.1. INTRODUCTION

Climate change has emerged as one of the most critical challenges affecting soil sustainability, agricultural productivity, and ecosystem functioning across the globe. Soil health indicators provide measurable evidence of how soils respond to climatic variability and environmental stress. Under changing climatic conditions, shifts in temperature, rainfall distribution, atmospheric greenhouse gas concentrations, and extreme weather events directly influence soil physical, chemical, and biological processes. Therefore, understanding the trends, responses, and emerging challenges associated with soil health indicators has become essential for developing climate-resilient soil management strategies.

Soil health is increasingly recognized as a fundamental component of sustainable agriculture and environmental resilience, particularly under the intensifying pressures of global climate change. It reflects the capacity of soil to function as a dynamic, living system that supports plant productivity, regulates water and nutrient cycling, and sustains biological activity. According to Doran and Safley (1997), soil health encompasses the ability of soil to maintain biological productivity while preserving environmental quality and ecosystem stability. However, this functional integrity is increasingly threatened by climate change, characterized by rising temperatures, altered precipitation regimes, and increasing atmospheric greenhouse gas (GHG) concentrations.

The role of climate in governing soil processes has long been established, with Jenny (1941) identifying it as a dominant factor in soil formation and development. Subsequent studies have reinforced that climatic variability significantly influences soil physical, chemical, and biological properties, which collectively serve as key soil health indicators. Girija Veni *et al.* (2020) reported that increasing temperatures and erratic rainfall patterns accelerate the depletion of soil organic carbon (SOC), a critical component influencing soil fertility, structural stability, and resilience. Similarly, IPCC (2014) highlighted that climate-induced variations in temperature and precipitation disrupt soil aggregation, increase erosion, and alter nutrient dynamics, thereby contributing to soil degradation.

In addition, soils play a critical role in global carbon cycling, acting both as a source and a sink of greenhouse gases. Lal (2003) noted that soil degradation can release stored carbon into the atmosphere, thereby intensifying climate change through positive feedback mechanisms.

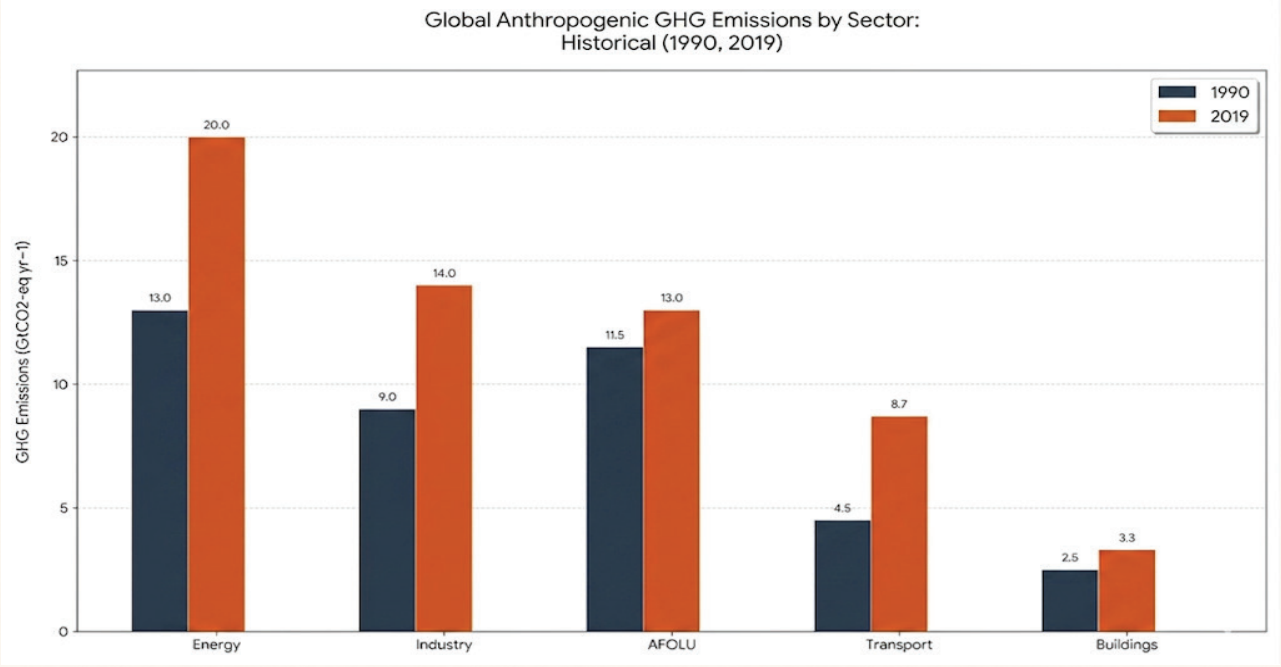
8.2. TRENDS IN CLIMATE CHANGE AND SOIL HEALTH INDICATORS

8.2.1. Global Climate Change Scenario

Global climate change is altering the functioning of terrestrial ecosystems, including soil systems that regulate nutrient cycling, carbon sequestration, water dynamics, and biological activity. Changes in climate drivers such as warming, drought, erratic rainfall, and flooding are increasingly influencing the behavior and stability of soil health indicators across agricultural and natural ecosystems.

Global climate change is primarily driven by increasing anthropogenic greenhouse gas (GHG) emissions, which have reached unprecedented levels in recent decades. According to IPCC

(2022), global net emissions were approximately 59 ± 6.6 $GtCO_2$-equivalent in 2019, representing an increase of about 54% since 1990. Carbon dioxide (CO_2) is the dominant greenhouse gas, contributing nearly 65% of total emissions, followed by methane (CH_4), nitrous oxide (N_2O), and fluorinated gases. Cumulative CO_2 emissions have risen sharply since the industrial era, with nearly 62% occurring after 1970, indicating the rapid acceleration of anthropogenic impacts on the climate system (Friedlingstein *et al.*, 2020).



The sector-wise distribution of emissions indicates that energy and industrial activities are the largest contributors, followed by transport, buildings, and the Agriculture, Forestry, and Other Land Use (AFOLU) sector, which alone contributes approximately 22% of total global emissions (IPCC, 2022). The contribution of these sectors and their temporal changes are clearly illustrated in Figure 1, showing a consistent increase in emissions from 1990 to 2019.

The increasing concentration of greenhouse gases has resulted in rising global temperatures, altered precipitation patterns, and a higher frequency of extreme climatic events. The IPCC (2021) warns that the remaining carbon budget for limiting global warming to 1.5°C may be exhausted within the next decade under current emission trends. These climatic changes have significant implications for soil systems, particularly in terms of soil carbon dynamics, moisture regimes, and overall soil health (Lal, 2003; Davidson and Janssens, 2006).

8.3. RESPONSES OF SOIL HEALTH INDICATORS TO CLIMATE CHANGE

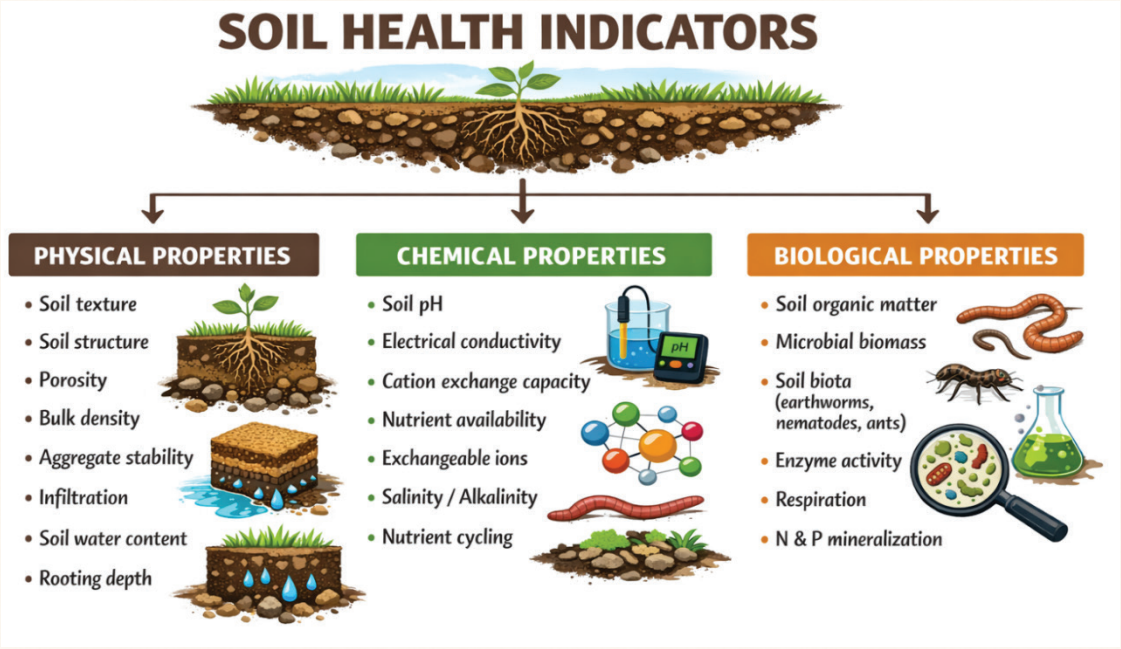
8.3.1. Overview of Soil Health Indicators

Soil health indicators serve as diagnostic tools for evaluating the response of soils to environmental change and management interventions. Under climate change scenarios, these indicators help assess soil resilience, degradation processes, nutrient dynamics, carbon stability, and ecosystem sustainability. The responses of soil health indicators to climatic stress are often interrelated, making integrated assessment essential for understanding long-term soil functionality.

Soil health indicators are measurable physical, chemical, and biological attributes that collectively reflect the capacity of soil to function as a dynamic living system capable of sustaining plant productivity, maintaining environmental quality, and supporting ecosystem services. The concept,

as defined by Doran and Safley (1997), emphasizes the ability of soil to perform essential ecological functions within natural and managed ecosystems. Rather than relying on a single parameter, soil health is evaluated through an integrated set of indicators that represent the structural condition, nutrient status, and biological activity of the soil (Karlen *et al.,* 2003; Bünemann *et al.*, 2018).

These indicators are broadly classified into three major groups physical, chemical, and biological each representing a distinct but interconnected dimension of soil functioning. Physical indicators describe the soil's structural integrity and water dynamics; chemical indicators reflect nutrient availability and soil reaction; while biological indicators capture the activity and diversity of soil organisms and biochemical processes. Together, they provide a comprehensive assessment of soil fertility, resilience, and sustainability (Lehmann *et al.,* 2020; Rinot *et al.,* 2019).



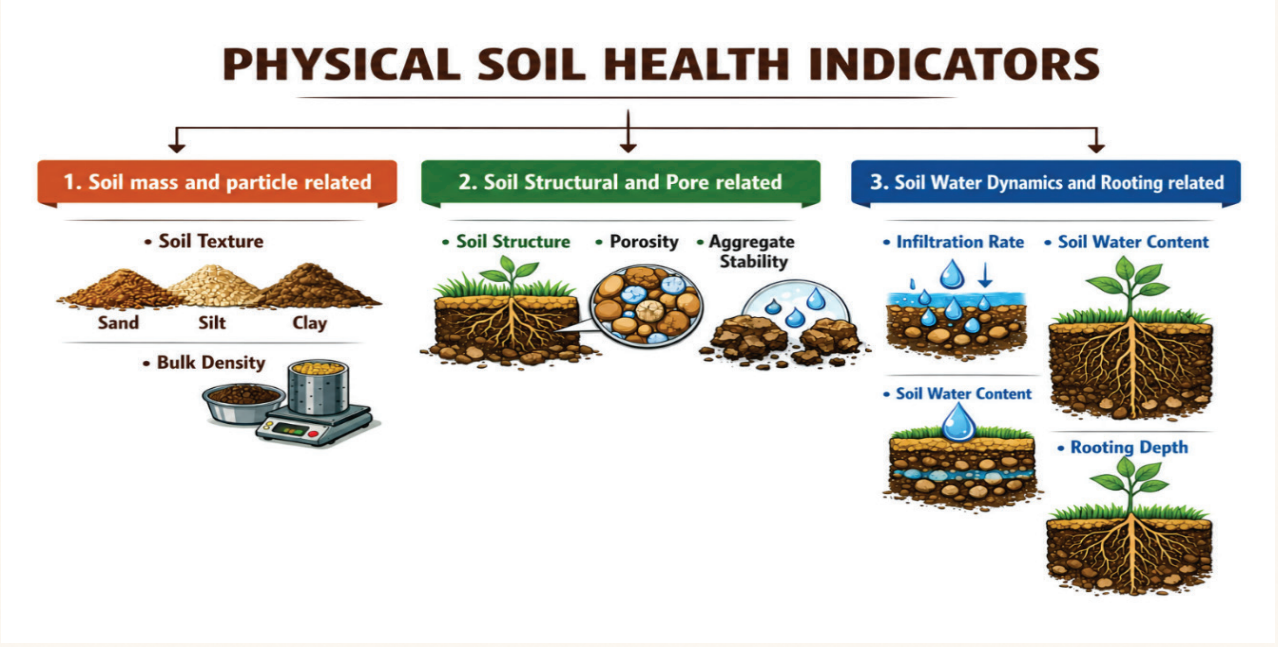
The interdependence among these indicators is critical, as changes in one component often influence the others. For instance, soil structure affects water retention and aeration, which in turn regulate microbial activity and nutrient transformations. Therefore, an integrated evaluation of soil health indicators is essential for understanding soil functionality under varying environmental conditions. The classification and major components of soil health indicators are illustrated in Fig. 2.

8.3.1.1. Physical Soil Health Indicators

Physical soil health indicators are highly sensitive to climate-induced disturbances and represent the structural and hydrological status of soils under changing environmental conditions. Variations in rainfall intensity, drought frequency, and temperature regimes significantly influence soil aggregation, porosity, compaction, infiltration, and water retention characteristics.

Soil physical indicators form the fundamental basis of soil functioning, directly influencing plant growth, water dynamics, and ecosystem sustainability. These properties include soil mass and particle-related characteristics, soil structural organization, and soil water dynamics. According to Brady and Weil (2017), soil physical properties regulate essential processes such as water retention, aeration, root penetration, and nutrient availability, thereby determining soil productivity.

8.3.1.1.1 Classification of Soil Physical Health Indicators



Soil physical health indicators have been systematically classified into three major sub-groups based on their functional similarities and roles in soil processes, as illustrated in Fig. 3.

8.3.1.1.2 Soil Mass and Particle-Related Properties

Soil mass and particle-related properties, particularly soil texture and bulk density, form the basic framework governing soil behavior and fertility. Soil texture strongly influences water retention, nutrient availability, and cation exchange processes. Brady and Weil (2017) emphasized that fine-textured soils (clay and silt) possess greater surface area, enhancing nutrient retention and water-holding capacity, whereas coarse-textured soils are prone to leaching losses and lower fertility. Hillel (2004) further reported that texture determines the soil's hydraulic behavior and nutrient diffusion rates, directly affecting plant nutrient uptake.

Bulk density is a key indicator of soil compaction and pore space distribution. Hamza and Anderson (2005) demonstrated that increased bulk density reduces total porosity, restricts root penetration, and limits oxygen diffusion, thereby negatively affecting plant growth and nutrient acquisition. Similarly, Lipiec *et al.* (2012) reported that compacted soils exhibit reduced microbial activity and nutrient cycling efficiency. Chen *et al.* (2014) linked bulk density with soil organic carbon (SOC), showing that soils with higher SOC tend to have lower bulk density and improved fertility.

8.3.1.1.3 Soil Structural and Pore-Related Properties

Soil structural and pore-related properties, including aggregation, porosity, and aggregate stability, play a central role in maintaining soil fertility by regulating air–water balance and protecting soil organic matter. Six *et al.* (2000) reported that stable soil aggregates physically protect SOC from decomposition, thereby enhancing long-term nutrient availability. Tisdall and Oades (1982) highlighted the importance of organic matter and microbial activity in aggregate formation, linking soil structure directly to fertility status.

Porosity and pore-size distribution control water retention, drainage, and aeration. Dexter (2004) emphasized that an optimal balance between macro- and micropores is essential for sustaining

plant growth, as macropores facilitate aeration and drainage while micropores retain plant-available water. Robinson *et al.* (2022) further demonstrated that pore connectivity governs the movement of water, gases, and nutrients within the soil, directly influencing root activity and microbial processes.

Blanco-Canqui and Ruis (2020) emphasized that well-structured soils enhance infiltration and reduce surface crusting, which is essential for maintaining soil fertility under varying environmental conditions.

8.3.1.1.4 Soil Water Dynamics and Rooting Properties

Soil water dynamics and rooting properties are key determinants of soil fertility as they regulate water availability, nutrient transport, and plant resilience. Properties such as infiltration rate, soil water retention, and hydraulic conductivity control the movement and storage of water within the soil profile. Hillel (2004) noted that soil water acts as a medium for nutrient transport and is essential for biochemical reactions and plant uptake processes.

Water retention characteristics determine the availability of water to plants under different moisture conditions. Saxton and Rawls (2006) demonstrated that soils with balanced texture and structure provide optimal water retention for crop growth. Wang *et al.* (2021) and Zhang *et al.* (2021) reported that stable hydraulic properties ensure consistent water supply, which is critical for nutrient uptake and crop productivity.

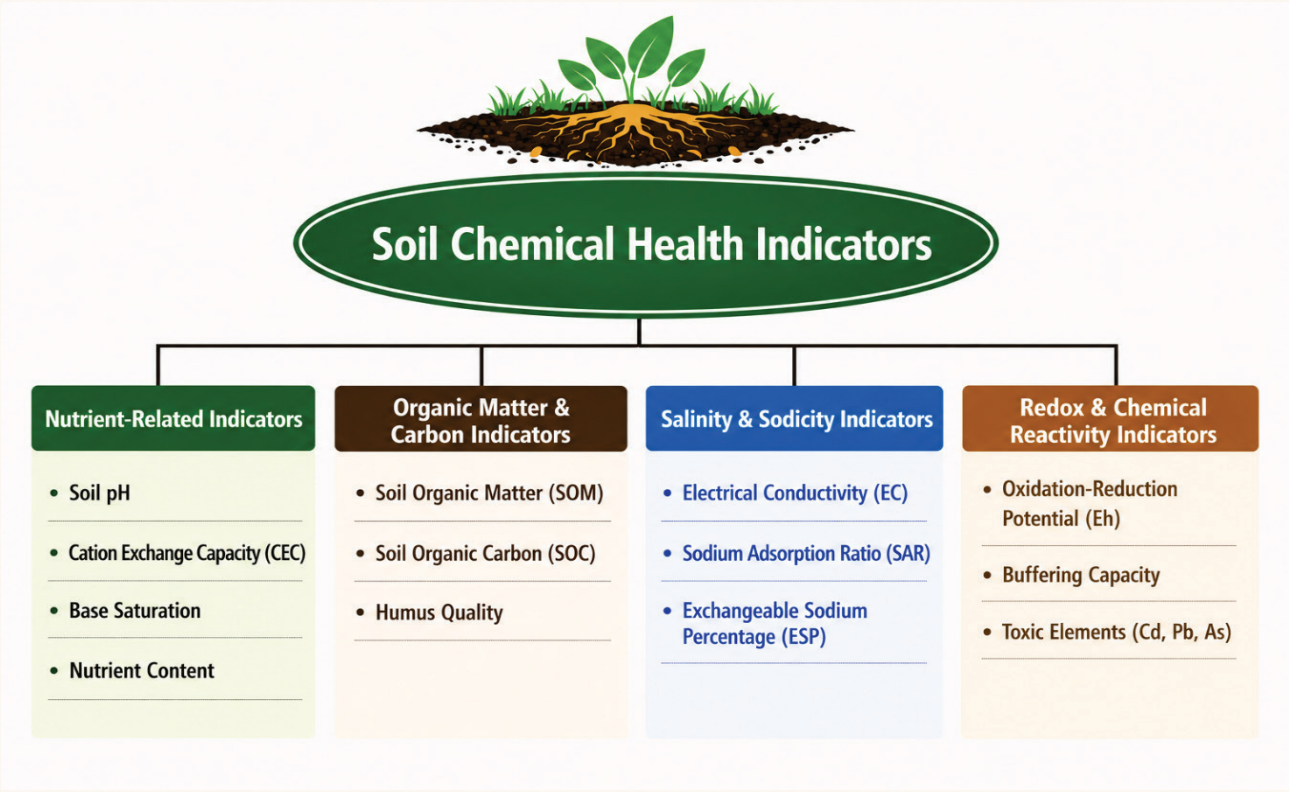
Rooting depth and distribution further influence soil fertility by determining the extent of soil explored for water and nutrients. Bengough *et al.* (2011) reported that favorable soil physical conditions promote deeper root growth, enhancing access to subsoil moisture and nutrients. In contrast, restricted rooting due to poor physical conditions reduces nutrient uptake efficiency and limits crop yield. Gregory (2006) also emphasized that root–soil interactions are strongly controlled by physical constraints such as compaction and pore continuity.

8.3.1.2 Chemical Soil Health Indicators

Chemical soil health indicators reflect the nutrient status, buffering capacity, salinity dynamics, and carbon stability of soils under changing climatic conditions. Climate-driven alterations in soil moisture and temperature strongly influence nutrient transformations, organic matter decomposition, and greenhouse gas emissions.

Soil chemical properties constitute the core foundation of soil fertility, nutrient cycling, and environmental sustainability. These properties regulate nutrient solubility, ionic balance, microbial activity, and buffering capacity, thereby directly influencing plant growth and productivity. Jenny (1994) emphasized that soil chemical characteristics are governed by the combined effects of climate, organisms, relief, parent material, and time. Brady and Weil (2008) identified soil pH as a master variable controlling nutrient availability and biochemical processes, while Lal (2004) highlighted the central role of soil organic carbon (SOC) in enhancing cation exchange capacity (CEC), structural stability, and overall soil health. Stevenson (1994) further noted that soil organic matter acts as a reservoir of nutrients and a key regulator of chemical buffering.

8.3.1.2.1 Classification of Soil Chemical Health Indicators



Soil chemical properties have been systematically classified into four major sub-groups based on their functional roles and interactions within the soil system, as illustrated in Fig. 4.

8.3.1.2.2 Nutrient-Related Properties

Nutrient-related properties, particularly soil pH, cation exchange capacity (CEC), and electrical conductivity (EC), play a decisive role in regulating nutrient availability and soil fertility. Soil pH governs the solubility and mobility of macro- and micronutrients, with optimal pH ranges ensuring maximum nutrient uptake efficiency (Brady and Weil, 2008; Fageria, 2009). Marschner (2012) demonstrated that extreme pH conditions can lead to nutrient deficiencies or toxicities, particularly affecting micronutrient availability such as iron, zinc, and manganese.

Cation exchange capacity represents the soil's ability to retain and supply positively charged nutrients (e.g., Ca^{2+}, Mg^{2+}, K^{+}, NH_4^{+}). Sumner and Noble (2003) reported that soils with higher CEC exhibit greater nutrient retention and buffering capacity, thereby sustaining fertility over time. Electrical conductivity reflects the concentration of soluble salts in soil solution and influences nutrient uptake and osmotic balance. Richards (1954) emphasized that excessive salt accumulation adversely affects plant growth by reducing water availability and nutrient absorption.

8.3.1.2.3 Organic Matter and Carbon-Related Properties

Soil organic matter (SOM) and soil organic carbon (SOC) are central to soil chemical functioning and fertility. SOM serves as a major reservoir of nutrients and contributes to the formation of stable organo-mineral complexes. Stevenson (1994) and Baldock and Skjemstad (2000) highlighted that the quality and composition of organic matter determine nutrient release patterns and decomposition rates.

SOC significantly enhances cation exchange capacity and buffering capacity, improving nutrient retention and reducing losses through leaching (Lal, 2004). Six *et al.* (2002) demonstrated that organic matter plays a critical role in stabilizing soil aggregates and protecting nutrients within soil structure. Batjes (1996) estimated global SOC stocks and emphasized their importance in maintaining soil fertility and ecosystem sustainability. Lehmann and Kleber (2015) further explained the chemical complexity of humus and its role in regulating nutrient cycling processes.

8.3.1.2.4 Salinity and Sodicity Properties

Salinity and sodicity are key chemical constraints affecting soil fertility and crop productivity. Salinity, indicated by electrical conductivity, influences osmotic potential and restricts water uptake by plants. Munns and Tester (2008) demonstrated that high salinity conditions impair plant physiological processes, leading to reduced growth and yield. Szabolcs (1989) highlighted the global significance of salinity as a major factor limiting agricultural productivity.

Sodicity, measured through sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP), adversely affects soil structure and permeability. Rengasamy (2006) reported that high sodium levels lead to clay dispersion, reduced infiltration, and poor aeration. Qadir *et al.* (2007) further emphasized that sodic soils exhibit degraded physical and chemical properties, limiting nutrient availability and plant growth.

8.3.1.2.5 Redox and Chemical Reactivity Properties

Redox potential (Eh) and buffering capacity are critical chemical properties regulating nutrient transformations and soil reactivity. Redox potential determines the oxidation–reduction status of soil, particularly in flooded or waterlogged conditions. Ponnamperuma (1972) demonstrated that redox reactions control the availability of nutrients such as nitrogen, phosphorus, iron, and sulfur in submerged soils. Reddy and DeLaune (2008) further explained that redox conditions influence biogeochemical cycling and nutrient transformations.

Chemical reactivity also affects the mobility and availability of heavy metals and other elements. Gambrell and Patrick (1981) reported that redox fluctuations alter the solubility and toxicity of metals in soil systems. Buffering capacity, as described by Fageria and Baligar (2001), enables soils to resist changes in pH and maintain chemical equilibrium, which is essential for sustaining nutrient availability.

8.3.1.2.6 Role of Soil Chemical Properties in Soil Fertility

Soil chemical properties directly determine the availability, retention, and transformation of nutrients within the soil system, thereby controlling soil fertility and crop productivity. Soil pH acts as a master variable influencing nutrient solubility and microbial activity, with optimal pH conditions enhancing nutrient uptake efficiency (Brady and Weil, 2008; Rengel, 2011). Deviations from optimal pH lead to nutrient imbalances, including deficiencies of essential elements or toxicities of metals such as aluminum and manganese (Fageria, 2009; Marschner, 2012).

Cation exchange capacity (CEC) plays a fundamental role in nutrient retention and supply. Soils with higher CEC can hold greater quantities of exchangeable nutrients and release them gradually to plants, thereby improving nutrient use efficiency (Sumner and Noble, 2003). Soil organic carbon significantly contributes to CEC and enhances nutrient buffering, reducing losses through leaching and volatilization (Lal, 2004). Stevenson (1994) emphasized that organic matter acts as both a nutrient reservoir and a stabilizing agent for soil chemical processes.

Salinity and sodicity exert strong control over soil fertility by influencing osmotic potential and soil structure. Elevated salinity reduces water availability to plants and interferes with nutrient uptake, while sodicity degrades soil structure and limits aeration and permeability (Richards, 1954; Rengasamy, 2006; Qadir *et al.*, 2007). Munns and Tester (2008) demonstrated that salinity stress significantly reduces plant growth and yield by disrupting physiological processes.

Redox potential regulates nutrient transformations and availability, particularly in flooded soils. Reddy and DeLaune (2008) showed that redox conditions control nitrogen transformations such as nitrification and denitrification, as well as the availability of phosphorus and sulfur. Gambrell and Patrick (1981) further noted that redox dynamics influence the mobility and toxicity of heavy metals, affecting plant health and soil quality.

Overall, soil chemical properties regulate nutrient dynamics, chemical balance, and biological activity, thereby influencing soil fertility and productivity.

8.3.1.3 Biological Soil Health Indicators

Biological soil health indicators are among the most responsive components of soil systems under climate change because microbial activity, enzyme dynamics, and soil respiration are directly regulated by temperature and moisture conditions. These indicators provide early signals of soil degradation, carbon turnover, and ecosystem resilience.

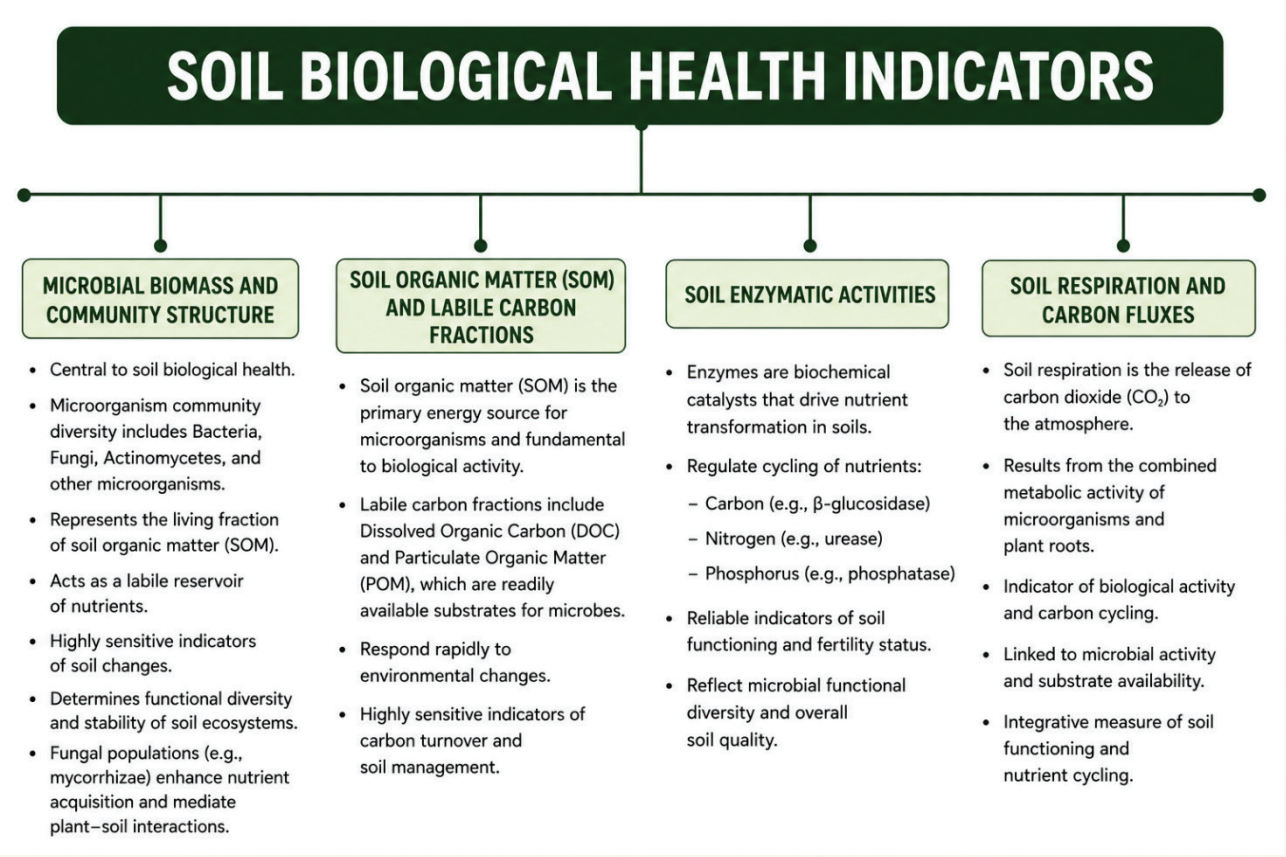
Soil biological health indicators are a dynamic and integral component of soil health, playing a central role in sustaining soil fertility through nutrient cycling, organic matter decomposition, and energy flow within the soil ecosystem. Soil biota—including microorganisms, soil fauna, and plant roots—drive key biochemical processes that regulate the transformation, availability, and retention of essential nutrients. Early work by Cavendish (1780s) and Boussingault (1830–1860) established the biological basis of nitrogen transformations, while Stevenson and Cole (2008) and Bardgett and Wardle (2010) further emphasized the importance of soil organisms in biogeochemical cycling, ecosystem stability, and plant productivity.

Microbial biomass, the active fraction of soil organic matter, serves as a reservoir of nutrients by immobilizing and releasing elements such as nitrogen, phosphorus, and sulfur through mineralization (Bonde *et al.*, 1988; Saha and Mandal, 2009). Microbial diversity enhances ecosystem stability and nutrient cycling efficiency (Bardgett and Wardle, 2010). Soil organic matter (SOM) supports microbial activity by supplying energy and nutrients, while labile carbon fractions provide readily available substrates for rapid microbial metabolism (Weil and Magdoff, 2004; Haynes, 2008; Post and Kwon, 2000; Wagai *et al.*, 2009).

Soil enzymes play a key role in biochemical transformations by breaking down complex organic compounds into plant-available forms. Sinsabaugh (2010) and Dick *et al.* (1994, 1996) demonstrated strong links between enzyme activity, nutrient cycling, and soil fertility. Soil respiration acts as an integrative indicator of microbial activity and organic matter decomposition, reflecting carbon turnover and nutrient release (Anderson, 1992; Waldrop *et al.*, 2003; Gregorich *et al.*, 1994).

Plant–microbe interactions, particularly mycorrhizal associations, enhance nutrient uptake and strengthen plant–soil relationships. Studies by Jeffries *et al.* (2003), Abbott and Johnson (2017), and Laliberté *et al.* (2012) highlight their role in improving phosphorus acquisition, reducing nutrient losses, and increasing ecosystem resilience.

8.3.1.3.1 Classification of Soil Biological Health Indicators



Soil biological properties have been systematically classified into four major sub-groups based on their functional roles and ecological significance, as illustrated in Fig. 5.

8.3.1.3.2 Microbial Biomass and Community Structure

Microbial biomass represents the living fraction of soil organic matter and serves as a key indicator of soil biological activity and fertility. Bonde *et al.* (1988) described microbial biomass as a labile reservoir of nutrients, playing a crucial role in nutrient immobilization and mineralization. Saha and Mandal (2009) further emphasized that microbial biomass carbon (MBC), nitrogen (MBN), and phosphorus (MBP) are sensitive indicators of soil fertility changes.

Microbial community composition, including bacteria, fungi, and actinomycetes, determines the functional diversity and stability of soil ecosystems. Bardgett and Wardle (2010) reported that diverse microbial communities enhance decomposition processes and nutrient cycling efficiency. Fungal populations, particularly mycorrhizae, play a significant role in nutrient acquisition and plant–soil interactions (Jeffries *et al.*, 2003; Abbott and Johnson, 2017).

8.3.1.3.3 Soil Organic Matter and Labile Carbon Fractions

Soil organic matter (SOM) provides the primary energy source for soil microorganisms and is fundamental to biological activity. Weil and Magdoff (2004) and Haynes (2008) highlighted SOM as a critical determinant of soil fertility, supporting microbial growth and nutrient cycling. Labile carbon fractions, including dissolved organic carbon and particulate organic matter, are particularly important as they serve as readily available substrates for microbial metabolism.

Post and Kwon (2000) and Wagai *et al.* (2009) reported that labile SOM fractions respond rapidly to environmental changes and are closely linked to microbial activity and nutrient mineralization. Knorr *et al.* (2005) emphasized that these fractions are highly sensitive and play a key role in regulating carbon turnover.

8.3.1.3.4 Soil Enzymatic Activities

Soil enzymes are biochemical catalysts that mediate essential nutrient transformation processes within the soil system. Sinsabaugh (2010) reported that enzymes such as β-glucosidase, urease, and phosphatase regulate the cycling of carbon, nitrogen, and phosphorus, respectively. Dick *et al.* (1994, 1996) demonstrated that enzyme activities are reliable indicators of soil biological functioning and are closely associated with soil fertility status.

Garcia-Ruiz *et al.* (2009) further emphasized that enzyme activity reflects microbial functional diversity and soil quality. Enzyme-mediated processes control the rate of organic matter decomposition and nutrient release, thereby directly influencing nutrient availability to plants.

8.3.1.3.5 Soil Respiration and Carbon Fluxes

Soil respiration represents the combined metabolic activity of soil microorganisms and plant roots, serving as a key indicator of biological activity and carbon cycling. Anderson (1992) highlighted that soil respiration reflects the decomposition of organic matter and the release of carbon dioxide (CO_2) into the atmosphere. Waldrop *et al.* (2003) further demonstrated that respiration rates are closely linked to microbial activity and substrate availability.

Gregorich *et al.* (1994) emphasized that soil respiration is influenced by the quantity and quality of organic matter, as well as environmental conditions. It serves as an integrative measure of soil biological functioning and nutrient cycling dynamics.

8.3.1.3.6 Role of Soil Biological Health Indicators

Soil biological health indicators play a central role in sustaining soil fertility by regulating nutrient cycling, organic matter decomposition, and energy flow within the soil ecosystem. Microbial biomass acts as a dynamic reservoir of nutrients, immobilizing and releasing essential elements such as nitrogen, phosphorus, and sulfur through mineralization processes (Bonde *et al.*, 1988; Saha and Mandal, 2009). Bardgett and Wardle (2010) emphasized that microbial diversity enhances ecosystem stability and improves nutrient cycling efficiency, thereby supporting plant growth.

Soil organic matter provides both energy and nutrients for microbial communities, facilitating continuous nutrient turnover. Weil and Magdoff (2004) and Haynes (2008) highlighted that SOM supports microbial activity and enhances nutrient availability. Labile carbon fractions, as reported by Post and Kwon (2000) and Wagai *et al.* (2009), are particularly important for rapid nutrient mineralization and microbial growth.

Soil enzymes regulate biochemical reactions essential for nutrient transformations. Sinsabaugh (2010) demonstrated that enzyme activity controls the breakdown of complex organic compounds into plant-available forms. Dick *et al.* (1994, 1996) further reported that enzyme activities are closely linked to soil fertility and productivity.

Soil respiration reflects the intensity of biological activity and organic matter decomposition. Anderson (1992) and Waldrop *et al.* (2003) emphasized that respiration is directly associated with carbon turnover and nutrient release. Gregorich *et al.* (1994) noted that higher respiration rates indicate active microbial processes, which contribute to nutrient availability and soil fertility.

Additionally, plant–microbe interactions, particularly mycorrhizal associations, enhance nutrient uptake and improve soil structure. Jeffries *et al.* (2003) and Abbott and Johnson (2017) highlighted the role of symbiotic relationships in improving phosphorus uptake and reducing nutrient losses. Laliberte *et al.* (2012) further emphasized that microbial interactions contribute to ecosystem resilience and sustainability.

Overall, soil biological properties regulate nutrient dynamics, organic matter turnover, and microbial activity, thereby supporting soil fertility and productivity.

8.4. SOIL SUSTAINABILITY CHALLENGES UNDER CLIMATE CHANGE

Climate change influences soil health indicators through complex interactions among warming, altered precipitation regimes, elevated atmospheric CO_2 concentrations, and increasing climatic extremes. The magnitude and direction of these impacts vary across soil types, land-use systems, and environmental conditions, but collectively they affect soil fertility, carbon sequestration, biological activity, and long-term sustainability.

8.4.1. Challenges to Physical Soil Health Indicators

Climate change significantly alters soil physical properties through changes in temperature regimes, precipitation patterns, and the frequency of extreme weather events. These changes directly influence soil structure, porosity, bulk density, and water dynamics.

Rising temperatures and reduced soil organic carbon (SOC) lead to increased soil compaction and bulk density, thereby restricting root growth and reducing aeration (Lal, 2019; Chen *et al.*, 2024). High-intensity rainfall accelerates soil erosion, selectively removing finer particles (clay and silt), resulting in coarser soil texture and reduced water-holding capacity (Lal, 2019; Purakayastha *et al.*, 2012). Conversely, prolonged drought conditions enhance soil hardening and surface crusting, further limiting infiltration and seedling emergence.

Soil structural stability is particularly vulnerable to climate variability. Repeated wetting–drying and freeze–thaw cycles weaken soil aggregates and reduce aggregate stability due to SOC depletion (Yang *et al.*, 2024; Sünnemann *et al.*, 2023). This leads to decreased porosity and disrupted pore connectivity, impairing water infiltration and gas exchange (Robinson *et al.*, 2022). Loss of vegetation cover under climate stress further exacerbates structural degradation (Blanco-Canqui and Ruis, 2020).

Soil water dynamics are highly sensitive to climatic shifts. Increased evapotranspiration reduces soil moisture availability, while extreme rainfall events cause runoff, surface sealing, and reduced infiltration (Lal, 2019). Climate-induced variability in hydraulic conductivity and water retention leads to inconsistent water supply for crops (Wang *et al.*, 2021; Zhang *et al.*, 2021). Additionally, subsurface compaction patterns influenced by climate stress restrict rooting depth and limit plant access to water and nutrients (Pathirana *et al.*, 2024).

8.4.2. Challenges to Chemical Soil Health Indicators

Soil chemical properties are profoundly affected by climate change through alterations in temperature, moisture regimes, and atmospheric CO_2 concentrations. These changes influence soil organic carbon dynamics, nutrient cycling, pH balance, and salinity.

One of the most critical impacts is the accelerated decomposition of soil organic matter (SOM) under warming conditions, leading to significant losses of SOC (Kirschbaum, 1995; Davidson and Janssens, 2006; Dijkstra *et al.*, 2022). Changes in precipitation patterns further regulate SOC

stabilization and loss, with drought reducing carbon inputs and heavy rainfall enhancing leaching (Zou *et al.*, 2024).

Nitrogen cycling is highly sensitive to climate change. Elevated temperatures enhance mineralization but also increase nitrogen losses through leaching, volatilization, and denitrification, thereby reducing nitrogen-use efficiency (Liu *et al.*, 2017; Miller and Geisseler, 2018). Alterations in carbon-to-nitrogen (C:N) and nitrogen-to-phosphorus (N:P) ratios disrupt nutrient balance and microbial functioning (Xu *et al.*, 2020).

Soil pH and salinity are also significantly impacted. Increased rainfall leads to leaching of base cations, causing soil acidification, while drought conditions promote salt accumulation and salinity stress (Reth, 2005; Qadir *et al.*, 2007). Flooding alters soil redox potential, affecting nutrient transformations and increasing the mobility of toxic elements (Reddy and DeLaune, 2008; Gambrell and Patrick, 1981).

Furthermore, climate change enhances greenhouse gas emissions from soils. Increased microbial respiration releases CO_2, while intensified nitrogen cycling contributes to N_2O emissions, creating positive feedback loops that exacerbate global warming (Rustad *et al.*, 2001; Smith *et al.*, 2015).

8.4.3. Challenges to Biological Soil Health Indicators

Soil biological properties, particularly microbial biomass and diversity, are highly sensitive to climate change. Temperature increases, moisture stress, and altered substrate availability collectively regulate microbial activity and ecosystem functioning.

Warming accelerates SOM decomposition, reducing the availability of labile carbon substrates necessary for microbial growth (Kirschbaum, 1995; Knorr *et al.*, 2005). Consequently, microbial biomass often declines under combined heat and drought stress (Basińska *et al.*, 2020; Bastida *et al.*, 2021).

However, microbial responses are context-dependent. Under favorable moisture and nutrient conditions, microbial biomass may increase due to enhanced plant productivity and substrate inputs (Reed *et al.*, 2020; Castro *et al.*, 2010). Indirect drivers such as vegetation dynamics, soil moisture, and organic inputs often dominate microbial responses to climate change (Kuzyakov *et al.*, 2019).

Fungal communities, particularly mycorrhizae, exhibit greater resilience compared to bacteria and play a crucial role in maintaining nutrient uptake and soil structure under climate stress (Abbott and Johnson, 2017; Martínez-García *et al.*, 2017).

Soil respiration, a key biological process, increases with temperature due to enhanced microbial metabolism, resulting in higher CO_2 emissions and loss of soil carbon (Wixon and Balser, 2009; Nissan *et al.*, 2023).

8.4.4. Climate-Induced Challenges to Soil Enzymatic Activities

Soil enzymes are highly sensitive indicators of climate change as they directly regulate biochemical processes involved in nutrient cycling. Enzymes such as β-glucosidase, urease, phosphatase, and dehydrogenase play critical roles in carbon, nitrogen, and phosphorus transformations.

Climate change affects enzyme activity primarily through temperature and moisture variations. Moderate warming can initially enhance enzyme activity by increasing microbial metabolism; however, prolonged warming and substrate depletion ultimately reduce enzyme production (Sinsabaugh, 2010; Davidson and Janssens, 2006). Drought conditions limit enzyme activity by

reducing microbial activity and substrate diffusion, while excessive moisture or flooding can create anaerobic conditions that suppress oxidative enzymes (Garcia-Ruiz *et al.*, 2009).

Empirical studies show variable responses of enzymes under climate stress. Girija Veni *et al.* (2020) and Daunoras *et al.* (2024) reported that β-glucosidase and phosphatase activities decline under prolonged warming and moisture stress, indicating reduced carbon and phosphorus cycling.

Soil enzyme activity is also closely linked to SOC and microbial biomass. Declines in organic matter reduce enzyme stabilization and persistence in soil (Dick *et al.*, 1994, 1996). However, adaptive management practices such as biochar application and organic amendments can enhance enzyme stability and activity under climate stress (Mahmoud *et al.*, 2019).

8.5. CONCLUSION

Climate change is increasingly influencing soil health indicators through complex interactions involving temperature rise, altered precipitation regimes, carbon dynamics, nutrient transformations, and biological activity. Physical, chemical, and biological soil properties respond differently to climatic stress; however, their interactions collectively determine soil fertility, ecosystem resilience, and long-term sustainability. The observed trends in soil degradation, declining soil organic carbon, altered microbial functioning, and disruptions in nutrient cycling highlight the urgent need for climate-resilient soil management strategies. Integrated assessment of soil health indicators provides a scientific basis for monitoring soil responses, improving adaptive management, and sustaining agricultural productivity under changing environmental conditions.

8.6. REFERENCES

Abbott, L.K. and Johnson, N.C. (2017). Interactions between arbuscular mycorrhizal fungi and soil microbial communities. *Mycorrhizal Mediation of Soil*. Elsevier, pp. 105–132.

Anderson, J.P.E. (1992). Soil respiration. *Methods of Soil Analysis, Part 2*. American Society of Agronomy, Madison, WI, pp. 831–871.

Baldock, J.A. and Skjemstad, J.O. (2000). Role of the soil matrix and minerals in protecting natural organic materials against biological attack. *Organic Geochemistry*, 31, 697–710.

Bardgett, R.D. and Wardle, D.A. (2010). *Aboveground–Belowground Linkages: Biotic Interactions, Ecosystem Processes, and Global Change*. Oxford University Press.

Basińska, A.M. *et al.* (2020). Climate change effects on soil microbial communities and enzyme activities. *Applied Soil Ecology*, 156, 103701.

Bastida, F. *et al.* (2021). Climate-sensitive soil microbial indicators under global warming scenarios. *Soil Biology and Biochemistry*, 152, 108–120.

Batjes, N.H. (1996). Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science*, 47, 151–163.

Bengough, A.G. *et al.* (2011). Root elongation, water stress, and mechanical impedance. *Plant and Soil*, 339, 19–38.

Blanco-Canqui, H. and Ruis, S.J. (2020). No-tillage and soil physical environment. *Geoderma*, 326, 164–200.

Bonde, T.A. *et al.* (1988). Microbial biomass as a fraction of potentially mineralizable nitrogen. *Soil Biology and Biochemistry*, 20, 447–452.

Boussingault, J.B. (1838). Recherches chimiques sur la végétation, entreprises dans le but d'examiner si les plantes prennent de l'azote à l'atmosphère. *Annales de Chimie et de Physique*, 67, 5–54.

Brady, N.C. and Weil, R.R. (2008). *The Nature and Properties of Soils* (14th ed.). Pearson Education.

Brady, N.C. and Weil, R.R. (2017). *The Nature and Properties of Soils* (15th ed.). Pearson Education.

Bünemann, E.K. *et al.* (2018). Soil quality – A critical review. *Soil Biology and Biochemistry*, 120, 105–125.

Burns, R.G. (1982). Enzyme activity in soil: Location and a possible role in microbial ecology. *Soil Biology and Biochemistry*, 14, 423–427.

Castro, H.F. *et al.* (2010). Soil microbial responses to warming and moisture change. *Global Change Biology*, 16, 163–176.

Cavendish, H. (1785). Experiments on Air. *Philosophical Transactions of the Royal Society of London*, 75, 372–384.

Chen, G. *et al.* (2014). Relationship between soil organic carbon and bulk density. *Soil Science Society of America Journal*, 78, 840–849.

Chen, X. *et al.* (2024). Climate warming impacts on soil compaction and bulk density. *Geoderma*, 445, 116–130.

Daunoras, J. *et al.* (2024). Soil enzymatic responses to changing climate conditions. *Applied Soil Ecology*, 195, 105–122.

Davidson, E.A. and Janssens, I.A. (2006). Temperature sensitivity of soil carbon decomposition and feedbacks to climate change. *Nature*, 440, 165–173.

Dexter, A.R. (2004). Soil physical quality. Part I: Theory, effects of soil texture, density, and organic matter. *Geoderma*, 120, 201–214.

Dick, R.P. (1994). Soil enzyme activities as indicators of soil quality. *Defining Soil Quality for a Sustainable Environment*. SSSA Special Publication No. 35, pp. 107–124.

Dick, R.P. *et al.* (1996). Soil enzyme activities and biodiversity measurements as integrative microbiological indicators. *Methods for Assessing Soil Quality*, SSSA Special Publication 49, pp. 247–271.

Dijkstra, F.A. *et al.* (2022). Soil carbon dynamics under warming climates. *Global Change Biology*, 28, 1145–1162.

Doran, J.W. and Safley, M. (1997). Defining and assessing soil health and sustainable productivity. *Biological Indicators of Soil Health*. CAB International, pp. 1–28.

Fageria, N.K. (2009). *The Use of Nutrients in Crop Plants*. CRC Press.

Fageria, N.K. and Baligar, V.C. (2001). Lowland rice response to soil acidity. *Communications in Soil Science and Plant Analysis*, 32, 1405–1417.

Friedlingstein, P. *et al.* (2020). Global Carbon Budget 2020. *Earth System Science Data*, 12, 3269–3340.

Gambrell, R.P. and Patrick, W.H. (1981). Chemical and microbiological properties of anaerobic soils. *Flooded Soils and Sediments*. Ann Arbor Science Publishers, pp. 375–423.

Garcia-Ruiz, R. *et al.* (2009). Soil enzyme activities under changing environmental conditions. *Soil Biology and Biochemistry*, 41, 112–121.

Girija Veni, V. *et al.* (2020). Impact of climate variability on soil enzymatic activities and SOC dynamics. *Journal of Environmental Biology*, 41, 1354–1362.

Gregorich, E.G. *et al.* (1994). Towards a minimum data set to assess soil organic matter quality. *Canadian Journal of Soil Science*, 74, 367–385.

Gregory, P.J. (2006). Roots, rhizosphere and soil: The route to a better understanding of soil science? *European Journal of Soil Science*, 57, 2–12.

Hamza, M.A. and Anderson, W.K. (2005). Soil compaction in cropping systems. *Soil and Tillage Research*, 82, 121–145.

Haynes, R.J. (2008). Labile organic matter fractions as indicators of soil organic matter quality. *Soil Biology and Biochemistry*, 40, 2249–2252.

Hillel, D. (2004). *Introduction to Environmental Soil Physics*. Elsevier Academic Press.

IPCC (2014). *Climate Change 2014: Impacts, Adaptation, and Vulnerability*. Cambridge University Press.

IPCC (2021). *Climate Change 2021: The Physical Science Basis*. Cambridge University Press.

IPCC (2022). *Climate Change 2022: Mitigation of Climate Change*. Cambridge University Press.

Jeffries, P. *et al.* (2003). The contribution of arbuscular mycorrhizal fungi in sustainable maintenance of plant health and soil fertility. *Biology and Fertility of Soils*, 37, 1–16.

Jenny, H. (1941). *Factors of Soil Formation*. McGraw-Hill.

Jenny, H. (1994). *Factors of Soil Formation: A System of Quantitative Pedology*. Dover Publications.

Karlen, D.L. *et al.* (2003). Soil quality: Why and how? *Geoderma*, 114, 145–156.

Kirschbaum, M.U.F. (1995). The temperature dependence of soil organic matter decomposition. *Soil Biology and Biochemistry*, 27, 753–760.

Knorr, W. *et al.* (2005). Long-term sensitivity of soil carbon turnover to warming. *Nature*, 433, 298–301.

Kuzyakov, Y. *et al.* (2019). Review and synthesis of microbial responses to climate change. *Global Change Biology*, 25, 3573–3590.

Lal, R. (2000). Soil management and restoration for C sequestration. *Soil and Tillage Research*, 53, 185–199.

Lal, R. (2003). Soil erosion and the global carbon budget. *Environment International*, 29, 437–450.

Lal, R. (2004). Soil carbon sequestration impacts on global climate change and food security. *Science*, 304, 1623–1627.

Lal, R. (2019). Climate change and soil degradation mitigation by sustainable management. *Journal of Soil and Water Conservation*, 74, 55A–62A.

Lehmann, J. and Kleber, M. (2015). The contentious nature of soil organic matter. *Nature*, 528, 60–68.

Lehmann, J. *et al.* (2020). Soil health and ecosystem functioning. *Nature Reviews Earth & Environment*, 1, 544–553.

Lipiec, J. *et al.* (2012). Soil compaction and its effects on crop growth. *International Agrophysics*, 26, 313–319.

Liu, X. *et al.* (2017). Climate change effects on nitrogen cycling. *Global Change Biology*, 23, 228–241.

Mahmoud, E. *et al.* (2019). Biochar impacts on soil enzymes and microbial activity. *Applied Soil Ecology*, 137, 130–140.

Marschner, P. (2012). *Marschner's Mineral Nutrition of Higher Plants* (3rd ed.). Academic Press.

Martínez-García, L.B. *et al.* (2017). Fungal resilience to climate change. *Ecology Letters*, 20, 123–135.

Miller, K.S. and Geisseler, D. (2018). Temperature impacts on nitrogen cycling. *Agronomy Journal*, 110, 123–135.

Munns, R. and Tester, M. (2008). Mechanisms of salinity tolerance. *Annual Review of Plant Biology*, 59, 651–681.

Nannipieri, P. *et al.* (2017). Soil enzymology: Classical and molecular approaches. *Biology and Fertility of Soils*, 48, 743–762.

Pathirana, U.P. *et al.* (2024). Climate-induced subsurface compaction and root restriction. *Soil Use and Management*, 40, 145–158.

Ponnamperuma, F.N. (1972). The chemistry of submerged soils. *Advances in Agronomy*, 24, 29–96.

Post, W.M. and Kwon, K.C. (2000). Soil carbon sequestration and land-use change. *Global Change Biology*, 6, 317–327.

Purakayastha, T.J. *et al.* (2012). Climate change and soil erosion impacts. *Current Science*, 102, 1238–1247.

Qadir, M. *et al.* (2007). Sodicity and salinity management in agricultural soils. *Agricultural Water Management*, 87, 207–216.

Reddy, K.R. and DeLaune, R.D. (2008). *Biogeochemistry of Wetlands: Science and Applications*. CRC Press.

Reed, S.C. *et al.* (2020). Soil microbial responses under global environmental change. *Nature Reviews Microbiology*, 18, 221–236.

Rengasamy, P. (2006). World salinization with emphasis on Australia. *Journal of Experimental Botany*, 57, 1017–1023.

Rengel, Z. (2011). Soil pH, soil health and climate interactions. *Plant and Soil*, 344, 1–23.

Reth, S. (2005). Soil acidification under changing climate. *Global Change Biology*, 11, 162–172.

Richards, L.A. (1954). *Diagnosis and Improvement of Saline and Alkali Soils*. USDA Agriculture Handbook 60.

Rinot, O. *et al.* (2019). Soil health assessment frameworks. *Soil Use and Management*, 35, 114–130.

Robinson, D.A. *et al.* (2022). Soil pore connectivity and ecosystem functioning. *Vadose Zone Journal*, 21, e20189.

Rustad, L.E. *et al.* (2001). A meta-analysis of the response of soil respiration to experimental ecosystem warming. *Oecologia*, 126, 543–562.

Saha, S. and Mandal, B. (2009). Soil microbial biomass and activity in relation to fertility. *Soil Biology and Biochemistry*, 41, 123–131.

Saxton, K.E. and Rawls, W.J. (2006). Soil water characteristic estimates by texture and organic matter. *Soil Science Society of America Journal*, 70, 1569–1578.

Sinsabaugh, R.L. (2010). Phenol oxidase, peroxidase and organic matter dynamics. *Biogeochemistry*, 108, 1–13.

Six, J. *et al.* (2000). Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregate-associated carbon. *Soil Science Society of America Journal*, 64, 681–689.

Six, J. *et al.* (2002). Stabilization mechanisms of soil organic matter. *Plant and Soil*, 241, 155–176.

Smith, P. *et al.* (2015). Biogeochemical cycles and biodiversity as key drivers of ecosystem services. *Global Change Biology*, 21, 100–115.

Stevenson, F.J. (1994). *Humus Chemistry: Genesis, Composition, Reactions* (2nd ed.). Wiley.

Stevenson, F.J. and Cole, M.A. (2008). *Cycles of Soil: Carbon, Nitrogen, Phosphorus, Sulfur, Micronutrients* (2nd ed.). Wiley.

Sumner, M.E. and Noble, A.D. (2003). Soil acidification: The world story. *Handbook of Soil Acidity*. Marcel Dekker, pp. 1–28.

Sünnemann, M. *et al.* (2023). Freeze–thaw cycles and aggregate stability under climate change. *Geoderma*, 430, 116–128.

Szabolcs, I. (1989). *Salt-Affected Soils*. CRC Press.

Tisdall, J.M. and Oades, J.M. (1982). Organic matter and water-stable aggregates in soils. *Journal of Soil Science*, 33, 141–163.

Wagai, R. *et al.* (2009). The role of particulate organic matter in soil carbon dynamics. *Geoderma*, 149, 1–8.

Waldrop, M.P. *et al.* (2003). Alteration of soil microbial communities under elevated temperature. *Applied and Environmental Microbiology*, 69, 6076–6082.

Wang, Y. *et al.* (2021). Climate variability and soil hydraulic properties. *Agricultural Water Management*, 250, 106–118.

Weil, R.R. and Magdoff, F. (2004). Significance of soil organic matter to soil quality and health. *Soil Organic Matter in Sustainable Agriculture*. CRC Press, pp. 1–43.

Wixon, D.L. and Balser, T.C. (2009). Complexity, climate change and soil carbon: A systems approach. *Ecology Letters*, 12, 740–752.

Xu, X. *et al.* (2020). Climate change impacts on soil stoichiometry and nutrient balance. *Global Ecology and Biogeography*, 29, 1–15.

Yang, H. *et al.* (2024). Wetting–drying cycles and soil aggregate stability under climate stress. *Catena*, 236, 107–122.

Zhang, X. *et al.* (2021). Soil hydraulic conductivity under climate variability. *Hydrological Processes*, 35, e14123.

Zou, Y. *et al.* (2024). Precipitation variability and soil organic carbon stabilization. *Global Change Biology*, 30, e17045.

CHAPTER 9: ADVANCED SERICULTURE GENOMICS, GENETICS, AND TRANSCRIPTOMICS FOR CLIMATE CHANGE RESILIENCE AND MITIGATION

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9.1. INTRODUCTION

The global sericulture industry, an ancient agro-based cottage sector supporting millions of rural livelihoods, is experiencing unprecedented disruptions due to anthropogenic climate change (Ashrith *et al.,* 2025). Sericulture relies on a highly synchronized, bi-component biological system: the cultivation of the perennial host plant, mulberry (*Morus spp.*), and the rearing of the domesticated silkworm, *Bombyx mori*, both of which are highly sensitive to escalating global temperatures, erratic precipitation patterns, and extreme weather events (Sujatha *et al.*, 2024). To achieve long-term viability in silk production, research must focus on building climate-resilient silkworm breeds. This report evaluates the genetic and physiological vulnerabilities of *Bombyx mori*, examines molecular breeding and marker-assisted selection (MAS) tools for thermotolerance, analyses transcriptomic and proteomic cellular stress responses, and outlines frontier gene-editing technologies designed to develop hardy, high-yielding silkworm strains.

9.1.1. Domestication History, Biological Vulnerabilities, and Climate Disruption in Sericulture

The history of sericulture is deeply intertwined with human civilization, originating in ancient China around 3630 BCE. The domestication of *Bombyx mori* from its wild ancestor, *Bombyx mandarina*, represents a milestone in agricultural and biotechnological history (Sun *et al.*, 2012). Over five millennia of continuous human selection, silkworms underwent profound genetic and morphological changes to facilitate human handling. These selection pressures led to alterations in body coloration, increased cocoon size, the loss of flight ability, and a complete loss of natural self-defense mechanisms, leaving the species entirely reliant on human care for survival and reproduction. This intensive domestication has stripped *Bombyx mori* of its ancestral environmental resilience, making it highly sensitive to modern climatic fluctuations (Manjunatha *et al.,* 2010). The silkworm genome is relatively compact, consisting of approximately 4.8 x 10^8 bp, which is roughly one-sixth the size of the human genome (Bukhari and Bali, 2019). Despite this compact genomic architecture, its physiological complexity is highly constrained by its poikilothermic nature (Chandrakanth *et al.,* 2015). As poikilotherms, silkworms cannot regulate their internal body temperature; their metabolic, physiological, and developmental processes are entirely dependent on ambient conditions.

The optimal rearing temperature range for commercial silkworms is exceptionally narrow, spanning 25 °C to 26 °C Minor deviations below this threshold (20 °C to 21 °C) or above it (28 °C to 29 °C) trigger severe physiological distress. Heat shocks speed up larval stages, reduce larval weight, decrease feed intake, and lower food conversion efficiency, leading to a failure in cocoon and pupal formation. Rearing young instars (Chawki) requires a warmer, highly humid microclimate of 26 °C to 28 °C and 80% to 85% relative humidity (RH), whereas adult instars (late stages) are highly sensitive to thermal stress and must be maintained at a cooler 23 °C to 24 °C and 70% to 75% RH (Sujatha *et al.*, 2024).

Climate change also alters regional relative humidity profiles and precipitation patterns, directly influencing the epidemiology of silkworm pathogens. A positive relationship exists between

rising humidity levels and the occurrence of viral, bacterial, and fungal infections (Sujatha *et al.,* 2024). Specifically, the incidence of *Bombyx mori* Nucleopolyhedrovirus (BmNPV), which causes grasserie disease, escalates under fluctuating temperature and humidity regimes, leading to devastating crop losses in tropical sericultural zones (Thaosen *et al.*, 2025). Because the larval fat body, the primary site of protein synthesis, energy storage, and immune response is located directly beneath the cuticle, ambient thermal spikes easily reach and damage this critical tissue, disrupting developmental synchronization and diminishing overall survival (Mousavi *et al.,* 2017; Hosseini Moghaddam *et al.,* 2008).

9.2. SILKWORM GERMPLASM DIVERSITY, VOLTINISM PROFILES, AND HYBRID BREEDING

The global germplasm of *Bombyx mori* represents a vital reservoir of genetic diversity, with more than 4,000 unique strains maintained across 46 international genetic resource institutes (Bukhari and Bali, 2019). In India, Central Sericultural Germplasm Resources Centre alone systematically conserves 490 diverse silkworm genetic stocks (Saha and Mondal, 2026). These genetic resources are broadly classified into univoltine, bivoltine, and polyvoltine (multivoltine) strains, which exhibit pronounced differences in qualitative, quantitative, and survival traits. Naturally occurring tropical multivoltine races (Pure Mysore or Nistari) are non-diapausing and have developed superior native thermotolerance and disease resistance through adaptation to hot, humid tropical climates (Manjunatha *et al.,* 2010). However, they produce low-quality silk characterized by short, greenish-yellow filaments. In contrast, temperate bivoltine breeds undergo embryonic diapause, achieve higher body weights, and secrete long, high-quality white silk, but are highly susceptible to thermal shock.

Historically, breeding programs in tropical regions relied on the introduction of hybrids utilizing a native multivoltine strain as the female parent to provide robust maternal resistance to high temperatures and diseases, and a temperate bivoltine strain as the male parent to improve the length and quality of the spun silk (Manjunatha *et al.,* 2010). In eastern India, specifically West Bengal, the foundation crosses SK6 x SK7 and their reciprocals are reared during unfavorable seasons because they maintain stable, albeit moderate, productivity under adverse climatic conditions (Chandrakanth, 2025).

To transition toward year-round bivoltine silk production, researchers are conducting thermal screening experiments on germplasm collections to isolate resilient pure lines (Chandrakanth, 2025). At SKUAST-Jammu, completely randomized design (CRD) trials under elevated temperature regimes identified ND5, U-4, U-6, and U-3 as elite heat-tolerant pure lines. These breeds maintain high pupation rates, stable cocoon traits, and excellent filament denier under thermal stress (Sharma and Bali, 2026).

Similarly, selective breeding has yielded thermotolerant bivoltine strains like BD2-S, SOF-BR, and BO2 (Sugnana Kumari *et al.*, 2011). These strains were developed by subjecting fifth-instar larvae to systematic thermal stress (36 ± 1 °C for 6 hours daily from the third day of the instar until spinning) and selecting individuals based on larval weight, cocoon yield, pupation rate, single cocoon weight, shell ratio, filament length, and denier. Another successful breeding milestone is the tropical bivoltine double hybrid Chamaraja (CSR50 x CSR51), developed specifically to sustain high cocoon productivity in warm, tropical environments (Sharma and Bali, 2026).

The long-standing bivoltine hybrid SH6 × NB4D2 has remained popular across North and North-West India, because of its stable performance across the region, but climate change now requires

hybrids that are better tuned to seasonal stress. Autumn-specific hybrids such as ASH-14 (Developed by Shivkumar *et al.*, 2024) demonstrate how season-focused breeding can improve productivity under fluctuating temperature and humidity. Nutrigenetic hybrids (Murali *et al.,* 2024) such as CSR50 × BCon4, CSR50 × BCon1, and RSJ14 × BCon1 further indicate the value of improving nutrient conversion efficiency when leaf quality becomes unstable (Bhardwaj *et al.*, 2026).

9.3. TRANSCRIPTOMICS OF CELL STRESS CHAPERONES

At the cellular level, the primary defense mechanism of *Bombyx mori* against thermal stress is the rapid, coordinated synthesis of heat shock proteins (HSPs) (Chandrakanth *et al.,* 2025). These molecular chaperones bind to denaturing polypeptides, prevent their aggregation, and assist in protein refolding to preserve cellular homeostasis during proteotoxic stress. The HSP family in *Bombyx mori* is divided into major categories based on molecular weight, including the small heat shock proteins (sHSPs, 19 to 30 kDa), HSP60, HSP70, and HSP90 (Xiao *et al.*, 2025).

The 70 kDa family is further classified into constitutively expressed heat shock cognates (five HSC70 genes) and stress-inducible forms (four HSP70 genes) (Hsp70 genome-wide, 2021). Under thermal (37 °C and 42 °C) or cold (2 °C) stress, the stress-inducible genes *HSP70-1*, *HSP70-2*, and *HSP70-3* are heavily upregulated, showing transcriptional increases of up to 4147.3-fold, 607.1-fold, and 1987.3-fold, respectively, to protect cellular integrity. Conversely, heat shock cognate genes (except *HSC70-2*) maintain constitutively high expression across various developmental stages, acting as housekeeping molecular chaperones (Fang *et al.,* 2021).

Real-time qPCR profiling has revealed that the upregulation of these chaperone genes is highly tissue-specific. The fat body exhibits the highest level of transcription, followed by the midgut and the silk glands. In comparative studies involving Nistari (tolerant), SK4C (moderately tolerant), and CSR2 (susceptible), the expression levels of these chaperones directly correlated with larval survival rates. Following a 1-hour heat shock at 36 °C and a subsequent 2-hour recovery period, Nistari exhibited a 10.3-fold and 9.7-fold increase in the transcription of *sHsp20.4* and *sHsp20.1*, respectively, along with a 2.3-fold increase in *Hsp70* compared to CSR2. The moderately tolerant SK4C showed moderate increases, with a 3.5-fold and 2.3-fold upregulation of *sHsp20.4* and *sHsp20.1*, and a 1.5-fold increase in *Hsp70* compared to CSR2 (Chandrakanth *et al.*, 2025).

Highly sensitive hybrids, particularly those with Japanese maternal parentage, demonstrate erratic and excessive upregulation of *HSP70* and *HSP90* under prolonged thermal stress (39 °C for 8 hours). This over-activation represents a last-ditch cellular survival response that often fails, leading to high mortality (Mousavi *et al.*, 2017).

Furthermore, fat body proteomic analyses under severe thermal stress (45 °C) reveal a complex physiological dynamic, while sHSPs (including HSP19.9, HSP20.1, HSP20.4, HSP20.8, and HSP21.4) accumulate rapidly under moderate thermal stress (41 °C), their protein spot intensity is significantly lower in tolerant multivoltines than in susceptible bivoltines under severe 45 °C heat shock. Meanwhile, the expression of HSP70 remains highly stable in the multivoltine fat body. This indicates that while HSP70 serves as a consistent chaperone under extreme stress, alternative molecular mechanisms, such as zinc finger proteins involved in DNA repair and transcriptional regulation play a vital role in the survival of tolerant multivoltine breeds (Hosseini Moghaddam *et al.*, 2008).

HSP and metabolomic upregulations are also critical in the embryonic stages of *Bombyx mori*. While standard industrial treatment to break diapause involves immersing silkworm eggs in a 1.075 g/mL hydrochloric acid solution at 46 °C for 5 minutes, raising the temperature and duration to

47.5 °C for 7 minutes not only prevents diapause but also inactivates *Nosema bombycis* in the eggs. During this high-temperature acid treatment, the up-regulation of *Hsp19.3*, *Hsp20*, *HSP60*, *HSP70*, and *HSP90* genes, alongside elevated concentrations of small peptides, γ-linolenic acid, and triglycerides, protects the developing embryos from high-temperature stress and associated oxidative damage (Xiao *et al.,* 2025).

9.4. MARKER-ASSISTED SELECTION (MAS) AND QTL MAPPING

Because thermotolerance is a polygenic trait governed by multiple quantitative trait loci (QTLs), conventional phenotypic selection often fails to yield stable, heat-resistant, high-producing bivoltine lines. To address this challenge, marker-assisted selection (MAS) is being integrated into silkworm breeding programs. A key breakthrough identified five microsatellite (SSR/ISSR) DNA markers closely linked to thermotolerance on the 8th chromosome of *Bombyx mori* (Chandrakanth *et al.,* 2015).

In breeding programs, donor parents exhibiting high pupation rates under extreme experimental stress (36±1 °C and 85±5% RH) and possessing the characteristic thermotolerant banding patterns are crossed with highly productive but temperature-susceptible recurrent parents. Through sequential backcrossing and inbreeding, MAS is utilized in each generation to track the inheritance of the 8th chromosome alleles alongside newly identified markers on other chromosomes. This strategy ensures the precise introgressive hybridization of thermotolerance genes into elite bivoltine lines without compromising critical post-cocoon parameters like filament length, reelability, and denier (Chandrakanth *et al.,* 2015).

Further validation of SSR markers, such as *LFL329*, *LFL1123*, *S0809*, and *S0813*, has allowed researchers to screen large bivoltine germplasm resources and select elite accessions showing 87% to 100% thermotolerance. These include accessions spinning oval cocoons (KPG-A, SMGS-2, YS-7, DD-2) and dumbbell cocoons (NB4D2, APS-4, APS-8, DD-1, NK3, CSR26) (Maheswari *et al.*, 2023). MAS is also utilized to map QTLs and clone genes associated with high cocoon yield, disease resistance, and morphological traits. By using SSR and SNP markers, researchers have identified key loci on chromosomes 2, 3, 11, and 18 associated with economic traits like cocoon weight, shell percentage, and filament length (Ashrith *et al.,* 2025).

MAS is also successfully deployed in breeding disease-resistant strains. Resistance to the Zhenjiang strain of the densonucleosis virus (DNV-Z) is controlled by the recessive gene *nsd-Z* (non-susceptibility to DNV-Z) (Li *et al.,* 2013). By utilizing seven closely linked SSR markers (such as the *Fl0316* locus) as flanking molecular tags on either side of the *nsd-Z* locus, breeders successfully crossed the resistant but low-yielding L10 strain with the highly productive Jingsong commercial strain. Tracking these co-dominant SSR markers over six backcross generations ensured that the recessive resistance gene was successfully homozygous in the developed line without losing the superior cocoon traits of the recurrent parent.

Additionally, the development of sequence-characterized amplified region (SCAR) markers like *TT-PB1* has revolutionized the analysis of thermotolerance inheritance. These molecular tools are supplemented by genomic and transcriptomic resources accessible via online databases such as SilkDB, KAIKObase and SilkTransDB, facilitating faster, more precise molecular breeding cycles (Ashrith *et al.,* 2025).

9.5. FUNCTIONAL GENOMICS AND GENE EDITING TECHNOLOGIES

The development of CRISPR/Cas9 and CRISPR/Cas12a genome-editing technologies has accelerated the functional characterization and target manipulation of genes governing climate

resilience and industrial traits in *Bombyx mori* (Ashrith *et al.*, 2025). To systematically identify genes linked to heat resistance, researchers executed a genome-wide CRISPR/Cas9 screening coupled with high-throughput sequencing in BmN silkworm cells exposed to a critical thermal threshold of 37 °C. This temperature was selected after gradient assays showed that 35°C provided insufficient selective pressure, while 39 °C caused extensive cell death (Peng *et al.,* 2026) (Table 1).

The high-throughput screen mapped the subcellular localization of the identified heat-resistance genes, revealing their distribution across multiple cellular compartments: the nucleus (40.2%), cytoplasm (27.9%), cell membrane (14.1%), extracellular space (9.2%), and mitochondria (8.2%). This screen identified the *Bombyx mori* membrane-bound alkaline phosphatase-like (*BmM-ALP*) gene as a critical thermoregulator. Transgenic overexpression of *BmM-ALP* significantly enhances larval thermal tolerance and prolongs survival under extreme heat stress. The underlying mechanism of action is a pleiotropic protective cascade: *BmM-ALP* reduces the cellular accumulation of harmful reactive oxygen species (ROS), suppresses heat-induced apoptosis, and reprograms mitochondrial energy metabolism via the phosphorylation and regulation of Vitamin B1 metabolism, thereby maintaining energy homeostasis under stress (Peng *et al.,* 2026).

Another major functional gene identified is the *Bombyx mori* singed (*Bmsn*) gene, which is highly involved in fat body response to high-temperature stress. Overexpression of the *Bmsn* gene in transgenic silkworms promotes cell proliferation activity, reduces lipid oxidation, suppresses ROS accumulation, and repairs heat-induced DNA damage. The transgenic strain exhibits a significantly increased survival rate under heat shock and produces a higher cocoon shell layer quantity, providing a robust candidate for climate adaptation (Liu *et al.,* 2024).

Table 1. Summary of Targeted Genetic Modifications and Corresponding Physiological Outcomes in *Bombyx mori*

Targeted Gene	Gene Editing Platform	Subcellular/ Tissue Target	Cellular and Physiological Response	Applied Phenotypic Outcome	Key References
BmM-ALP	CRISPR/Cas9 Overexpression	Cell Membrane / Mitochondria	Reprograms mitochondrial energy metabolism; Vitamin B1 phosphorylation; reduces ROS.	High thermal tolerance; prolonged survival under heat shock.	(Peng *et al.,* 2026)
Bmsn	CRISPR/Cas9 Overexpression	Fat Body Cells	Promotes cell proliferation; repairs DNA damage; suppresses ROS accumulation.	Significantly higher larval survival and increased cocoon layer quantity under heat.	(Liu *et al.,* 2024)
BmEcKL1	CRISPR/Cas9 Knockout	Middle and Posterior Silk Glands	Prevents ecdysteroid-mediated apoptosis and autophagy under environmental stress.	Promotes silk gland cell growth and increases total silk protein synthesis.	(Li *et al.,* 2024)

Targeted Gene	Gene Editing Platform	Subcellular/ Tissue Target	Cellular and Physiological Response	Applied Phenotypic Outcome	Key References
ie-1	CRISPR/Cas12a Knockout	Viral BmNPV Genome	Generates specific double-strand breaks causing large fragment genomic deletions in the virus.	1,000-fold increase in antiviral resistance compared to wild-type.	Dong *et al.* (2020)
FibH	CRISPR/Cas9 Gene Replacement	Silk Gland cells	Replaces repetitive crystalline regions with synthetic spider silk DNA via Homologous Recombination.	Production of hybrid spider-silk fibers with superior tensile strength and elasticity.	(Pack *et al.*, 2024)

CRISPR technologies are also deployed to target economic and developmental traits during thermal fluctuations. Autophagy and apoptosis in the larval silk gland are regulated by ecdysteroids. Disrupting the BmEcKL1 gene (an ecdysteroid kinase-like gene) specifically in the middle (MSGs) and posterior (PSGs) silk glands using CRISPR/Cas9 prevents ecdysteroid-mediated cellular apoptosis and autophagy during thermal fluctuations. This targeted knockout promotes silk gland cell growth and enhances overall silk protein synthesis, bypassing the developmental blocks caused by climate stress (Li *et al.,* 2024).

Furthermore, CRISPR is used to mitigate the climate-driven escalation of infectious diseases. Transgenic silkworm lines expressing the CRISPR/Cas12a (FnCas12a) system guided by crRNAs targeting the essential *ie-1* gene of the BmNPV virus have been engineered. This system achieves highly efficient, target-specific double-strand breaks in the viral genome, resulting in large fragment deletions that suppress viral replication. These transgenic hybrid lines exhibit up to a 1,000-fold increase in antiviral resistance compared to wild-type controls, outperforming traditional SpCas9 editing approaches and providing a biotechnological shield against pathogen outbreaks (Dong *et al.*, 2020).

Researchers are also using gene editing to replace the highly repetitive crystalline region of the fibroin heavy chain (*FibH*) gene with synthetic spider silk DNA sequences. By using guide RNAs to target specific double-strand breaks in *FibH* and introducing donor DNA vectors for homologous recombination (HR), transgenic silkworms have been engineered to spin hybrid spider-silk fibers with superior tensile strength and elasticity, opening new pathways for climate-resilient biomaterials (Pack *et al.,* 2024).

9.6. CONCLUSION

The rapid escalation of global temperatures and unpredictable climate patterns present an immediate threat to the environmental and developmental stability of *Bombyx mori*. To secure the future of global sericulture, the industry must transition from conventional phenotypic selection to precision molecular breeding. Integrating MAS to map QTLs, alongside advanced transcriptomic and proteomic profiling of tissue-specific HSPs across diverse germplasm, provides a robust framework to identify and select for native thermotolerance. Furthermore, frontier genome-editing tools like CRISPR/Cas9 and Cas12a offer unprecedented capabilities to target specific genetic pathways, overexpressing critical thermal regulators such as *BmM-ALP* and *Bmsn* while systematically knocking out pathogen susceptibility genes like *ie-1* or manipulating silk gland development via *BmEcKL1* knockout. By leveraging these genomic innovations, sericulture can build long-term biological resilience and ensure sustainable silk production under the ongoing challenges of global climate change.

9.7. REFERENCES

Ashrith, S., Pavithra, M. R., Jekinakatti, B., Shwetha, G. V., Nandha Kumar, R., Arun Kumar, M. R. and Suhas, B. V. (2025). Advances in molecular breeding and CRISPR-Cas9-mediated genome editing in silkworms: Applications and future prospects. *International Journal of Advanced Biochemistry Research*, *9*(8), 656–661. `

Bhardwaj, S., Roy, P., Naik, P., Saif, Z., Verma, J., Shabnam, A. A., Saini, P., Illahi, I. and Singh, S. (2026). *Climatic vulnerability and resilience in North and North-West Indian sericulture. Central Sericultural Research and Training Institute, Central Silk Board.* ISBN 978-81-997904-9-0.

Bukhari, R. and Bali, R. K. (2019). *Characterization of silkworm (Bombyx mori L.) breeds on the basis of morphological and molecular parameter*. *Journal of Emerging Technologies and Innovative Research (JETIR), 6*(6), 672–696.

Chandrakanth, N., Moorthy, S. M., Ponnuvel, K. M. and Sivaprasad, V. (2015). Identification of microsatellite markers linked to thermotolerance in silkworm by bulk segregant analysis and in silico mapping. *Genetika*, *47*(3), 1063–1078. https://doi.org/10.2298/GENSR1503063C.

Dong, Z., Qin, Q., Hu, Z., Zhang, X., Miao, J., Huang, L. and Pan, M. (2020). CRISPR/Cas12a mediated genome editing enhances *Bombyx mori* resistance to BmNPV. *Frontiers in Bioengineering and Biotechnology*, *8*, 841. https://doi.org/10.3389/fbioe.2020.00841/full.

Fang, S. M., Zhang, Q., Zhang, Y. L., Zhang, G. Z., Zhang, Z. and Yu, Q. Y. (2021). Heat shock protein 70 family in response to multiple abiotic stresses in the silkworm. *Insects*, *12*(10), 928.

Hossein Hosseini Moghaddam, S., Du, X., Li, J., Cao, J., Zhong, B. and Chen, Y. (2008). Proteome analysis on differentially expressed proteins of the fat body of two silkworm breeds, *Bombyx mori*, exposed to heat shock exposure. *Biotechnology and Bioprocess Engineering*, *13*(5), 624-631.

Li, S., Lao, J., Sun, Y., Hua, X., Lin, P., Wang, F. and Xia, Q. (2024). CRISPR/Cas9-mediated editing of BmEcKL1 gene sequence affected silk gland development of silkworms (*Bombyx mori*). *International Journal of Molecular Sciences*, *25*(3), 1907.

Liu, Z., Li, C., Yang, W., Wu, Q., Xiao, W., Zhu, Y., Wei, Q., Dong, Z., Zhang, G. and Lu, C. (2024). The *Bombyx mori* singed gene is involved in the high-temperature resistance of silkworms. *Insects*, *15*(4), 264. https://doi.org/10.3390/insects15040264.

Manjunatha, H. B., Rajesh, R. K. and Aparna, H. S. (2010). Silkworm thermal biology: A review of heat shock response, heat shock proteins and heat acclimation in the domesticated silkworm, *Bombyx mori*. *Journal of Insect Science*, *10*(1), 204. https://doi.org/10.1673/031.010.20401

Mousavi, S. F., Hosseini Moghaddam, S. H., Ghavi Hossein-Zadeh, N. and Mirhosseini, S. Z. (2017). Gene expression of HSP90 and HSP70 in four silkworm hybrids (*Bombyx mori* L.) in response to severe thermal shock. *Invertebrate Survival Journal*, *14*(1), 56–62.

Pack, R., Xia, L., Zhang, X., Jones, J. A. and Lewis, R. V. (2024) *Genome editing of Bombyx mori (silkworm) with the Cas9/CRISPR system for potential host of synthetic spider silk gene. Department of Biology and Biological Engineering, Utah State University.*

Peng, Z., Liu, Z., Wei, S., Zhu, Y., Jia, X., Xiao, W. and Chen, P. (2026). Genome-Wide CRISPR/Cas9 Screening Reveals BmM-ALP Orchestrates the Antioxidant Response and Metabolic Adaptations for Heat Resistance in *Bombyx mori*. *ACS Synthetic Biology*.

Saha, S. and Mondal, R. (Eds.). (2026). Sustainable sericulture in India. *Springer Nature Switzerland.*

Sharma, P. and Bali, K. (2026). Screening and Identification of Thermo-Tolerant Silkworm (*Bombyx mori* L.) Breeds for Sustainable Sericulture Under Thermal Stress Using the Evaluation Index Method. *Journal of Agriculture and Ecology Research International*, *27*(2), 30-42.

Sugnana Kumari, S., Venkata Subbarao, S., Misra, S. and Suryanarayana Murtyd, U. (2011). Screening strains of the mulberry silkworm, *Bombyx mori*, for thermotolerance. *Journal of Insect Science*, *11*(1), 116.

Sujatha, G. S., Kumar, G. A., Teja, K. S. S., Devi, D. L., Vidya Madhuri, E., Panda, A., Rupali, J. S. and Gautam, S. K. (2024). A comprehensive review of the effect and mitigation of climate change on sericulture. *International Journal of Environment and Climate Change*, *14*(7), 776-788. https://doi.org/10.9734/ijecc/2024/v14i74317

Sun, W., Yu, H., Shen, Y., Banno, Y., Xiang, Z. and Zhang, Z. (2012). Phylogeny and evolutionary history of the silkworm. *Science China Life Sciences*, *55*(6), 483-496.

Thaosen, M., Das, J., Borah, D. K. and Das, G. C. (2025). Evaluation of six multivoltine silkworm breeds of *Bombyx mori* (Lepidoptera: Bombycidae) for their resistance to *Bombyx mori* Nucleopolyhedrovirus (BmNPV). *Environment Conservation Journal*, *26*(4), 1188–1195. https://doi.org/10.36953/ECJ.34083144

Xiao, Y., Li, Q., Sun, Z., Fu, B., Yang, Q., Jiang, M. and Xing, D. (2025). Transcriptomics and Metabolomics Combined to Analyze the Response Mechanism of Silkworm Eggs to High-Temperature Stress. *Insects*, *16*(8), 862.

CHAPTER 10: CLIMATE-SMART APPROACHES IN SERICULTURE EXTENSION

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10.1. INTRODUCTION

Sericulture, as an agro-based rural enterprise, plays a vital role in livelihood generation, employment creation, and socio-economic development, particularly in developing countries like India. However, the sector is increasingly vulnerable to climate variability, including rising temperatures, erratic rainfall, droughts, and extreme weather events. These changes directly affect mulberry cultivation, silkworm rearing, cocoon production, and ultimately farmers' income. Climate change poses unprecedented challenges to agriculture and allied sectors, including sericulture. Rising temperatures, erratic rainfall, prolonged droughts, and increased pest and disease outbreaks threaten the sustainability of Mulberry sericulture. In this context, "Sericulture Extension" becomes a vital instrument for empowering farmers to adapt, mitigate risks and build resilience. Extension professionals act as catalysts, transferring climate-smart technologies, fostering participatory learning and ensuring that rural communities can sustain livelihoods despite environmental uncertainties.

Sericulture has always been more than a livelihood; it is a cultural and ecological practice deeply rooted in rural India. Yet, the sector faces unprecedented challenges due to climate change. Erratic rainfall, prolonged dry spells, rising temperatures and unpredictable pest outbreaks threaten both productivity and farmer incomes. Extension is not merely about transferring technology; it is about empowering farmers to adapt. *Sericulture extension workers act as catalyst in the developmental process and transfer the latest technologies to the farmers in their own language for better understanding, adoption and diffusion of the technologies.* This farmercentric approach is the foundation of climate smart sericulture extension. Climate Smart Sericulture Extension emerges as a transformative approach that integrates climate resilience, productivity enhancement, and sustainability into extension systems. It combines traditional extension methods with climate-informed technologies, participatory approaches, and digital tools to support farmers in adapting to climate change while reducing environmental impacts.

10.2. CONCEPT OF SERICULTURE EXTENSION

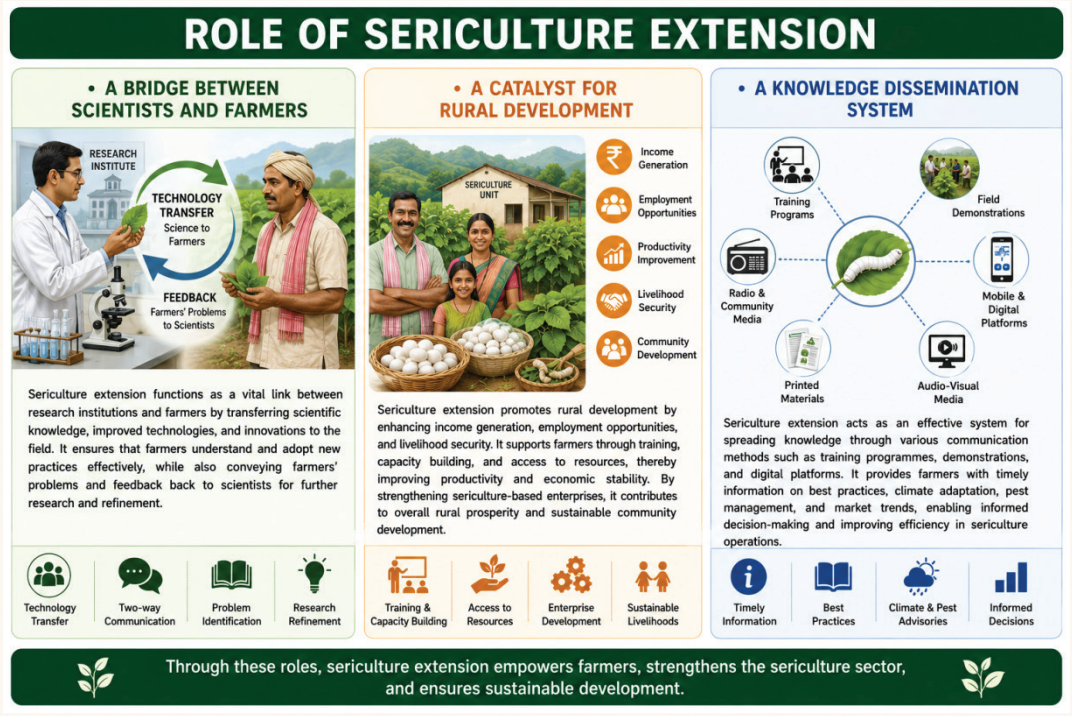
Sericulture extension is a specialized branch of extension education focusing on improving the economic and social conditions of people engaged in sericulture. It facilitates the transfer of technology (ToT) from research institutions to farmers and promotes adoption of improved practices.

Extension acts as:

- **A bridge between scientists and farmers:**

  Sericulture extension functions as a vital link between research institutions and farmers by transferring scientific knowledge, improved technologies, and innovations to the field. It ensures that farmers understand and adopt new practices effectively, while also conveying farmers' problems and feedback back to scientists for further research and refinement.

- A **catalyst for rural development:**



Sericulture extension promotes rural development by enhancing income generation, employment opportunities and livelihood security. It supports farmers through training, capacity building and access to resources, thereby improving productivity and economic stability. By strengthening sericulture-based enterprises, it contributes to overall rural prosperity and sustainable community development.

- A **knowledge dissemination system:**
- Sericulture extension acts as an effective system for spreading knowledge through various communication methods such as training programmes, demonstrations, and digital platforms. It provides farmers with timely information on best practices, climate adaptation, pest management, and market trends, enabling informed decision-making and improving efficiency in sericulture operations.

The Central Silk Board and State Departments of Sericulture play a major role in promoting sericulture through extension programmes, training and technology transfer.

10.3. NEED FOR CLIMATE SMART SERICULTURE EXTENSION

10.3.1. Climate Challenges in Sericulture

Climate change poses serious challenges to sericulture. Rising temperatures cause heat stress in silkworms, reducing cocoon quality and yield. Erratic rainfall disrupts mulberry growth, leading to poor leaf availability. Droughts weaken host plants, while excessive humidity fosters pest and disease outbreaks such as thrips, mites and fungal infections. Shifts in seasonal patterns affect silkworm rearing cycles, creating mismatches between leaf supply and larval demand. Socio economic impacts, including farmer migration and reduced income, further strain the sector. Together, these abiotic, biotic, socio-economic, resource constraints and livelihood stresses threaten the sustainability of sericulture, demanding climate smart extension strategies and adaptive technologies for resilience.

10.3.1.1 Abiotic stresses

Abiotic stresses caused by climate change are severely impacting sericulture. Heat waves increase silkworm mortality and reduce cocoon quality, while irregular rainfall disrupts mulberry growth and limits leaf supply. Water scarcity further weakens host plants, reducing resilience against pests and diseases. These stresses create mismatches between silkworm rearing cycles and leaf availability, lowering productivity and farmer income. To safeguard sustainability, climatesmart extension strategies such as mulching, rainwater harvesting, and shade nets are essential for protecting host plants and ensuring silkworm survival under changing environmental conditions.

Abiotic stresses in Sericulture are given as follows-

- **Heat waves** → cause silkworm stress, mortality and poor cocoon quality.
- **Irregular rainfall** → disrupts mulberry growth and leaf supply.
- **Water scarcity** → weakens host plants, reducing resilience.
- **Mismatch in cycles** → silkworm demand vs. leaf availability.
- **Reduced income** → farmers face economic vulnerability.
- **Adaptive solutions** → mulching, rainwater harvesting, shade nets.

Sl.No.	Risk	Impact	Solution
1	Heat Waves	Silkworm mortality	Shade nets
2	Drought	Reduced leaf yield	Drip irrigation
3	Irregular Rainfall	Crop mismatch	Season planning

10.3.1.2 Biotic stresses:

Biotic stresses in sericulture are intensifying with climate change. Pests like thrips, mites, whitefly, leaf roller, gall fly, and bark eater, along with diseases such as virosis, pebrine, muscardine, leaf rust, and flacherie, severely damage silkworm health, mulberry productivity, and cocoon quality, undermining sustainability and farmer livelihoods.



10.3.1.3 Socioeconomic stresses:

Socioeconomic stresses weaken sericulture sustainability. Seasonal migration of rural labor reduces workforce availability, while fluctuating cocoon prices create income instability. Limited fodder supply further strains mulberry cultivation, affecting silkworm rearing. Together, these challenges increase risks for farmers, making livelihoods vulnerable and demanding supportive policies and adaptive extension strategies.

10.3.1.4 Resource constraints:

Resource constraints hinder sericulture development. Smallholder farmers often lack access to adaptive technologies, timely credit, and reliable climate information. Limited infrastructure and extension support reduce resilience, making it difficult to adopt climatesmart practices. Strengthening resource access and farmer capacity is vital for sustainable and climateresilient sericulture.

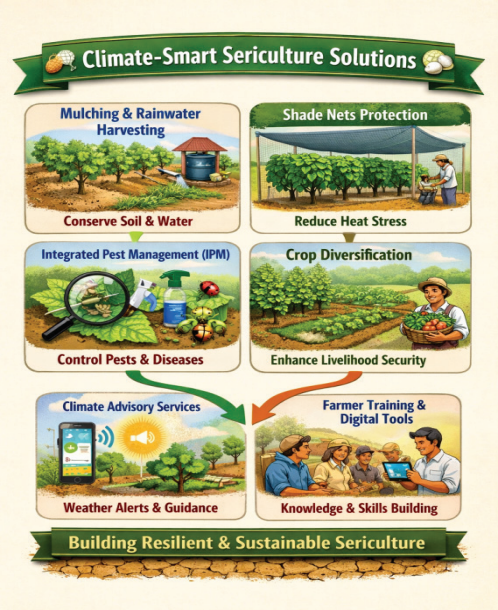
- Limited access to adaptive technologies
- Inadequate credit and financial support
- Poor availability of climate information
- Weak extension and infrastructure services

10.3.1.5 Livelihood vulnerability:

Livelihood vulnerability in sericulture arises from climate variability, market fluctuations, and resource limitations. Farmers face unstable incomes, crop losses, and reduced employment opportunities. Dependence on seasonal rearing and limited diversification heighten risks, making rural livelihoods fragile and demanding targeted support, insurance, and adaptive extension strategies for resilience.

10.3.1.6 Adoptive solutions for climate change in sericulture:

Climate change challenges demand adaptive solutions integrated with climatesmart sericulture extension. Farmers can safeguard mulberry and silkworms through practices like mulching, rainwater harvesting, and shade nets to reduce heat stress and conserve resources. Extension agents play a vital role by promoting integrated pest management, crop diversification, and timely climate advisories. Digital tools, farmer training, and participatory demonstrations strengthen resilience, ensuring better cocoon quality and stable livelihoods. Together, adaptive technologies and extension strategies empower smallholders to withstand climate variability, reduce risks, and sustain sericulture as a viable rural enterprise.



Benefits of Adaptive Solutions are-

- Improved silkworm survival under heat stress and humidity fluctuations

- Better mulberry leaf yield through water conservation and soil health practices
- Reduced pest and disease incidence with integrated pest management (IPM)
- Stable cocoon quality and productivity despite climate variability
- Enhanced farmer resilience through diversified income sources Ex. IFS
- Sustainable livelihoods supported by access to credit, climate information and extension services i.e., easy loan availability, credit support from govt.

10.3.2. Limitations of Conventional Extension:

10.3.2.1 Lack of climate-specific advisories:

Conventional extension often provides general guidance without considering local climate variations. Farmers lack timely, locationspecific advice on temperature, rainfall and humidity impacts on mulberry and silkworms, reducing their ability to adapt effectively to changing conditions.

10.3.2.2 Poor integration of weather information

Weather data is rarely integrated into sericulture advisories. Without forecasts or early warnings, farmers cannot plan irrigation, pest control or silkworm rearing schedules. This gap leads to crop losses and inefficient resource use during unpredictable weather events.

10.3.2.3 Weak feedback mechanisms from farmers

Traditional extension systems follow a oneway communication model. Farmer experiences, local innovations and field challenges are seldom captured or used to refine advisories. This weak feedback loop limits learning, adaptation and responsiveness to realtime problems.

10.3.2.4 Limited digital outreach

Conventional extension relies heavily on physical meetings and printed materials. Limited use of mobile apps, social media and digital platforms restricts information flow, especially during emergencies. Expanding digital outreach can ensure faster, wider and more inclusive farmer engagement.

10.3.3. Climate smart Sericulture Extension: To overcome limitation of conventional extension

Conventional extension systems often fail to address climate variability, offering generic advisories and limited farmer engagement. Weak integration of weather data, poor feedback mechanisms, and minimal digital outreach hinder timely decisionmaking. To overcome these gaps, climatesmart sericulture extension emphasizes adaptive communication, ICTbased advisories, participatory learning and realtime feedback. Strengthening digital platforms, a weatherlinked training and farmer network ensures resilience, improved productivity and sustainable livelihoods under changing climatic conditions.



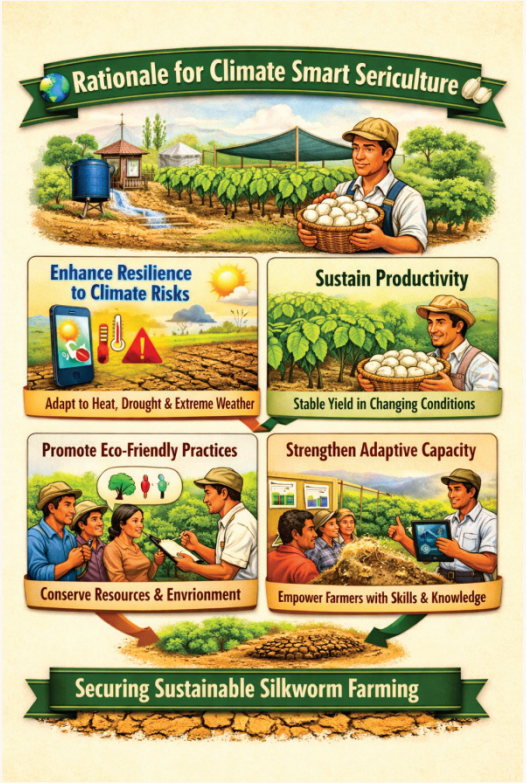
Key solutions:

- **ClimateSpecific Advisories & WeatherBased Alerts:** Providing localized advisories linked to weather forecasts helps farmers anticipate heat waves, rainfall shifts, and humidity changes. Timely alerts guide irrigation, pest control, and silkworm rearing, reducing risks and improving productivity under climate variability.
- **Digital Extension Tools & Mobile Connectivity:** Mobile apps, SMS alerts, and online platforms expand outreach, ensuring farmers receive realtime guidance. Digital tools bridge information gaps, deliver training modules, and connect farmers with experts, making extension faster, inclusive, and accessible even in remote areas.
- **Participatory Farmer Feedback Systems:** Interactive feedback channels capture farmer experiences, indigenous practices, and local challenges. This twoway communication refines advisories, strengthens trust, and ensures extension services remain practical, adaptive, and responsive to ground realities.
- **Capacity Building through ClimateSmart Training:** Training programmes equip farmers with knowledge of adaptive practices like mulching, IPM, and rainwater harvesting. Handson demonstrations, exposure visits, and digital learning tools enhance skills, empower communities, and build resilience for sustainable sericulture under changing climates.

10.3.4. Rationale for Climate Smart Approach

ClimateSmart Sericulture Extension aims to strengthen resilience and sustainability in silk farming by integrating climatespecific advisories, adaptive technologies, and participatory learning. It empowers farmers to manage climatic risks, conserve resources, and maintain productivity through timely weather alerts, digital communication, and capacitybuilding programmes that promote ecofriendly and inclusive sericulture practices.

Climate Smart Sericulture Extension aims to:



- ✓ **Enhance resilience to climate risks:** Climate smart sericulture strengthens the ability of farmers and production systems to withstand climate variability such as droughts, heat waves, and irregular rainfall. By adopting resilient practices like improved mulberry varieties, water conservation, and protective rearing systems, farmers can reduce losses and maintain stable cocoon production under adverse environmental conditions.
- ✓ **Sustain productivity under changing conditions:** Maintaining consistent productivity is essential despite fluctuating climatic conditions. Climate smart practices such as efficient irrigation, balanced nutrition for mulberry plants, and controlled rearing environments help ensure continuous leaf supply and healthy silkworm growth. These measures enable farmers to achieve stable yields and quality cocoon production throughout varying seasons.
- ✓ **Promote eco-friendly practices:** Climate smart sericulture encourages the use of environmentally sustainable methods such as

organic inputs, biological pest control, and reduced chemical usage. Practices like mulching, composting, and integrated farming systems improve soil health and biodiversity. These approaches not only protect the environment but also ensure long-term sustainability of sericulture production systems.

- ✓ **Strengthen farmers' adaptive capacity:** Enhancing farmers' ability to respond to climate challenges involves training, awareness, and access to timely information. Extension services, digital advisories, and participatory approaches help farmers make informed decisions. By building skills and knowledge, farmers become better equipped to adopt new technologies and adjust practices according to changing climatic conditions.

10.4. PRINCIPLES OF CLIMATE SMART SERICULTURE EXTENSION

Principles of Climate Smart Sericulture Extension focus on enhancing resilience, sustaining productivity, and promoting environmental sustainability. It emphasizes adaptation to climate variability, mitigation of environmental impacts, efficient resource use, and eco-friendly practices. The approach also strengthens farmers' adaptive capacity through knowledge dissemination, participatory methods, and use of climate information for informed decision-making.

1. **Adaptation:** Adjust farming practices to climate variability. Adaptation involves modifying sericulture practices to cope with climate variability. Farmers adopt techniques like mulching, shade nets, and rainwater harvesting to manage temperature and moisture fluctuations, ensuring stable mulberry growth and silkworm health under changing environmental conditions.
2. **Mitigation:** Reduce greenhouse gas emissions. Mitigation focuses on minimizing the environmental impact of sericulture by reducing greenhouse gas emissions. This includes adopting eco-friendly practices such as organic farming, reduced chemical inputs, energy-efficient rearing houses, and sustainable resource use. Such practices contribute to environmental conservation while ensuring long-term sustainability of sericulture systems.
3. **Productivity:** Increase yield and quality sustainably. This principle emphasizes achieving higher cocoon yield and better silk quality without degrading natural resources. It involves improved mulberry cultivation, balanced nutrition, scientific silkworm rearing, and efficient farm management. Sustainable productivity ensures consistent income for farmers while preserving soil health and ecological balance.
4. **Resilience:** Strengthen system stability. Resilience refers to the ability of sericulture systems to withstand and recover from climate shocks such as droughts, heat waves, or pest outbreaks. Strengthening resilience includes diversifying practices, improving infrastructure, and adopting risk management strategies to ensure stable production and reduce vulnerability to environmental stresses.
5. **Inclusiveness:** Focus on women, smallholders and marginal farmers. Inclusiveness ensures that climate smart sericulture benefits all sections of society, especially women and small-scale farmers. Extension services provide training, access to resources, and financial support to vulnerable groups. This approach promotes equity, enhances participation, and improves livelihoods while ensuring sustainable and inclusive growth in sericulture.

10.5. CLIMATE SMART PRACTICES IN SERICULTURE

10.5.1. Climate Resilient Mulberry Cultivation

Climate resilient mulberry cultivation involves adopting practices that help plants withstand climate variability such as drought, heat, and irregular rainfall. It includes use of drought-tolerant varieties, efficient irrigation methods like drip systems, mulching for moisture conservation, and soil health management. These measures ensure consistent leaf yield, quality, and sustainable silkworm rearing.

- ✓ **Drought-resistant varieties:** Drought-resistant mulberry varieties are developed to withstand water scarcity and high temperatures. These varieties maintain leaf yield and quality even under limited moisture conditions. Their deep root systems and efficient water use help to ensure consistent fodder supply for silkworms, reducing production risks and improving resilience in climate-stressed environments.
- ✓ **Efficient irrigation (drip irrigation):** Efficient irrigation methods like drip irrigation deliver water directly to the root zone, minimizing wastage and evaporation. This system ensures optimal moisture levels for mulberry growth while conserving water resources. It also reduces labor and improves nutrient uptake, resulting in better leaf quality and higher productivity under water-scarce conditions.
- ✓ **Mulching for moisture conservation:** Mulching involves covering the soil surface with organic or inorganic materials to reduce evaporation and retain soil moisture. It helps regulate soil temperature, suppress weed growth, and improve soil structure. In mulberry cultivation, mulching ensures continuous moisture availability, enhancing plant growth and supporting consistent leaf production for silkworm feeding.
- ✓ **Soil health management:** Soil health management focuses on maintaining soil fertility and structure through organic manures, biofertilizers, and balanced nutrient application. Healthy soil improves water retention, nutrient availability, and root development in mulberry plants. This leads to better leaf yield and quality, ensuring sustainable sericulture production under changing climatic conditions.

10.5.2. Sustainable Silkworm Rearing

Sustainable Silkworm Rearing emphasizes ecofriendly and efficient practices that maintain silkworm health and cocoon quality while conserving resources. It involves using clean rearing houses, organic disinfectants, balanced feeding, and proper temperature and humidity control. These measures reduce disease risks, enhance productivity, and ensure longterm environmental and economic sustainability in sericulture.

- **Temperature and humidity control:** Maintaining optimal temperature (26–28°C) and humidity (70–80%) is vital for silkworm health. Proper control prevents stress, ensures uniform growth and reduces disease risk. Using sensors, ventilation and humidifiers helps stabilize conditions, supporting consistent cocoon formation and sustainable rearing cycles.
- **Improved rearing houses**: Modern rearing houses with good ventilation, insulation, and hygienic design create a favorable environment for silkworms. They reduce exposure to pests, pathogens and climatic fluctuations. Improved structures enhance productivity, minimize losses and provide farmers with reliable facilities for sustainable cocoon production.
- **Disease-resistant silkworm breeds:** Breeding and adopting diseaseresistant silkworm strains reduce vulnerability to pathogens and climatic stress. These breeds ensure higher survival rates, stable cocoon yield, and better quality silk. Promoting hybrids and resilient varieties strengthens sustainability, lowers chemical dependence, and secures farmer livelihoods.
- **Hygienic practices:** Strict hygiene in rearing houses prevents disease outbreaks. Regular disinfection, clean trays, sanitized equipment and safe waste disposal reduce pathogen spread. Ecofriendly disinfectants and biosafety measures maintain silkworm health, ensuring sustainable production and protecting farmers' investments in sericulture.

10.5.3. Water Resource Management

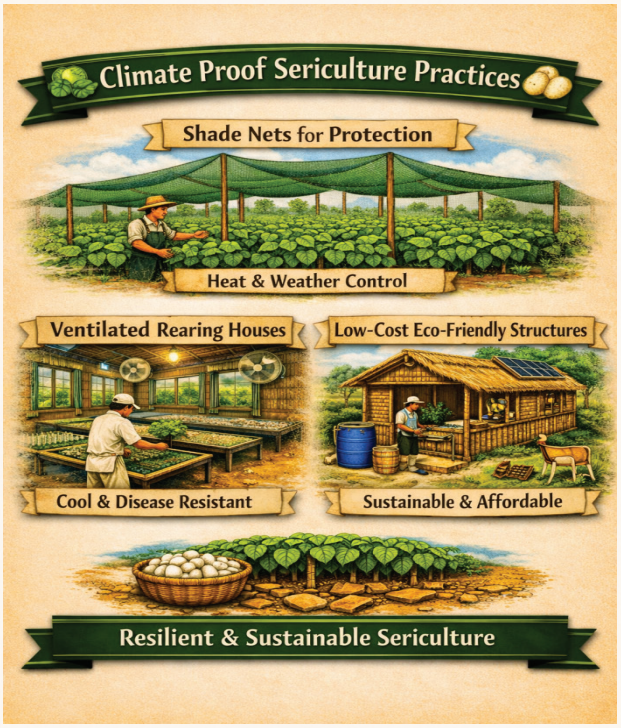
Water Resource Management in ClimateSmart Sericulture Extension emphasizes efficient use and conservation of water to sustain mulberry cultivation and silkworm rearing under climate variability. Practices such as rainwater harvesting, drip irrigation, mulching and recycling wastewater reduce

dependency on erratic rainfall. These methods enhance soil moisture, improve productivity and ensure longterm sustainability for farmers.

- ✓ **Rainwater harvesting:** Collecting and storing rainwater through rooftop channels, tanks, and recharge pits ensures reliable water supply for mulberry fields. It reduces dependence on erratic rainfall, supports irrigation during dry spells, and enhances sustainability by conserving natural resources for longterm sericulture productivity.
- ✓ **Recycling water:** Recycling wastewater from rearing houses and irrigation systems minimizes wastage and promotes efficient resource use. Treated water can be reused for mulberry cultivation, reducing costs and conserving freshwater. This practice strengthens resilience, lowers environmental impact, and supports ecofriendly sericulture extension.
- ✓ **Efficient irrigation scheduling:** Scheduling irrigation based on crop needs, soil moisture, and weather forecasts ensures optimal water use. It prevents overirrigation, conserves resources, and maintains healthy mulberry growth. Efficient scheduling enhances productivity, reduces costs, and supports sustainable sericulture under changing climatic conditions.

10.5.4. Climate Proof Infrastructure:

ClimateProof Infrastructure in Sericulture focuses on developing durable, weatherresilient facilities that protect silkworms and mulberry crops from climatic extremes. It includes constructing wellventilated rearing houses, using heatinsulating materials, installing solarpowered ventilation and ensuring proper drainage. These measures safeguard production, reduce losses and promote sustainable sericulture under changing climate conditions.



- **Shade nets:** Shade nets protect mulberry plants and silkworms from excessive heat, wind, and rainfall. They regulate microclimate conditions, reduce leaf scorching and maintain humidity. This lowcost adaptation ensures steady leaf production and healthy silkworm growth even during extreme weather events.
- **Ventilated rearing houses:** Ventilated rearing houses provide controlled airflow and temperature stability. Proper ventilation prevents heat build-up, reduces disease incidence, and maintains ideal humidity for silkworm development. These structures enhance cocoon quality and safeguard rearing operations against climatic fluctuations.
- **Low-cost eco-friendly structures:** Ecofriendly rearing units built with locally available materials bamboo, thatch, or mud offer insulation and sustainability. They minimize construction costs, reduce carbon footprint, and maintain favourable conditions for silkworm rearing. Such climateproof designs promote resilience and environmental harmony in rural sericulture systems.

10.5.5. Integrated Pest and Disease Management:

Integrated Pest and Disease Management (IPDM) in ClimateSmart Sericulture Extension promotes ecofriendly control of pests and diseases through a balanced approach. It combines biological control agents, resistant mulberry varieties, cultural practices and timely monitoring. IPDM reduces pesticide use, safeguards silkworm health and ensures sustainable cocoon production under changing climatic conditions.

- ✓ **Biological control methods:** Use of natural predators like ladybird beetles, *Chrysoperla*, and parasitoids such as *Trichogramma* helps suppress mulberry pests. Beneficial microbes like *Trichoderma* and *Pseudomonas fluorescens* control soilborne diseases. These ecofriendly agents maintain ecological balance and reduce chemical pesticide dependency in sericulture.
- ✓ **Use of eco-friendly inputs:** Application of Neembased bio-pesticides, botanical extracts, and organic manures enhances plant health and pest resistance. Ecofriendly inputs minimize environmental pollution, protect silkworms from toxic residues and promote sustainable leaf production. They ensure safe, residuefree sericulture aligned with climatesmart principles.
- ✓ **Early warning systems:** Weatherbased pest forecasting and digital monitoring tools help predict outbreaks of thrips, mites and fungal diseases. Timely alerts enable preventive action, reducing crop loss and chemical use. Early warning systems strengthen resilience and support proactive management in climatesmart sericulture.

10.6. EXTENSION METHODS IN CLIMATE SMART SERICULTURE

Extension Methods in ClimateSmart Sericulture focus on adapting communication and training to climate challenges. Individual farm visits guide farmers on microclimate management, group workshops promote collective solutions like water harvesting and mass media spreads seasonal advisories. Digital tools deliver realtime alerts, ensuring resilient, farmerfriendly technology transfer and sustainable sericulture practices. Extension methods remain the backbone of technology dissemination. These are categorized as follows:

10.6.1. Individual Contact Methods

Individual Contact Methods in ClimateSmart Sericulture involve direct farmer engagement through farm visits, personal counselling and onetoone demonstrations. Extension workers provide tailored advice on microclimate management, pest control and water conservation. This personalized approach ensures farmers adopt resilient practices effectively, strengthening sustainability and productivity in sericulture systems.

- **Farm and home visits:** Extension workers visit farms and homes to provide personalized advice on mulberry cultivation, silkworm rearing, and climateresilient practices. Direct observation helps identify problems early, ensuring timely solutions and stronger farmer confidence in adopting sustainable technologies.
- **Personal guidance:** Onetoone counseling empowers farmers with tailored solutions for pest management, water conservation, and climate adaptation. This individualized support builds trust, encourages adoption of ecofriendly practices, and strengthens resilience in sericulture systems against unpredictable climatic challenges.
- **Advisory services:** Advisory services deliver timely recommendations through leaflets, mobile alerts, and farmer meetings. They provide seasonal guidance on pest outbreaks, irrigation scheduling, and disease prevention. These services ensure farmers receive practical, climatesmart solutions to sustain productivity and reduce risks.

10.6.2. Group Contact Methods

Group Contact Methods in ClimateSmart Sericulture emphasize collective learning and farmer participation. Techniques include training programmes, workshops, demonstrations, and farmer field schools. These methods encourage peer exchange, promote adoption of climateresilient practices, and strengthen community capacity to manage pests, water and infrastructure sustainably, ensuring longterm sericulture productivity.

- **Group discussions:** Farmers collectively share experiences, challenges, and solutions on climateresilient sericulture practices. These discussions encourage peer learning, build confidence and promote adoption of ecofriendly technologies, strengthening community resilience against pests, diseases and climatic variability.
- **Demonstrations:** Practical demonstrations showcase improved mulberry cultivation, pest management and water conservation techniques. Farmers observe results directly in the field, which enhances understanding, motivates adoption and ensures climatesmart practices are effectively transferred to large groups.
- **Farmer field schools:** Farmer field schools provide participatory, seasonlong training where farmers learn by doing. They experiment with ecofriendly inputs, biological controls and climateproof infrastructure. This handson approach builds capacity, fosters innovation and ensures sustainable sericulture practices are embedded at community level.

10.6.3. Mass Contact Methods:

Mass Contact Methods in ClimateSmart Sericulture spread knowledge widely through farmer rallies, exhibitions, radio, television and digital platforms. These methods reach large audiences simultaneously, delivering seasonal advisories, pest alerts and climateresilient practices. They ensure rapid dissemination of innovations, strengthening awareness and adoption across rural sericulture communities.

- **Radio and television:** Radio and television programmes broadcast seasonal advisories, pest alerts and climateresilient practices to large audiences. They spread awareness quickly, highlight success stories and ensure farmers receive timely guidance for sustainable sericulture under changing climatic conditions.
- **Mobile apps and SMS alerts:** Mobile apps and SMS alerts deliver realtime information on weather forecasts, pest outbreaks and management practices. These tools empower farmers with instant, locationspecific guidance, enabling proactive decisions and strengthening resilience in sericulture systems.
- **Social media platforms:** Social media platforms share training videos, infographics, and farmer experiences on climatesmart sericulture. They connect communities, encourage peer learning and spread innovations widely. Interactive engagement ensures rapid adoption of ecofriendly practices and builds collective resilience against climate challenges.

10.6.4. Climate Smart Adaptation in Methods:

ClimateSmart Adaptation in Extension Methods emphasizes tailoring communication and training to climate variability. It integrates farm visits, group learning and mass outreach with digital tools, ensuring farmers receive timely, locationspecific guidance. This adaptive approach strengthens resilience, promotes ecofriendly practices and sustains sericulture productivity under changing climatic conditions.

- **Use of weather-based advisories:** Weatherbased advisories provide farmers with timely guidance on rainfall, temperature, and pest risks. These advisories help plan irrigation,

mulching, and disease prevention, ensuring climateresilient sericulture practices and reducing vulnerability to unpredictable weather fluctuations.

- **Mobile-based decision support systems:** Mobile decision support systems deliver instant recommendations on pest control, nutrient management, and climate adaptation. Farmers receive locationspecific solutions, enabling proactive decisions. These tools strengthen resilience, minimize crop losses, and promote sustainable sericulture under changing climatic conditions.
- **Digital extension platforms:** Digital platforms integrate training modules, videos, and advisories for farmers. They enable largescale dissemination of climatesmart practices, connect communities, and provide realtime updates. This approach ensures effective technology transfer, empowering farmers to adopt ecofriendly, resilient methods in sericulture.

10.7. PARTICIPATORY APPROACHES IN CLIMATE SMART EXTENSION

Participatory Approaches in ClimateSmart Extension emphasize farmer involvement in decisionmaking and knowledge sharing. Methods include participatory rural appraisal, group discussions and farmer field schools. Farmers contribute local coping strategies; validate technologies and cocreate solutions. This inclusive process builds trust, strengthens resilience and ensures sustainable adoption of climatesmart sericulture practices. Participatory Rural Appraisal (PRA) techniques help integrates farmers' knowledge with scientific recommendations.

Key PRA tools include:

- **Seasonal calendars (for climate trends):** These helps to understand the month wise/ season wise incidences of various abiotic and biotic abnormalities in particular area. This helps us to understand pest, disease problems in a particular season, employment availability, labour migration, rainfall patterns, labour wages, labour availability, water availability, market prices, crops, food consumption, diseases of food plants & silkworms etc.
- **Transect walks:** A transact walk is a kind of exploratory walk which is under taken by team along with the villagers to observe and record every send in minute detail of a particular area.
- **Matrix ranking:** Matrix ranking is a participatory tool where farmers collectively evaluate climatesmart sericulture options against key criteria such as cost, effectiveness, and sustainability. By scoring practices like IPDM, water conservation, and ecoinputs, communities identify priorities, strengthen decisionmaking, and adopt resilient technologies suited to local conditions. eg. Preferential use of egg washing methods by various stalk-holders can be identified.
- **Timeline analysis:** Historical events in the village are discussed with elderly people and a time line is constructed to understand the village past record and future course of action can be designed. Eg., Disease and pest incidence, severity and management options followed.
- **Venn diagrams:** Various inside and outside agencies or institutions help for the upliftment of the rural people. The Venn diagram shows the diagram of a village and its institutions. The institutions are depicted in different size circles, the bigger the size, the more is its importance to village, and the institutions are depicted at various distances. It is also called Chapathi diagram.

These tools help in:

- **Identifying climate risks:** Farmers and extension agents jointly assess local vulnerabilities, mapping drought, floods, pests, and diseases.
- **Designing location-specific interventions:** Tailored practices like mulching, water harvesting, and ecoinputs address unique regional climate challenges effectively.

- **Enhancing farmer participation:** Active farmer involvement ensures cocreation of solutions, strengthens ownership, and promotes adoption of resilient practices.

10.8. EXTENSION MODELS FOR CLIMATE SMART SERICULTURE

10.8.1. Integrated Scheme Approach:

Government schemes play a crucial role in climate-smart extension:

Silk Samagra / Silk Samagra-2:

- **Focus on R&D, training, and technology transfer:** Silk Samagra emphasizes research, farmer training, and technology dissemination, ensuring innovations reach communities for sustainable sericulture development.
- **Promotes climate-resilient practices:** The scheme supports ecofriendly inputs, water conservation, and pest management, helping farmers adopt resilient practices against climate variability.
- **Encourages digital monitoring systems:** Digital tools track farm performance, pest outbreaks, and resource use, enabling timely interventions and strengthening climatesmart sericulture management.

10.8.2. Institute–Village Linkage Programme (IVLP):

The **Institute–Village Linkage Programme (IVLP)** is a participatory extension approach that bridges research institutions with farming communities. It facilitates onfarm trials, technology validation and farmer feedback, ensuring innovations are adapted to local conditions. By integrating scientific knowledge with indigenous practices, IVLP strengthens climatesmart sericulture, enhances farmer capacity and promotes sustainable livelihoods.

- **Participatory research approach:** Farmers collaborate with scientists to test technologies, share local insights, and cocreate climateresilient solutions for sericulture.
- **Farmer involvement in technology validation:** Farmers actively evaluate new practices onfarm, providing feedback that ensures technologies are practical, adaptable, and climatesmart.
- **Climate adaptation through local innovations:** Communities integrate indigenous knowledge with modern practices, developing innovative, locationspecific solutions that strengthen resilience in sericulture systems.

10.8.3. Cluster-Based Approach:

ClusterBased Approach in ClimateSmart Sericulture emphasizes collective organization of farmers into clusters for effective technology transfer, training, and monitoring. It facilitates resource sharing, joint demonstrations, and participatory decisionmaking. By addressing local vulnerabilities together, clusters strengthen resilience, promote ecofriendly practices, and ensure sustainable productivity in sericulture under changing climatic conditions.

- **Promotes collective action:** Cluster groups jointly adopt IPM, water harvesting and ecofriendly inputs, ensuring coordinated pest control and sustainable sericulture.
- **Improves resource efficiency:** Shared equipment like battery dusters, irrigation systems and biofertilizers reduce costs, optimize resources and enhance productivity across clusters.
- **Enhances resilience at community level:** Collective adoption of shade nets, green manure and digital advisories strengthens community resilience against climate variability and pest outbreaks.

10.9. TRANSFER OF TECHNOLOGY (TOT) IN CLIMATE SMART SERICULTURE

Transfer of Technology (ToT) in ClimateSmart Sericulture ensures rapid dissemination of innovations from research institutions to farming communities. It uses demonstrations, farmer field schools and digital platforms to promote ecofriendly practices. By minimizing time lag, ToT strengthens resilience, enhances productivity and empowers farmers to adopt sustainable sericulture technologies under changing climatic conditions. Transfer of Technology is the process of delivering research-based innovations to farmers effectively.

10.9.1. Components of ToT:

- **On-station trials (OST):** OST is an important component of Trial of Technology (ToTs) and its main function is the testing of Tasar technologies developed from outcome of the research & development projects/ experiments and to validate the results in the on-stations (Main station/ RSRS/ RECs) with application of all the package of practices suggested by the researcher/ scientists. Researchers to detect statistically significant differences on biological criteria between treatments through OSTs, about the new Tasar technology.
- **On-farm Trial (OFT)**: It is another important component of ToTs and its main function in sericulture is the testing of Tasar technologies developed from the outcome of the R & D project / experiment and evaluated in the on-station trials and further testing in the farmers/ stakeholder field level (field practices) for demonstration of technology to the famers'/ stakeholders and also to disseminate the technology among the farming community. This helps to ensure that OFT will have the best chances of being useful to the largest possible number of Tasar farm families/ Tasar stakeholders. OFT thus offers the opportunity to study technical, economic and social effects, and their interactions.
- **Extension communication programmes (ECP's):** As a part of the mandated activities, Central Silk Board is organizing various extension communication programmes viz., Resham Krishi Mela/ Reelers Mela cum exhibition, Farmers Days, Field days, Awareness programme, Technology Demonstration, Workshops/ Seminar/ Conference and Vichar Goshties etc., on a regular basis to disseminate the technologies to the end users in sericulture sector, which is included in the Annual Action Plan. Though there is no restriction for the number of participants per each event, the minimum / range of participants with event-wise budget provisions are indicated, which may be treated as benchmark for organizing extension programmes in the field.

10.9.2. Climate Smart ToT Strategies:

ClimateSmart ToT Strategies emphasize participatory demonstrations, farmer field schools, and digital platforms for rapid dissemination of innovations. Weatherbased advisories, mobile decision support, and cluster approaches ensure locationspecific guidance. By integrating traditional knowledge with modern practices, these strategies empower farmers, strengthen resilience, and promote sustainable sericulture under changing climatic conditions.

- **Climate-resilient technologies:** Promotes mulching, biofertilizers, shade nets, and IPM practices, ensuring sustainable cocoon production under droughts, heat waves, and pest outbreaks.
- **Weather advisory integration:** Integrates rainfall, temperature, and pest forecasts into extension services, guiding farmers with timely, locationspecific climatesmart sericulture management practices.
- **Digital knowledge dissemination:** Uses mobile apps, SMS alerts, and online platforms to spread training modules, advisories, and innovations quickly across farming communities.

10.10. ROLE OF ICT IN CLIMATE SMART EXTENSION

Role of ICT in ClimateSmart Extension is pivotal for bridging knowledge gaps and empowering farmers. ICT tools such as mobile apps, SMS alerts and digital platforms provide realtime weather advisories, pest management guidance and training resources. Radio, television and social media expand outreach, ensuring timely dissemination of climateresilient practices. By integrating participatory communication, ICT enhances farmer decisionmaking, promotes ecofriendly technologies and strengthens resilience against climate variability. It also supports digital monitoring systems, enabling datadriven interventions and clusterbased coordination. Ultimately, ICT transforms extension into a dynamic, adaptive process that sustains sericulture productivity while addressing local climate challenges effectively. Information and Communication Technologies (ICTs) are transforming extension systems.

Key ICT Tools:



- **Mobile applications:** Mobile apps provide farmers with realtime weather forecasts, pest alerts, and advisory modules. They support decisionmaking, promote ecofriendly practices, and strengthen resilience by delivering locationspecific guidance directly to farmers' smartphones for timely sericulture management.
- **SMS-based advisories:** SMS advisories deliver concise, locationspecific messages on weather, pest outbreaks, and management practices. They ensure rapid communication, even in remote areas with limited internet access, empowering farmers to adopt climatesmart sericulture practices effectively and sustainably.
- **WhatsApp groups:** WhatsApp groups connect farmers, extension agents, and experts for instant knowledge sharing. They enable discussions, advisory dissemination, and peer learning. Farmers receive timely updates, videos, and infographics, strengthening collective resilience and adoption of climatesmart sericulture practices.
- **Online training platforms:** Online platforms host training modules, videos, and interactive sessions on climatesmart sericulture. They expand outreach, provide flexible learning opportunities, and ensure farmer's access updated technologies. This digital approach enhances capacity building and supports sustainable sericulture under climate variability.

Benefits of ICT tools:

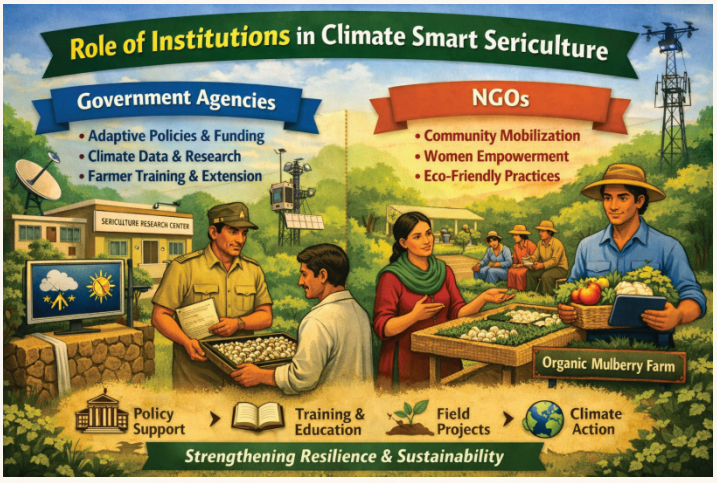
- **Real-time climate information:** Provides farmers instant weather alerts, pest forecasts, and rainfall predictions, enabling timely decisions for crop protection and resource management.
- **Wider outreach:** Extension programmes, digital platforms, and farmer networks spread knowledge quickly, ensuring rural communities access climatesmart practices and sustainable technologies.

- **Faster technology dissemination:** Demonstrations, ICT tools, and training modules accelerate adoption, bridging research to practice, empowering farmers with innovations for improved productivity and resilience.

10.11. ROLE OF INSTITUTIONS IN CLIMATE SMART SERICULTURE

10.11.1. Government Agencies

Government agencies play a pivotal role in climatesmart sericulture by formulating adaptive policies, funding research and promoting sustainable technologies. They coordinate extension networks, provide realtime climate data, support farmer training and ensure effective dissemination of ecofriendly practices. Their collaboration strengthens resilience, productivity and environmental sustainability in sericulture communities.



- Policy support
- Financial assistance
- Training programmes

10.11.2. NGOs:

NGOs contribute significantly to climatesmart sericulture by mobilizing communities, promoting sustainable practices and facilitating farmer training. They bridge gaps between research institutions and rural stakeholders, implement demonstration projects and support women's participation. Through awareness campaigns and capacity building, NGOs enhance resilience, technology adoption and environmental conservation in sericulture ecosystems.

NGOs play a critical role in:

- Technology dissemination
- Capacity building
- Community mobilization
- Climate adaptation strategies

10.11.3. Research Institutions:

Research institutions play a crucial role in climatesmart sericulture by developing resilient silkworm breeds, sustainable host plant varieties, and ecofriendly technologies. They conduct climate impact studies, innovate pest management strategies, and collaborate with extension agencies for technology transfer. Their scientific research strengthens adaptation, productivity, and environmental sustainability in sericulture systems.

- Development of climate-resilient technologies
- Capacity building
- Field validation

10.12. GENDER AND CLIMATE SMART SERICULTURE

Gender plays a transformative role in climatesmart sericulture by ensuring equitable participation and empowerment of women in sustainable practices. Women contribute significantly to silkworm rearing, host plant management and ecofriendly innovations. Integrating gender perspectives enhances knowledge sharing, decisionmaking and resilience to climate challenges. Promoting women's leadership strengthens adaptation, productivity, and community sustainability.

Women play a crucial role in sericulture:

- Provide majority of labour
- Participate in rearing, reeling, and processing

Climate smart extension should:

- Empower women farmers
- Provide skill training
- Promote women-led enterprises

10.13. Value Chain Approach in Climate Smart Sericulture

The **Value Chain Approach in Climate Smart Sericulture** emphasizes strengthening every stage from input supply to market linkage. Climateresilient mulberry cultivation, ecofriendly silkworm rearing, and sustainable cocoon production form the foundation. Extension services, ICT tools, and institutional support accelerate technology adoption. Efficient processing, quality assurance, and diversified product development enhance competitiveness. Linking farmers to fair markets, cooperatives, and digital platforms ensures better income and resilience. By integrating research, training, and community participation, the value chain approach builds sustainability, empowers rural households, and secures sericulture's role as a climateadaptive livelihood system.

Sericulture involves a complex value chain:

- Mulberry cultivation
- Silkworm rearing
- Cocoon production
- Silk processing

Climate-smart interventions across the value chain include:

- Efficient resource use
- Reduced waste
- Sustainable processing methods

10.14. MARKETING AND CLIMATE RESILIENCE

Marketing plays a vital role in building climate resilience by connecting farmers to stable, fair and diversified markets. Strengthening cooperatives, digital platforms and valueadded product chains ensures better income security despite climate shocks. Transparent pricing, branding of ecofriendly silk and consumer awareness campaigns enhance demand. By integrating climatesmart practices into marketing strategies, institutions empower farmers to adapt, reduce vulnerability and sustain livelihoods. Effective marketing not only stabilizes incomes but also motivates adoption of resilient technologies, making sericulture a sustainable and climateadaptive enterprise for rural communities.

Climate-smart marketing strategies include:

- Market information systems
- Price stabilization mechanisms
- Producer cooperatives
- Value addition and branding

10.15. STRATEGIES FOR STRENGTHENING CLIMATE SMART EXTENSION

Strengthening climatesmart extension requires integrating ICT tools for realtime climate information, participatory training, and farmerfriendly communication. Building institutional partnerships among government agencies, NGOs, and research centers ensures wider outreach and faster technology dissemination. Demonstration plots, feedback systems, and genderinclusive approaches enhance adoption. Policy support, capacity building, and community mobilization further empower farmers to adapt sustainably.

1. **Capacity building of extension workers:** Training extension workers in climatesmart practices, ICT tools, and participatory methods enhances their ability to deliver timely, farmerfriendly solutions, strengthening resilience.
2. **Integration of climate services:** Linking weather forecasts, pest alerts, and advisory systems into extension ensures farmers receive realtime information, enabling adaptive decisions and risk reduction.
3. **Promotion of digital agriculture:** Using mobile apps, online platforms, and ICT tools accelerates knowledge dissemination, supports precision farming, and empowers farmers with accessible, climatesmart technologies.
4. **Strengthening institutional linkages:** Collaboration among government agencies, NGOs, and research centers improves outreach, resource sharing, and technology transfer, fostering sustainable climatesmart sericulture development.
5. **Encouraging public-private partnerships:** Partnerships with private enterprises enhance innovation, investment, and market access, complementing public efforts to scale climatesmart technologies and empower farming communities.

10.16. FUTURE PROSPECTS

Climate smart sericulture holds immense potential for sustainable rural development. Future prospects include integrating advanced ICT tools for realtime climate services, developing resilient mulberry varieties and silkworm breeds and expanding ecofriendly technologies. Strengthening institutional collaborations, promoting gender inclusivity and enhancing value chain linkages will ensure resilience, productivity and profitability. Publicprivate partnerships, digital marketing platforms and global demand for ecofriendly silk further create opportunities. By combining research, extension and community participation, climate smart sericulture can evolve into a robust livelihood system that empowers farmers, conserves resources and contributes to climate adaptation and sustainable economic growth.

Climate Smart Sericulture Extension will evolve through:

- **Artificial intelligence and data analytics:** AI and data analytics enable predictive modelling, pest forecasting and resource optimization, empowering farmers with actionable insights for climatesmart sericulture, enhancing resilience, productivity, and sustainability across diverse agroecological zones.

- **Precision sericulture:** Precision sericulture uses sensors, drones, and ICT tools to monitor mulberry growth, silkworm health and resource use. It ensures targeted interventions, reduces waste and improves efficiency, making sericulture more adaptive and climateresilient.
- **Climate forecasting integration:** Integrating climate forecasting into extension services provides farmers with timely weather alerts, rainfall predictions and pest risk assessments. This proactive approach supports adaptive planning, minimizes losses, and strengthens resilience against climate variability in sericulture systems.
- **Sustainable and circular economy approaches:** Circular economy practices in sericulture promote waste recycling, organic inputs and ecofriendly technologies. By reusing resources and minimizing environmental impact, these approaches enhance sustainability, reduce carbon footprint and create climateresilient livelihoods for rural communities.

10.17. CONCLUSION

Climate smart sericulture extension represents a transformative pathway for sustaining livelihoods and adapting to climate challenges. By integrating ICT tools, participatory approaches, and resilient technologies, extension services empower farmers to make informed decisions and adopt ecofriendly practices. Institutions such as government agencies, NGOs, and research centers play complementary roles in policy support, training, and innovation, while gender inclusivity ensures equitable participation and community resilience. The value chain approach strengthens every stage from production to marketing, enhancing competitiveness and income security. Future prospects lie in artificial intelligence, precision sericulture, and circular economy models. Together, these strategies foster sustainability, resilience, and prosperity, positioning sericulture as a climateadaptive enterprise for rural communities.

10.18. REFERENCES

Central Silk Board. (2025). *Annual Report*. Government of India.

Central Tasar Research & Training Institute. (2025). *Research Bulletins and Extension Materials*. CTR&TI, Ranchi.

Food and Agriculture Organization. (2013). *Climate-Smart Agriculture Sourcebook*. FAO.

Indian Council of Agricultural Research. (2024). *Sericulture and Climate Resilience Publications*. ICAR.

Indian Journal of Sericulture. (Various issues). *Research articles on sericulture and climate adaptation*.

Journal of Agriculture and Climate Change. (Various issues). *Studies on climate resilience and sustainable farming*.

Khan, P.M. (2010). *Textbook of Extension Education*. Himanshu Publications, New Delhi.

NGO Reports. (2023). *Community Mobilization and Sustainable Sericulture Practices*.

Ray, G. L. & Mondal, S. (2011). *Agricultural Extension: Communication and Management*. Kalyani Publishers, Ludhiana.

Reddy, A. A. & Reddy, B. S. (2010). *Extension Education*. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi.

Robbins, S. P. & Coulter, M. (2018). *Management*. Pearson Education.

Sandhu, A. S. (2005). *Handbook of Agricultural Extension*. Directorate of Extension Education, Punjab Agricultural University, Ludhiana.

Stoner, J. A. F., Freeman, R. E., & Gilbert, D. R. (2008). *Management*. Pearson Prentice Hall.

United Nations Development Programme. (2021). *Gender and Climate Resilience Studies*. UNDP.

World Bank. (2022). *Climate-Smart Agriculture and Rural Livelihoods*. World Bank Publications.

CHAPTER 11: CHANGING CLIMATIC SCENARIOS AND THEIR INFLUENCE ON MULBERRY PEST AND DISEASE MANAGEMENT

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11.1. INTRODUCTION

Sericulture is an important agro-based rural industry that provides employment and economic support to millions of people worldwide, especially in Asian countries such as India and China. Mulberry cultivation forms the foundation of sericulture because mulberry leaves constitute the exclusive food source for the domesticated silkworm, *Bombyx mori* L. The productivity and nutritional quality of mulberry leaves directly influence silkworm growth, cocoon yield, and silk quality. Therefore, healthy mulberry cultivation is essential for sustainable sericulture production. However, mulberry cultivation is severely constrained by several insect pests, mites, nematodes, and diseases that reduce both leaf yield and quality. The occurrence and severity of these pests and diseases are strongly influenced by environmental and climatic factors.

Climate change has become one of the most important global environmental concerns in recent decades. According to the Intergovernmental Panel on Climate Change (IPCC, 2021), increasing greenhouse gas emissions have resulted in rising global temperatures, changes in rainfall distribution, elevated atmospheric carbon dioxide (CO_2) levels, increased drought frequency, and more frequent extreme weather events. These changes have profound impacts on agricultural ecosystems by influencing crop growth, pest development, disease epidemiology, and ecological interactions.

Insects are highly sensitive to environmental conditions because they are poikilothermic organisms whose metabolic activity, development, survival, reproduction, and dispersal are regulated by temperature and humidity. Bale *et al.* (2002) reported that rising temperature directly affects herbivorous insect physiology and can accelerate developmental rate, increase fecundity, and enhance population growth. Climate change also affects plant physiology by altering nutrient composition, carbon-to-nitrogen ratio, and secondary metabolite production, thereby influencing herbivore feeding behaviour and host susceptibility (Zvereva and Kozlov, 2006). Similarly, fungal and bacterial pathogens are strongly influenced by environmental conditions that determine their growth, sporulation, infection, and dissemination.

In mulberry ecosystems, changing climatic conditions have significantly altered the population dynamics and seasonal incidence of important pests such as thrips, whiteflies, mealybugs, broad mites, and leaf rollers. Rahmathulla (2012) emphasized that climatic factors play a major role in determining pest incidence and disease severity in mulberry-based sericulture systems. Climate-induced stress also weakens plant defence mechanisms and increases vulnerability to pest and disease attack. Furthermore, changing environmental conditions disrupt interactions among pests, host plants, predators, parasitoids, and microbial antagonists, resulting in ecological imbalance and frequent pest outbreaks. Therefore, understanding climate-driven changes in mulberry pest and disease dynamics is essential for developing sustainable and climate-resilient management strategies (Fig. 1).

11.2. INFLUENCE OF CLIMATE CHANGE ON MAJOR MULBERRY PESTS

Thrips, *Pseudodendrothrips mori*, are among the most destructive sap-feeding pests of mulberry. Both nymphs and adults feed by scraping and sucking sap from tender leaves, causing curling,

bronzing, silvery appearance, and drying of leaves. Severe infestation adversely affects leaf quality and silkworm feeding. Rahmathulla *et al.* (2015) reported a strong relationship between temperature and seasonal abundance of major mulberry pests including thrips. High temperature and low relative humidity favour rapid multiplication and increased reproductive potential of thrips populations. Climate warming accelerates developmental rate and shortens the life cycle, thereby increasing the number of generations per year. Reduced rainfall further enhances infestation because rainfall normally suppresses thrips populations by washing insects from leaf surfaces. Consequently, climate change is expected to intensify thrips outbreaks and increase economic losses in sericulture systems.

Whiteflies such as *Dialeuropora decempuncta* are important sap-feeding pests causing chlorosis, yellowing, and premature leaf senescence in mulberry plants. Honeydew secretion by whiteflies promotes development of sooty mold fungi that reduce photosynthetic activity and leaf quality. Elevated temperature and prolonged dry conditions favour whitefly survival, reproduction, and dispersal. Climate-induced water stress weakens mulberry plants and increases their susceptibility to whitefly infestation. Bale *et al.* (2002) observed that rising temperature enhances herbivore activity and population growth in many agricultural ecosystems. Therefore, warming conditions are likely to increase the incidence and distribution of whiteflies in mulberry cultivation.

Mealybugs including *Maconellicoccus hirsutus* and *Paracoccus marginatus* are becoming increasingly important under changing climatic conditions. These pests feed on plant sap and inject toxic saliva, causing leaf curling, deformation, stunted growth, and reduced vigour. Warm and dry environmental conditions favour rapid multiplication of mealybugs. Sakthivel *et al.* (2019) reported that changing climatic conditions significantly influence the incidence of sap-feeding pests in mulberry ecosystems. Climate-induced reduction in natural enemy populations further contributes to increased mealybug outbreaks.

Broad mite, *Polyphagotarsonemus latus*, is another serious pest affecting mulberry cultivation. Feeding by broad mites causes bronzing, curling, crinkling, and deformation of leaves, reducing their nutritional value for silkworm rearing. Jones and Brown (1983) demonstrated that temperature and humidity strongly influence the reproductive performance and population growth of broad mites. Luypaert *et al.* (2014) further reported that warm environmental conditions significantly accelerate broad mite population development. Therefore, climate warming and fluctuating humidity are expected to increase broad mite incidence and persistence in mulberry gardens.

Leaf rollers and defoliators such as *Diaphania pulverulentalis* are also influenced by climatic variability. Increased humidity and moderate temperatures during monsoon periods favour larval survival and feeding activity. Rahmathulla (2012) reported that climatic fluctuations significantly influence seasonal incidence of defoliators in mulberry cultivation. Climate variability may also disrupt synchronization between pests and natural enemies, thereby increasing outbreak potential (Table: 1).

11.3. IMPACT OF CLIMATE CHANGE ON MULBERRY DISEASES

Climate change significantly affects the occurrence, severity, and epidemiology of mulberry diseases. Environmental conditions determine pathogen survival, growth, sporulation, infection efficiency, and dissemination. Variations in temperature, rainfall, and humidity strongly influence fungal, bacterial, and viral diseases in mulberry ecosystems.

Powdery mildew is one of the important fungal diseases affecting mulberry leaves. The disease is favoured by moderate temperature and high humidity conditions. Increased humidity and prolonged

cloudy weather enhance fungal sporulation and infection. Disease severity increases under dense canopy conditions where moisture accumulation is high. Powdery mildew reduces photosynthetic efficiency and leaf quality, thereby affecting silkworm growth and cocoon production.

Leaf spot diseases caused by fungal pathogens such as *Cercospora* and *Alternaria* species are also highly influenced by climatic conditions. Increased rainfall and prolonged leaf wetness create favourable conditions for pathogen germination and dissemination. Climate variability associated with irregular rainfall often leads to sudden outbreaks of leaf spot diseases. Warm and humid conditions additionally favour pathogen multiplication and spread.

Root rot and wilt diseases are becoming increasingly severe under changing rainfall patterns. Excessive soil moisture and waterlogging associated with heavy rainfall favour the development of soil-borne pathogens. Drought stress followed by sudden rainfall weakens root systems and increases susceptibility to infection. Climatic stress also alters soil microbial balance and increases disease severity.

Bacterial diseases are similarly favoured by warm and humid environmental conditions. Rain splash, irrigation water, and wind-driven moisture facilitate spread of bacterial pathogens. Climate-induced stress weakens plant defence mechanisms and increases vulnerability to bacterial infection. Consequently, changing climatic conditions are expected to intensify disease incidence in mulberry ecosystems.

11.4. INFLUENCE OF CLIMATE CHANGE ON MULBERRY DISEASE EPIDEMIOLOGY

Climate change significantly affects the epidemiology of mulberry diseases by altering environmental factors such as temperature, rainfall, humidity, and atmospheric carbon dioxide concentration. These climatic factors strongly influence pathogen survival, sporulation, infection efficiency, dissemination, and disease severity. Many fungal and bacterial pathogens thrive under warm and humid conditions, while prolonged drought stress weakens host plants and increases susceptibility to infection. Garrett *et al.* (2006) reported that climate change can alter disease cycles, pathogen distribution, and epidemic intensity in agricultural ecosystems. In mulberry cultivation, irregular rainfall patterns and prolonged humidity create favorable conditions for rapid multiplication and spread of fungal pathogens causing powdery mildew, leaf spot, and root diseases.

Elevated atmospheric CO_2 concentration indirectly influences mulberry diseases by modifying host plant physiology and canopy structure. Increased CO_2 often enhances vegetative growth and canopy density, resulting in poor air circulation and increased humidity within the crop canopy. Such microclimatic conditions are highly favorable for fungal disease development. Elevated CO_2 also alters carbon-to-nitrogen ratio and secondary metabolite composition in mulberry leaves, which may affect host resistance against pathogens (Manning and Tiedemann, 1995). Climate-induced physiological stress further weakens plant defense mechanisms and increases disease susceptibility.

Climate change additionally influences the occurrence and severity of soil-borne diseases in mulberry ecosystems. Excessive rainfall, flooding, and waterlogging associated with erratic precipitation patterns favor the development of soil-borne fungal pathogens such as Fusarium spp., Rhizoctonia spp., and Pythium spp., which cause root rot and wilt diseases. Drought stress followed by sudden rainfall weakens root systems and increases vulnerability to infection. Pautasso *et al.* (2012) emphasized that climate variability strongly affects soil temperature, moisture, and microbial interactions, thereby influencing the development and spread of soil-borne diseases in agricultural systems.

Changing climatic conditions also alter host–pathogen interactions in mulberry cultivation. High temperature, drought, and irregular rainfall negatively affect physiological processes such as photosynthesis, nutrient uptake, and secondary metabolite production, thereby weakening plant defense systems. At the same time, many pathogens adapt rapidly to environmental changes because of their short life cycles and high reproductive potential. Climate change may therefore enhance pathogen aggressiveness and virulence while reducing effectiveness of host resistance mechanisms. Garrett *et al.* (2011) reported that climate change can influence host–pathogen coevolution and increase the emergence of aggressive pathogen strains in crop ecosystems.

Development of climate-resilient disease management strategies is therefore essential for sustainable mulberry cultivation under changing environmental conditions. Integrated disease management approaches involving cultural practices, biological control, resistant varieties, climate forecasting, and need-based fungicide application provide effective and environmentally safe disease suppression. Proper field sanitation, timely pruning, balanced irrigation, and improved air circulation reduce disease incidence by minimizing favorable conditions for pathogen development. Biological control agents such as Trichoderma spp. and Pseudomonas fluorescens also offer eco-friendly alternatives for disease management. Weather-based disease forecasting systems can further help predict outbreaks and facilitate timely implementation of management practices under future climate scenarios.

11.5. CLIMATE CHANGE AND PEST POPULATION DYNAMICS

Climate change significantly alters pest population dynamics by affecting insect survival, development, fecundity, migration, and seasonal abundance. Rising temperature accelerates insect metabolism and shortens developmental duration, allowing pests to complete more generations annually. Yamamura and Kiritani (1998) estimated that global warming could considerably increase insect voltinism in agricultural ecosystems. Increased voltinism results in rapid population buildup and prolonged pest activity during cropping seasons.

Changing climate also affects geographical distribution of pests. Warming temperatures enable insects to survive in regions that were previously unsuitable because of cooler environmental conditions. Tripathi *et al.* (2017) reported that climate change may alter the distribution and diversity of mulberry insect fauna in temperate and subtropical regions of India. Such changes increase the risk of emergence of new pests and invasive species in mulberry cultivation.

Altered rainfall patterns and seasonal variability further influence pest emergence and outbreak patterns. Irregular rainfall disrupts normal seasonal cycles and affects synchronization between pests and management practices. Climate variability additionally influences interactions among pests, predators, parasitoids, and microbial antagonists. Reduced efficiency of natural enemies under changing climatic conditions often leads to ecological imbalance and increased pest outbreaks.

Elevated atmospheric CO_2 indirectly influences pest population dynamics through changes in host plant physiology. Increased carbon-to-nitrogen ratio and altered secondary metabolite composition influence herbivore feeding behaviour, growth, and survival (Zvereva and Kozlov, 2006). Sap-feeding insects often benefit from stress-induced physiological changes in host plants, leading to increased infestation severity.

Table 1. Influence of Climatic Factors on Major Mulberry Pests and Diseases

Pest/Disease	Scientific Name	Favorable Climatic Conditions	Major Symptoms/Damage
Mulberry thrips	*Pseudodendrothrips mori*	High temperature and low relative humidity	Leaf curling, bronzing, silvery patches, drying of leaves
Whitefly	*Dialeuropora decempuncta*	Warm temperature and prolonged dry conditions	Chlorosis, yellowing, honeydew secretion, sooty mold development
Pink mealybug	*Maconellicoccus hirsutus*	Warm and dry climate	Leaf curling, stunted growth, deformation
Papaya mealybug	*Paracoccus marginatus*	High temperature and drought stress	Sap depletion, curling, reduced vigor
Broad mite	*Polyphagotarsonemus latus*	Warm temperature with moderate humidity	Crinkling, bronzing, leaf deformation
Leaf roller	*Diaphania pulverulentalis*	Moderate temperature and high humidity	Leaf folding and defoliation
Powdery mildew	*Phyllactinia corylea*	Moderate temperature and high humidity	White powdery growth on leaves
Leaf spot disease	*Cercospora moricola* / *Alternaria* spp.	High humidity and prolonged leaf wetness	Necrotic spots and premature leaf fall
Root rot disease	*Fusarium* spp. / *Rhizoctonia* spp.	Excessive soil moisture and waterlogging	Root decay, wilting, plant death
Bacterial blight	*Pseudomonas mori*	Warm and humid conditions	Water-soaked lesions and leaf blight

11.6. CLIMATE-RESILIENT PEST AND DISEASE MANAGEMENT STRATEGIES

The increasing influence of climate change on mulberry pests and diseases necessitates the development of climate-resilient and sustainable management strategies. Integrated Pest Management (IPM) provides an eco-friendly and sustainable approach for managing pests and diseases under changing environmental conditions.

Cultural practices play a major role in reducing pest and disease incidence in mulberry cultivation. Timely pruning, field sanitation, removal of infested plant parts, balanced fertilization, proper irrigation, and weed management help minimize pest buildup and improve plant vigour. Excessive nitrogen fertilization should be avoided because it promotes succulent growth favourable for sap-feeding pests such as thrips, mealybugs, whiteflies, and mites.

Biological control is an important component of sustainable pest management in sericulture systems. Conservation and augmentation of natural enemies including ladybird beetles, chrysopids, spiders, parasitoids, and entomopathogenic fungi help maintain ecological balance and naturally suppress pest populations. Biological control methods are especially important in sericulture because they avoid pesticide residue problems that can adversely affect silkworm health and silk quality.

Semiochemical-based pest management has emerged as a promising climate-resilient approach for sustainable pest suppression. Semiochemicals such as pheromones, kairomones, herbivore-induced plant volatiles, and microbial volatiles can be utilized for monitoring, mass trapping, repellence,

and behavioral manipulation of pests. These approaches are environmentally safe, species-specific, and compatible with integrated pest management programs.

Mechanical methods including yellow sticky traps, light traps, and destruction of heavily infested shoots also contribute to pest reduction in mulberry ecosystems. Such methods are eco-friendly and suitable for integration with biological and cultural practices.

Although chemical pesticides may be necessary during severe pest outbreaks, their use should be strictly need-based and limited to situations where pest populations exceed economic threshold levels. Safer pesticides with low residual toxicity should be preferred in sericulture systems. Botanical pesticides and neem-based formulations provide safer alternatives compared to conventional synthetic insecticides.

Climate-based pest forecasting systems are increasingly important for predicting pest outbreaks and implementing timely management interventions. Monitoring environmental parameters such as temperature, rainfall, humidity, and wind speed helps identify favourable conditions for pest and disease development. Integration of weather forecasting with digital agriculture technologies can improve surveillance and decision-making under changing climate conditions (Table: 2).

11.7. CONCLUSION

Climate change is increasingly influencing the population dynamics, distribution, and severity of mulberry pests and diseases by altering environmental conditions such as temperature, rainfall, humidity, and atmospheric carbon dioxide concentration. These climatic changes significantly affect pest survival, development, reproduction, dispersal, and ecological interactions, often resulting in frequent outbreaks and deterioration of mulberry leaf quality. Climate-induced stress additionally weakens plant defence mechanisms and disrupts the activity of natural enemies, thereby aggravating pest and disease problems in mulberry ecosystems.

Major mulberry pests including thrips, whiteflies, mealybugs, broad mites, and leaf rollers are expected to become increasingly severe under warming conditions, while fungal and bacterial diseases are also showing altered epidemiology. Conventional management strategies alone are insufficient to address the challenges posed by climate change. Therefore, development of climate-resilient integrated pest and disease management strategies involving cultural practices, biological control, semiochemical-based approaches, climate forecasting, resistant varieties, and judicious use of safer pesticides is essential for sustainable mulberry cultivation and sericulture production. Future research focusing on climate-driven pest ecology, host–pest interactions, forecasting models, and eco-friendly technologies will play a vital role in ensuring sustainability of sericulture under changing global climate scenarios.

Table 2. Climate-Resilient Management Strategies for Mulberry Pests and Diseases

Management Strategy	Components/Practices	Role in Climate Resilience
Cultural management	Timely pruning, field sanitation, balanced fertilization, proper irrigation	Reduces pest buildup and improves plant vigor under climate stress
Biological control	Conservation of predators, parasitoids, and entomopathogenic fungi	Maintains ecological balance and suppresses pest populations naturally
Semiochemical-based management	Pheromones, kairomones, herbivore-induced plant volatiles	Enables monitoring, attraction, repellence, and behavioral manipulation

Management Strategy	Components/Practices	Role in Climate Resilience
Mechanical management	Yellow sticky traps, light traps, destruction of infested shoots	Reduces pest populations without chemical residues
Resistant varieties	Development of pest- and disease-tolerant mulberry genotypes	Enhances adaptation to changing climate conditions
Botanical pesticides	Neem-based formulations and plant-derived products	Provides eco-friendly pest suppression with minimal silkworm toxicity
Need-based chemical control	Judicious application of safer pesticides at ETL	Minimizes resistance development and pesticide residue problems
Climate forecasting and surveillance	Monitoring temperature, humidity, and rainfall patterns	Facilitates early warning and timely pest management interventions
Integrated Pest Management (IPM)	Integration of cultural, biological, mechanical, and chemical methods	Ensures sustainable and climate-resilient pest management

11.7. REFERENCES

Bale, J. S., Masters, G. J., Hodkinson, I. D., Awmack, C., Bezemer, T. M., Brown, V. K., Butterfield, J., Buse, A., Coulson, J. C., Farrar, J., Good, J. E. G., Harrington, R., Hartley, S., Jones, T. H., Lindroth, R. L., Press, M. C., Symrnioudis, I., Watt, A. D., & Whittaker, J. B. (2002). Herbivory in global climate change research: Direct effects of rising temperature on insect herbivores. *Global Change Biology*, 8(1), 1–16. https://doi.org/10.1046/j.1365-2486.2002.00451.x

Garrett, K. A., Dendy, S. P., Frank, E. E., Rouse, M. N., & Travers, S. E. (2006). Climate change effects on plant disease: Genomes to ecosystems. *Annual Review of Phytopathology*, 44, 489–509. https://doi.org/10.1146/annurev.phyto.44.070505.143420

Garrett, K. A., Forbes, G. A., Savary, S., *et al.* (2011). Complexity in climate-change impacts: An analytical framework for effects mediated by plant disease. *Plant Pathology*, 60(1), 15–30. https://doi.org/10.1111/j.1365-3059.2010.02413.x

IPCC. (2021). *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Jones, V. P., & Brown, R. D. (1983). Reproductive responses of the broad mite, Polyphagotarsonemus latus (Acari: Tarsonemidae), to constant temperature-humidity regimes. *Annals of the Entomological Society of America*, 76(3), 466–469. https://doi.org/10.1093/aesa/76.3.466

Luypaert, G., Witters, J., Van Huylenbroeck, J., Maes, M., De Riek, J., & De Clercq, P. (2014). Temperature-dependent development of the broad mite Polyphagotarsonemus latus (Acari: Tarsonemidae) on Rhododendron simsii. *Experimental and Applied Acarology*, *63*(3), 389-400.

Manning, W. J., & Tiedemann, A. V. (1995). Climate change: Potential effects of increased atmospheric carbon dioxide (CO_2), ozone (O_3), and ultraviolet-B (UV-B) radiation on plant diseases. *Environmental Pollution*, 88(2), 219–245. https://doi.org/10.1016/0269-7491(95)91446-R

Pautasso, M., Döring, T. F., Garbelotto, M., Pellis, L., & Jeger, M. J. (2012). Impacts of climate change on plant diseases — opinions and trends. *European Journal of Plant Pathology*, 133, 295–313. https://doi.org/10.1007/s10658-012-9936-1

Rahmathulla, V. K. (2012). Management of climatic factors for successful silkworm crop and higher silk production: A review. *Psyche*, 2012, 1–12. https://doi.org/10.1155/2012/121234

Rahmathulla, V. K., Sathyanarayana, K., & Angadi, B. S. (2015). Influence of abiotic factors on population dynamics of major insect pests of mulberry. *International Journal of Industrial Entomology*, 31(2), 118–125.

Sakthivel, N., Narendra Kumar, J. B., Dhahira Beevi, N., Devamani, M., & Teotia, R. S. (2019). *Mulberry pests: Current status and management practices*. Central Sericultural Research and Training Institute, Central Silk Board, Mysuru, India.

Sharma, H. C. (2014). Climate change effects on insects: Implications for crop protection and food security. *Journal of Crop Improvement*, 28(2), 229–259. https://doi.org/10.1080/15427528.2014.888349

Tripathi, V. K., Tiwari, A. K., & Singh, P. (2017). The effects of climate change on the mulberry insect fauna in India's temperate and subtropical regions. *JournalNX*, 3(11), 58–66.

Yamamura, K., & Kiritani, K. (1998). A simple method to estimate the potential increase in the number of generations under global warming in temperate zones. *Applied Entomology and Zoology*, 33(2), 289–298. https://doi.org/10.1303/aez.33.289

Zvereva, E. L., & Kozlov, M. V. (2006). Consequences of simultaneous elevation of carbon dioxide and temperature for plant–herbivore interactions: A meta-analysis. *Global Change Biology*, 12(1), 27–41. https://doi.org/10.1111/j.1365-2486.2005.01086.x

CHAPTER 12: CLIMATE-RESILIENT SOIL MANAGEMENT FOR SUSTAINABLE SERICULTURE

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12.1. INTRODUCTION

Sericulture, or silk production, is an sericultural practice that involves rearing mulberry silkworms (*Bombyx mori*). These silkworms are a type of moth originally native to China and were domesticated from their wild ancestor, *Bombyx mandarina*, with which they can still interbreed. Molecular research suggests that the flightless *B. mori* evolved from *B. mandarina* in China around 4,600 years ago (Arunkumar *et al.*, 2006). Silkworm are completely dependent on humans for survival and reproduction, making them the world's only fully domesticated insect. Due to domestication, they have become pale, lost the ability to fly, and rely entirely on humans for food and breeding. The sericulture industry produces more than 400 Mega tonnes of silk annually (Holland *et al.*, 2019) and can be expanded for large-scale production similar to coffee or cocoa cultivation. It can be practiced profitably at both small artisanal and large industrial levels. For thousands of years, sericulture has supported local economies and played an important role in the growth of trade networks and globalization during the first millennium CE. Today, sericulture is recognized as an Intangible Cultural Heritage by UNESCO. The sericulture industry involves three main activities: cultivating mulberry trees, rearing silkworms, and harvesting silk. Each of these activities can be carried out in a way that is respectful to the insects, the workers involved, and the environment.

Silkworm feed only on the leaves of mulberry trees, especially *Morus alba*, which is native to China and India. *M. alba* is a fast-growing small to medium-sized tree that can reach 10-20 m in height. It grows well in well-drained soils, including sandy, loamy, or clay soils, and thrives under full to partial sunlight. The tree is tolerant to frost and can also adapt to subtropical climates. The cultivation of mulberry leaves as feed for silkworms is a key component of sericulture. Approximately one metric ton of mulberry leaves can produce about 25-30 kg of silkworm cocoons. Sericulture has been an important part of many rural economies for centuries. Sericulture is a unique farming activity that supports the agricultural sector and provides sustainable livelihoods to millions of people worldwide. India is the world's second-largest producer of raw silk (Rana and Sethi, 2025).

A fundamental component of sustainable sericulture is effective soil management, as soil health directly influences the growth, productivity, and physiological vigour of mulberry plantations, which constitute the primary nutritional resource for silkworm rearing (Figure 1).

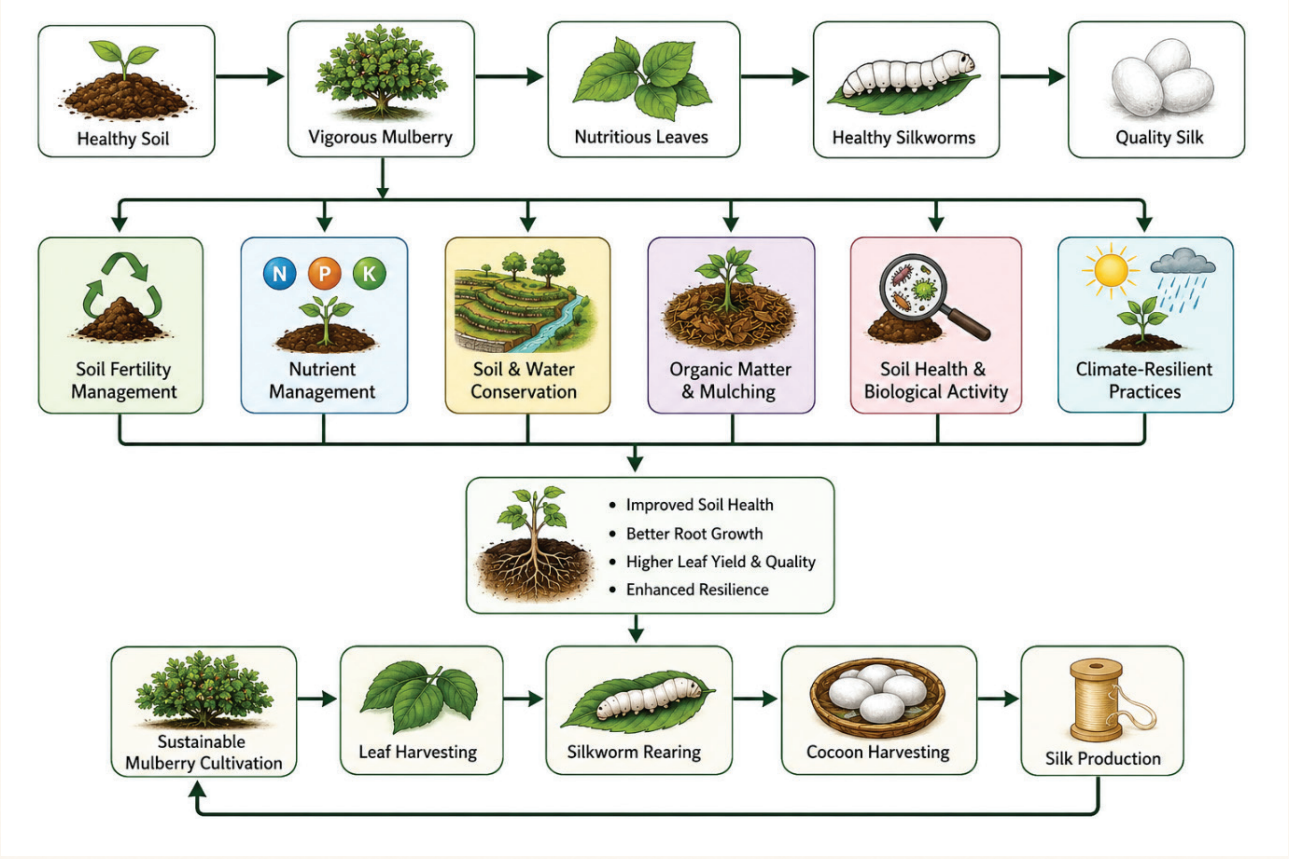


Figure 1: Sustainable mulberry silk production cycle

12.2. IMPORTANCE OF SOIL IN MULBERRY CULTIVATION

Soil quality is a fundamental determinant of agricultural productivity, as it regulates plant growth through the provision of essential nutrients, water availability, and a suitable habitat for beneficial soil microorganisms. In sericulture-based production systems, soil forms the ecological foundation for mulberry cultivation, which is indispensable for sustaining silkworm rearing. Mulberry plantations require favourable soil conditions for the development of extensive root systems and the production of nutrient-rich foliage essential for silkworm nutrition. Beyond nutrient supply, soil health also governs critical ecosystem functions such as water retention, erosion regulation, and overall agroecosystem resilience. Therefore, the adoption of scientifically sound soil management practices is essential for sustainable mulberry cultivation, ensuring long-term soil conservation, enhanced productivity, and ecological sustainability for future generations. Thus, the adoption of appropriate soil management practices is essential not only for sustaining high productivity and quality of mulberry foliage, but also for ensuring the long-term ecological and economic sustainability of sericulture systems.

12.2.1. Key soil management practices

12.2.1.1 Soil fertility management

Optimum soil fertility constitutes the foundation of successful mulberry cultivation. Regular soil testing for nutrient status and pH provides critical information for determining the requirement of soil amendments and nutrient management strategies. The ideal soil pH for mulberry cultivation ranges between 5.5 and 6.8; therefore, appropriate amendments are often necessary to regulate

soil acidity and maintain the desired hydrogen ion concentration (Saha *et al.*, 2022). Enhancement of soil organic matter improves soil structure, water-holding capacity, and nutrient availability, thereby promoting healthier plant growth. The incorporation of organic inputs such as compost, green manures, and animal manures can substantially enhance soil fertility and contribute to the long-term sustainability of mulberry-based production systems. Organic matter also promotes the development of a diverse and active microbial community, which plays a crucial role in nutrient cycling, soil fertility enhancement, and natural disease suppression. In sustainable sericulture systems, the application of organic amendments aligns with ecological principles and reduces dependence on synthetic fertilizers, which may adversely affect soil health and environmental quality. Organic inputs such as well-decomposed compost, green manures, and animal manures are highly effective in improving soil fertility and structural stability. These amendments supply essential plant nutrients, including nitrogen, phosphorus, and potassium, while simultaneously enhancing soil organic carbon content and stimulating beneficial microbial activity within the rhizosphere. Effective soil management begins with comprehensive soil assessment and testing. Evaluation of the physical, chemical, and biological properties of soil provides critical insights into its existing health and fertility status. Regular soil analysis enables sericulturists to identify nutrient deficiencies or toxicities, assess soil pH, and determine the availability of essential micronutrients and trace elements. Such information facilitates the development of an integrated soil fertility management strategy tailored to the specific nutritional and agronomic requirements of mulberry plantations.

12.2.1.2 Intercropping

The integration of mulberry cultivation with other crops through intercropping systems can substantially enhance soil health and overall agroecosystem sustainability. Diversified cropping systems promote biodiversity, which contributes to improved nutrient cycling, enhanced soil structure, and reduced incidence of pests and diseases. Leguminous crops are particularly advantageous due to their ability to biologically fix atmospheric nitrogen, thereby enriching soil fertility. Intercropping mulberry with compatible species such as legumes or vegetables enables efficient land utilization while improving the resilience and productivity of farming systems. Furthermore, increased biodiversity within and around mulberry plantations introduces diverse root architectures and biological interactions that positively influence soil fertility and structural stability. Such practices also support ecological balance and reduce pest pressure in mulberry-based production systems (Rafiqui *et al.*, 2023). Furthermore, the incorporation and maintenance of hedgerows and agroforestry-based production systems confer significant agroecological advantages by enhancing on-farm biodiversity and supporting functional ecological interactions. These systems provide ecological niches for beneficial arthropods, including pollinators and biological control agents, thereby strengthening natural pest regulation mechanisms. Simultaneously, agroforestry interventions contribute to improved soil conservation through the mitigation of erosive forces, stabilization of soil aggregates, and regulation of microclimatic conditions. Continuous deposition of leaf litter and biomass residues further enhances soil organic carbon pools, nutrient recycling processes, and overall soil biogeochemical functioning.

12.2.1.3 Conservation tillage and cover cropping

Conventional tillage practices often lead to soil degradation, accelerated erosion, disruption of soil aggregates, and depletion of soil organic matter. In contrast, conservation tillage approaches adopted in sustainable sericulture systems, including reduced-tillage and no-tillage practices, play a critical role in preserving soil structure, enhancing water retention capacity, and minimizing erosive losses.

These practices promote the stability of soil ecosystems by sustaining diverse and functionally active microbial communities that are essential for nutrient cycling and overall soil health.

Mulberry plantations require well-structured soils with adequate porosity to facilitate efficient root penetration, aeration, and water infiltration. Soil structural integrity can be significantly improved through reduced tillage practices and the incorporation of organic matter. Unlike conventional tillage, which frequently results in soil compaction and habitat disruption for soil biota, reduced tillage conserves soil architecture and maintains favourable conditions for beneficial organisms. Similarly, the application of ground cover through mulching or cover cropping protects the soil surface from erosive forces caused by wind and water, thereby reducing nutrient losses and maintaining soil fertility. Cover crops such as clover and vetch are particularly valuable for erosion control, weed suppression, and enhancement of soil organic carbon through biomass incorporation. Upon decomposition, these cover crops release essential nutrients that improve soil fertility and support healthier mulberry growth (Petkov *et al.*, 2015). Furthermore, soil and water conservation measures such as contour farming and terracing on sloping lands effectively reduce surface runoff, mitigate soil erosion, and improve in situ moisture conservation, thereby enhancing the resilience and sustainability of mulberry-based production systems.

12.2.1.4 Integrated pest management

Soil health is intrinsically linked with sustainable pest management strategies in mulberry-based sericulture systems. Integrated Pest Management (IPM) represents a holistic and ecologically driven approach that integrates cultural, biological, and judicious chemical interventions for effective pest suppression while minimizing adverse environmental impacts. Adoption of IPM practices substantially reduces the dependence on synthetic pesticides, thereby preventing soil contamination, preserving beneficial microbial communities, and maintaining soil ecological integrity.

Priority is therefore given to biological control agents, natural predators, biopesticides, and ecologically sound cultural practices for effective pest regulation without disrupting soil ecosystem functioning. Healthy soils support diverse and resilient biological communities that naturally contribute to pest suppression and ecological balance. Studies have demonstrated that biochar application can significantly reduce the incidence of tukra, powdery mildew, and leaf spot diseases in mulberry plantations (Ahmed *et al.*, 2017). Furthermore, crop rotation and the introduction of pest- and disease-resistant mulberry varieties can reduce the need for chemical interventions and enhance system resilience. Continuous pest surveillance, combined with the strategic application of biopesticides and organic insect repellents, contributes to the development of a sustainable, environmentally compatible, and long-term pest management framework in sericulture systems.

12.3. STEPS TOWARDS SUSTAINABLE SERICULTURE

1. Scientific research and technological innovations in sericulture should be strategically oriented toward the optimization and valorisation of underexploited components of the silk value chain, particularly the effective utilization of silkworm secondary by-products. Such advancements necessitate substantial governmental intervention through sustained financial support, policy-driven incentives, and investment in interdisciplinary research and development programmes.
2. Universities and agricultural research institutions should formulate comprehensive and interdisciplinary curricula in sericulture and allied agricultural sciences to strengthen technical competence, analytical capabilities, and skill-oriented professional training at all academic levels. Furthermore, the establishment of robust institutional linkages among governmental agencies, research organizations, universities, private enterprises, non-governmental

organizations, and industry professionals is imperative for fostering innovation, technology transfer, and sustainable sectoral development.

3. Government agencies should institutionalize a decentralized framework of sericulture extension services at regional and local levels to enhance awareness generation, capacity building, and dissemination of scientific knowledge among farming communities. These extension systems should facilitate the transfer of advanced technologies through structured training programmes, field demonstrations, participatory approaches, and continuous technical advisory support.
4. Comprehensive documentation, characterization, and scientific evaluation of indigenous and contemporary sericulture practices are essential for strengthening knowledge dissemination, educational outreach, and stakeholder sensitization. Such systematic documentation would also contribute toward the preservation of traditional knowledge systems while facilitating evidence-based policy formulation and technological interventions.
5. The development of an integrated and resource-efficient farming system incorporating sericulture with complementary agricultural enterprises, including dairy and livestock production, aquaculture, poultry farming, and horticultural crop cultivation, should be prioritized. Such integrated production systems can enhance ecological sustainability, optimize nutrient cycling, improve resource-use efficiency, diversify farm income, and strengthen the resilience of rural livelihoods.
6. Governments and financial institutions should establish dedicated credit mechanisms and revolving reserve funds providing low-interest loans and financial incentives to stakeholders engaged in sericulture. The availability of accessible institutional credit would significantly enhance investment capacity, operational sustainability, and entrepreneurial participation within the sericulture sector.
7. Strategic infrastructural development, particularly the establishment of decentralized silk processing and value-addition industries across major sericultural regions, should be emphasized to strengthen the silk supply chain. Such industrial expansion would not only generate substantial rural employment opportunities but also ensure market accessibility, reduce post-harvest and transportation constraints, and enhance the economic viability and competitiveness of silk-based enterprises.

12.4. CLIMATIC PERTURBATIONS AND THEIR IMPLICATIONS FOR SERICULTURAL PRODUCTION SYSTEMS

12.4.1. Influence of temperature variability on the physiological growth and development of silkworm

The growth, physiological metabolism, and developmental processes of silkworm are highly influenced by fluctuations in environmental temperature. As a poikilothermic organism, the silkworm is extremely sensitive to thermal variations, and its survival, larval development, feeding behaviour, cocoon formation, and silk productivity are regulated by surrounding temperature conditions. Silkworm growth and development exhibit a strong positive correlation with optimum temperature regimes (Rahmathulla, 2012). Maintenance of favourable and stable thermal conditions is essential for normal physiological functioning, efficient nutrient assimilation, and successful completion of larval and pupal stages. Conversely, exposure to suboptimal or extreme temperature fluctuations adversely affects metabolic activities, retards growth, impairs silk gland development, and ultimately reduces cocoon yield and silk quality.

The optimum temperature regime for successful rearing of silkworm generally ranges between 25-26°C, which is considered highly conducive for normal physiological growth, metabolic activity, larval development, and efficient silk production. Maintenance of this favourable thermal environment ensures proper feeding behaviour, nutrient assimilation, moulting, cocoon formation,

and overall survivability of silkworm larvae. However, deviations from this optimum temperature range, particularly exposure to lower temperatures of 20-21°C or elevated temperatures exceeding 28-29°C, exert adverse effects on the growth and developmental performance of silkworms (Zhang, 2018). Suboptimal thermal conditions may retard metabolic processes, reduce feeding efficiency, prolong larval duration, impair silk gland development, and increase susceptibility to physiological stress and pathogenic infections. Consequently, such temperature-induced stress conditions significantly diminish cocoon quality, silk filament yield, and the overall productivity of sericultural systems.

Exposure to heat shock conditions has been reported to markedly elevate larval mortality rates, accelerate larval developmental stages, and significantly reduce larval body weight. Moreover, thermal stress adversely affects food consumption, assimilation, and utilization efficiency in silkworms, thereby impairing metabolic performance and nutrient conversion. Such physiological disturbances ultimately culminate in diminished cocoon formation efficiency, while in severe cases, the successful development of pupae and adult imagoes may also be completely inhibited. The optimum rearing temperature for young silkworm larvae ranges between 26-28°C, accompanied by a relative humidity of approximately 80-85%, which is essential for ensuring proper growth, survival, and physiological development during the early instars. In contrast, for larvae that have attained the later developmental stages, the temperature is generally maintained at 23-24°C with a comparatively lower relative humidity of around 70-75%, thereby providing favourable environmental conditions for healthy maturation and efficient cocoon development (Zhang, 2018). Substantial deviations from the optimum environmental conditions may induce physiological abnormalities that adversely affect the functional activity of the silk glands. Such stress conditions can suppress the biosynthetic processes involved in silk protein production, thereby reducing the secretion of the fluid protein constituents essential for fibre formation and ultimately impairing silk yield and quality. (Bekkamov and Samatova, 2023)

Table 1. Impacts of major climate stressors on sericulture systems (Source: Kaushik *et al.* (2025)

Stressor	Impact on mulberry	Impact on silk-worms	Impact on non-mul-berry systems	References
Heat	Reduced photosynthesis, impaired leaf water status, and decline in primary metabolites	Accelerated larval development but reduced larval mass, cocoon weight, shell ratio, filament length	High mortality in outdoor systems (e.g., Muga); reduced moth emergence in Eri	Li *et al.*, 2022; Sarkhel *et al.*, 2017; Ashraf and Qamar, 2023; Lalitha *et al.*, 2020
Drought	Leaf biomass decline, reduced nutritive value, osmotic stress, root vulnerability	Increased susceptibility to diseases due to stress; oxidative damage	Reduced availability of Soalu and Som host plants in Muga systems	Ackah *et al.*, 2021; Das, 2021; Sujatha *et al.*, 2024
Flooding / Excess rainfall	Waterlogging, fungal attacks on roots, degraded leaf quality	Higher incidence of flacherie and muscardine diseases due to humidity fluctuations	Habitat loss and reduced rearing success in outdoor silk systems	Sujatha *et al.*, 2024; Manzoor and Qayoom, 2024

Stressor	Impact on mulberry	Impact on silk-worms	Impact on non-mul-berry systems	References
Erratic rainfall	Misaligned pruning and leaf flush cycles; inconsistent leaf yield	Stress during late instars leading to poor cocoon formation	Unpredictable rainfall directly disrupts outdoor Muga rearing	Manzoor and Qayoom, 2024; Das *et al.*, 2023
Pests / Diseases	More frequent leaf feeders, sap-suckers, and mealybugs	Increased Uzi fly, viral and bacterial disease outbreaks, mortality	Outdoor silk (Muga, Tasar) is highly exposed to pest/ disease spread due to uncontrolled environments	Subedi *et al.*, 2023; Deepika *et al.*, 2024

Table 2. Comparative vulnerability of different silkworm types under climate change (Source: Kaushik *et al.* (2025)

Silkworm type	Climate exposure (indoor/ outdoor)	Sensitivity to climate change	Adaptation options
Mulberry (*Bombyx mori*)	Mostly indoor (controlled rearing)	Moderate heat and erratic rainfall reduce leaf quality; silkworms are sensitive to high humidity	Heat/drought-tolerant mulberry varieties, microclimate control in rearing houses, resistant silkworm strains
Tasar (*Antheraea mylitta*)	Outdoor (forest-based, Central and Eastern India)	High exposed to deforestation, pest/disease outbreaks, and irregular rainfall	Host-plant conservation, habitat restoration, pest management, integration with agroforestry
Temperate Tasar (*Antheraea proylei*)	Outdoor (temperate Himalayan belt)	Highly sensitive to fluctuating temperatures, reduced forest cover, and climate-induced habitat shifts	Protection of natural habitats, selective breeding, pest/disease control, expansion of agroforestry systems
Muga (*Antheraea assamensis*)	Strictly outdoor (NE India)	Very high, extremely climate-sensitive; rainfall shifts reduce host availability and silkworm survival	Protection of Som/Soalu plantations, climate-adapted scheduling, early warning systems, diversification of income
Eri (*Samia ricini*)	Mostly indoor (semi-domesticated)	Low-moderate more flexible due to multiple host plants; but heat reduces seed cocoon viability	Indoor rearing expansion, alternate host use, heat-resilient strains, farmer training

12.4.2. Influence of extreme weather events on the physiological growth and development of silkworms

Climate change has considerably intensified the occurrence of extreme weather events, including prolonged droughts, severe heat waves, and heavy precipitation, all of which exert profound adverse effects on silkworm rearing and cocoon productivity. Temperature plays a pivotal role in regulating silkworm physiology, metabolic activities, and cocoon formation, with the optimum thermal

range for silkworm growth generally lying between 22-27°C (Rahmathulla, 2012). Temperatures falling below 20°C or exceeding 30°C are considered highly unfavourable for silkworm health, often predisposing larvae, particularly during the early instars, to increased disease incidence and physiological stress (Rahmathulla, 2012).

Elevated temperatures during the later larval instars may accelerate larval growth and shorten the developmental duration, whereas lower temperatures tend to retard growth and prolong the larval period. Silkworms are especially vulnerable to extreme heat stress, which disrupts normal protein synthesis pathways and induces extensive cellular damage (Sureshkumar *et al* 2002). Excessive thermal stress may adversely affect vital biological macromolecules, including DNA, RNA, lipids, and proteins, thereby impairing cellular integrity and metabolic efficiency (Gowda and Reddy, 2007). In response to such stress conditions, silkworms activate heat shock response mechanisms characterized by the expression of heat shock proteins (HSPs), which function as molecular chaperones to protect cellular proteins from denaturation and degradation (Nagaraju, 2002). Owing to their protective role in enhancing thermal tolerance, heat shock response systems are presently being exploited in breeding programmes aimed at developing thermotolerant silkworm varieties capable of withstanding climate-induced thermal stress.

Ambient relative humidity constitutes a critical microclimatic determinant governing silkworm rearing efficiency and physiological performance, with the optimum relative humidity range generally maintained between 75-85% for successful larval growth and cocoon development (Singh and Saratchandra, 2012). Deviations from this optimal hygrometric regime, particularly when coupled with elevated temperatures, generate highly conducive conditions for the proliferation and transmission of pathogenic microorganisms affecting silkworm populations. Increased atmospheric moisture, in association with thermal stress, enhances the incidence and severity of viral, bacterial, and fungal diseases in silkworms by facilitating pathogen survival, replication, and infectivity. Previous investigations have demonstrated a positive correlation between fluctuations in humidity levels and the occurrence of microbial infections in silkworm larvae (Sharma *et al.*, 2020).

Furthermore, climate change-induced extreme precipitation events and hydrological disturbances exert substantial detrimental impacts on mulberry cultivation, the primary nutritional resource for silkworms. Flooding resulting from intense rainfall events can severely damage or completely destroy mulberry plantations, thereby disrupting feed availability and compromising sericultural productivity. Conversely, prolonged drought conditions and inadequate soil moisture availability adversely influence both the qualitative and quantitative attributes of mulberry foliage by impairing leaf succulence, nutrient composition, and biomass accumulation. Such reductions in mulberry leaf nutritional quality negatively affect larval feeding efficiency, growth, metabolism, silk protein synthesis, and cocoon formation in silkworms (Rahmathulla, 2012). In addition, alterations in climatic variables and seasonal weather patterns associated with ongoing climate change are progressively modifying traditional silkworm rearing seasons, thereby affecting the synchronization between mulberry leaf availability and silkworm developmental requirements.

Extreme climatic events exert profound adverse effects not only on silkworm growth and cocoon production but also on post-cocoon technological and commercial parameters associated with silk quality. Elevated temperatures prevailing during the cocoon spinning phase significantly impair cocoon reelability by adversely influencing filament formation, sericin deposition, and the structural uniformity of silk fibers. Thermal stress during spinning may consequently reduce raw silk recovery efficiency and induce substantial variability in filament denier, thereby compromising the uniformity, tensile strength, and market value of raw silk produced (Mathur *et al.*, 2000).

Moreover, cocoon moisture content represents a critical determinant of post-cocoon processing efficiency and silk quality. For optimum preservation, storage stability, and reelability, cocoons should ideally possess a moisture content below 20%. Excessive moisture accumulation within cocoons promotes physiological deterioration, microbial contamination, filament adhesion, and degeneration of silk protein integrity, all of which negatively influence reeling performance and raw silk yield (Gowda and Reddy, 2007). Climatic anomalies characterized by elevated atmospheric humidity and fluctuating temperatures, therefore pose serious challenges to maintaining desirable cocoon physicochemical properties and ensuring high-quality silk production.

12.5. INFLUENCE OF CLIMATE CHANGE ON SILKWORM HOST PLANT DYNAMICS

12.5.1. Effects of altered precipitation regimes on mulberry cultivation and productivity

Climate change exerts profound influences on the physiological and phenological processes of mulberry plants, particularly affecting dormancy regulation, bud break initiation, and sprouting behaviour (Shaista *et al.*, 2023). Rising global temperatures and associated climatic perturbations alter the thermal and moisture regimes essential for normal phenological development, thereby disrupting the synchronization between mulberry growth cycles and silkworm rearing schedules. Their investigation revealed that climate change-induced warming has prolonged the sprouting period of mulberry plants by approximately 10 days (Shaista *et al.*, 2023), indicating substantial modifications in seasonal growth dynamics and vegetative developmental patterns.

Furthermore, the Western Himalayan region, an ecologically significant zone for mulberry cultivation and sericultural activities, is experiencing considerable spatiotemporal variability in precipitation regimes. Saini and Attada (2023) reported heterogeneous alterations in Indian Summer Monsoon (ISM) rainfall distribution across the region, wherein certain areas are receiving intensified monsoonal precipitation while others are witnessing declining rainfall frequency and reduced precipitation events. Climate projection models further indicate increased rainfall variability characterized by a greater frequency of extreme precipitation events, erratic monsoonal behaviour, and prolonged intra-seasonal dry spells during the ISM period (Saini and Attada, 2023). Such hydro-meteorological anomalies are likely to adversely influence mulberry growth, soil moisture availability, nutrient assimilation, and leaf biomass production, thereby imposing significant constraints on sustainable sericultural productivity and silkworm rearing systems in the Western Himalayan ecosystem.

Kambale *et al.* (2023) investigated the projected trends in crop water requirements of mulberry under different climate change scenarios and reported a consistent increasing trend in crop evapotranspiration (ETc) across all studied regions and climatic projections. The observed increase in ETc indicates a strong interrelationship between climatic variability and the water requirements of mulberry cultivation systems. Elevated temperatures, altered precipitation regimes, and increased atmospheric evaporative demand associated with climate change are expected to intensify transpiration losses and soil water depletion, thereby substantially increasing irrigation requirements for sustainable mulberry production (Kambale *et al.*, 2023). Such changes may adversely affect mulberry leaf yield, physiological efficiency, nutrient uptake, and overall plantation productivity under water-limited conditions.

Seidavi *et al.* (2017) further predicted that global warming could significantly reduce mulberry leaf yield while simultaneously increasing silk filament breakage, ultimately leading to declines in raw silk production and silk content. These findings suggest that climate change exerts direct physiological and biochemical effects at the host plant level, which subsequently influence silkworm nutrition, growth performance, cocoon quality, and silk synthesis. In addition to these direct impacts,

climate-induced ecological disturbances are also expected to alter insect pest dynamics and disease epidemiology within mulberry-based sericultural ecosystems.

Among the most severe consequences of climate change is its influence on the population dynamics, distribution, and outbreak frequency of insect pests associated with mulberry cultivation. Seidavi *et al.* (2017) observed substantial alterations in pest incidence patterns across mulberry-growing regions, with several pests exhibiting increased prevalence, expanded seasonal occurrence, and recurrent infestations. Pests such as the Bihar hairy caterpillar, pink mealybug, thrips, leaf webber, and mites, which were previously sporadic or seasonally restricted, are now being reported with much greater frequency and persistence throughout the year (Seidavi *et al.*, 2017). Elevated temperatures and changing humidity regimes likely accelerate pest reproductive cycles, enhance survival rates, and facilitate wider geographical distribution. Moreover, climate change has also contributed to increased incidence and severity of mulberry diseases. Pathological conditions such as root-knot disease, powdery mildew, leaf rust, and leaf spot, which were historically considered relatively uncommon, have emerged as widespread and economically significant diseases affecting mulberry plantations in many regions of the world (Seidavi *et al.*, 2017). The increased prevalence of these phyto-pathological disorders may be attributed to favorable environmental conditions for pathogen proliferation under changing climatic scenarios, thereby posing serious threats to mulberry health, leaf productivity, and the sustainability of global sericulture systems.

Elevated atmospheric carbon dioxide (CO_2) concentrations may enhance water use efficiency and improve Photosystem II (PSII) functionality in mulberry seedling leaves under drought stress conditions by promoting photosynthetic carbon assimilation and reducing stomatal water loss. Liu *et al.* (2019) reported that increased CO_2 levels can partially mitigate the adverse physiological effects of water deficit stress in mulberry plants through improved osmotic regulation, chlorophyll stability, and photosynthetic efficiency. However, these beneficial effects are unlikely to occur in isolation and may be substantially counterbalanced by other concomitant manifestations of climate change. According to Liu *et al.* (2019), the positive impacts of elevated CO_2 on mulberry physiology may be offset by rising ambient temperatures, increased concentrations of tropospheric ozone, and altered precipitation regimes associated with global climate change. Elevated temperatures can intensify respiratory losses, disrupt enzymatic activities, and impair photosynthetic metabolism, whereas higher tropospheric ozone concentrations induce oxidative stress, cellular membrane damage, and premature leaf senescence in mulberry plants (Liu *et al.*, 2019). Additionally, irregular precipitation patterns, including prolonged droughts and extreme rainfall events, further exacerbate physiological stress and negatively influence plant growth, leaf biomass accumulation, and nutritional quality. Consequently, the combined and interactive effects of multiple climatic stressors may ultimately diminish the adaptive advantages conferred by elevated atmospheric CO_2 concentrations in mulberry cultivation systems.Top of Form

12.6. CONCLUSION

Climate-resilient soil management practices play a crucial role in improving farmers' knowledge, adoption of sustainable agricultural techniques, and long-term environmental sustainability. Farmers trained in climate-resilient soil management demonstrated better technical understanding and more informed decision-making than untrained farmers. However, the continued reliance on chemical inputs highlights the need for sustained awareness and behavioural change interventions.

Future strategies should focus on strengthening extension services and promoting sustainable soil management practices to enhance farmer livelihoods and environmental resilience. An integrated approach involving farmer capacity building, institutional support, and evidence-based policies is

essential. Greater emphasis should be placed on eco-friendly soil and nutrient management practices through farmer field schools and collaboration with NGOs. Expanding digital advisory services and improving market support systems can further strengthen income stability. Policymakers should encourage training programs, promote subsidies for bio-inputs, and integrate climate-resilient soil management into broader rural development initiatives to ensure long-term agricultural and socio-economic sustainability. Sustainable mulberry production is fundamentally dependent on scientifically informed soil management practices that enhance soil fertility, structural stability, and biological diversity. Key components of sustainable soil management in sericulture include comprehensive soil assessment, incorporation of organic amendments, crop rotation, conservation tillage, cover cropping, integrated pest management, and efficient water management strategies. Collectively, these practices contribute to improved soil functionality, enhanced nutrient dynamics, and greater agroecosystem resilience.

Sustainable soil management is essential not only for achieving higher mulberry leaf productivity and meeting the growing global demand for silk, but also for preserving environmental quality and ecological integrity within sericulture systems. In the context of increasing climatic and ecological challenges, the long-term sustainability of sericulture largely depends on the conservation and restoration of soil health.

Therefore, responsible soil stewardship must be recognized as both an agricultural necessity and a strategic imperative for safeguarding the future of sericulture and the livelihoods dependent upon it. Through the adoption of ecologically sustainable and resource-efficient soil management practices, mulberry cultivation can evolve into a resilient production system that supports long-term productivity, environmental sustainability, and intergenerational resource conservation.

12.7. REFERENCE

Ackah M, Shi Y, Wu M, Wang L, Guo P, Guo L, *et al.* (2021) Metabolomics response to drought stress in *Morus alba* L. variety Yu-711. Plants (Basel). 10(8):1636.

Ahmed, F., Islam, M. S. and Iqbal, M. T. (2017). Biochar amendment improves soil fertility and productivity of mulberry plant. Eurasian Journal of Soil Science, 6(3): 226-237

Arunkumar, K. P., Metta, M., and Nagaraju, J. (2006). Molecular phylogeny of silkmoths reveals the origin of domesticated silkmoth, *Bombyx mori* from Chinese *Bombyx mandarina* and paternal inheritance of *Antheraea proylei* mitochondrial DNA. *Molecular Phylogenetics and Evolution*, *40*(2), 419-427.

Ashraf H, Qamar A. (2023) A review on heat stress altering the insect life history strategies and underlying mechanisms: special reference to an economically important Lepidoptera, *Bombyx mori* (Linnaeus, 1758) (Lepidoptera: Bombycidae). Lepidopterol. 51(202):339-357.

Bekkamov C, Samatova S. (2023) Impact of temperature variations in worm containers and nutrition amount on silk glands and silk productivity. In IOP Conference Series: Earth and Environmental Science. 1142(1):012065.

Das N. (2021) Impact of Muga Silk (*Antheraea assamensis*) on community livelihood in the Brahmaputra Valley of Assam-India. Am J Environ Prot. 10(3):59-65.

Das P, Saikia M, Neog D. Effect of climate change on Eri and Muga cultivation and the resultant impact on rural income and employment in Assam. J Livest Sci. 2023;14. 25.

Deepika I, Ramesh KV, Kumar I, Singh A, Debnath R, Dubey H, *et al.* (2024) Molecular diagnostics in sericulture: a paradigm shift towards disease diagnosis in silkworms. Entomol Exp Appl. 172(5):372-382. 24.

Gowda V, Reddy MS. (2007) Influence of different environmental conditions on cocoon parameters and their effects on reeling performance of bivoltine hybrids of silkworm, *Bombyx mori* L. Journal of Sericultural Research. 2(1):1-8.

Holland, C., Numata, K., Rnjak-Kovacina, J., and Seib, F. P. (2019). The biomedical use of silk: past, present, future. *Advanced healthcare materials*, *8*(1), 1800465.

Kambale JB, Barikara U, Hadimani DK. (2023) Climate Change and Its Impact on Crop Water Requirement of Mulberry (*Morus* spp., Moraceae) Crop in Yadgir District, Karnataka, India. International Journal of Environment and Climate Change. 13(8):1969-1977.

Kaushik, A., Borah, G., Saikia, S., Kaushiki, B., and Phukan, T. (2025). Climate-resilient sericulture: Strategies for sustainable silk production in a changing climate. *International Journal of Advanced Biochemistry Research*, 9(8): 891–897. www.biochemjournal.com

Lalitha N, Singha BB, Das B, Choudhury B. (2020) Impact of climate change in prospects of Eri silkworm seed production in Assam-a review. Innov Farming. 5(1):10-14.

Li R, Su X, Zhou R, Zhang Y, Wang T. (2022) Molecular mechanism of mulberry response to drought stress revealed by complementary transcriptomic and iTRAQ analyses. BMC Plant Biol. 2022;22(1):36.

Liu, X., Zhang, H., Wang, J., Wu, X., Ma, S., Xu, Z., Zhou, T., Xu, N., Tang, X., and An, B. (2019). Increased CO_2 concentrations increasing water use efficiency and improvement PSII function of mulberry seedling leaves under drought stress. *Journal of Plant Interactions*, 14(1): 213–223. DOI: 10.1080/17429145.2019.1603405

Manzoor S, Qayoom K. (2024) Impact of climate change on sericulture. Asian Res J Agric. 17(3):107-113. 7. Bhat MR, Radha P, Faruk AA, Vas M, Brahma D, Bora NR, *et al.* Climate change and its impact on sericulture. Int J Zool Appl Biosci. 2024;9(4):13-25.

Mathur *et al.*, (2000) Effect of tender shoot feeding on silkworm technological parameters of silkworm, *Bombyx mori* L. Sericologia. 2000;40:79-89

Nagaraju J. (2002) Application of genetic principles for improving silk production. Current Science. 2002;83(4):409-414.

Petkov, Z. and Street, V. (2015). Organic mulberry plantations. Organic Sericulture-Now and the Future ORGASERI-2015 Sinaia, Romania April 19th -24th 2015: 65

Rafiqui, A. R., Ganie, A. H., Mir, A. H., Ayoub, O. B., Mir, M. R., Khan, I. L. and Sharma, R. K. (2023). Intercropping in Mulberry (*Morus* spp.): A Review. Research Journal of Chemical and Environmental Sciences, 11 (3): 01-07.

Rahmathulla VK. (2012) Management of climatic factors for successful silkworm (*Bombyx mori* L.) crop and higher silk production: a review. Psyche: A Journal of Entomology. (1):121234.

Rana P, Sethi S. (2025) Utilising agro-waste in textile industry: advancing sustainability with a year-round waste cycle. Mater Circular Econ. 7(1), 30. https://doi.org/10.1007/s42824-025-00188-3

Saha, S., Kumar, P., Raj, S. and Choudhury, B. M. (2022). Sericulture: Management and practices of mulberry silkworm. International Journal of Pharmaceutical Research and Applications, 7(2): 35-46.

Saini, R., and Attada, R. (2023). Analysis of Himalayan summer monsoon rainfall characteristics using Indian high-resolution regional reanalysis. *International Journal of Climatology*, 1–22. DOI: 10.1002/joc.8087

Sarkhel S, Shrivastava S, Pouranik M. (2017) The effective influence of temperature on the varied characteristic of silkworm: a review. Asian J Exp Sci. 31(2):31-37.

Seidavi A, Dadashbeiki M, Alimohammadi Saraei MH, van den Hoven R, Payan Carreira R, Laudadio V, Tufarelli V. (2017) Effects of dietary inclusion level of a mixture of probiotic cultures and enzymes on broiler chickens' immunity response. Environmental Science and Pollution Research. 24:4637-4644

Shaista Mehraj, Afifa S. Kamili NA, Ganie MR, Mir, Mehreen Manzoor RK, Sharma SA, Mir. (2023) Correlation Analysis between Mulberry Sprouting and Weather Parameters under Changing Climate Scenario. Research Journal of Chemical and Environmental Sciences. 11:1-4.

Sharma A, Chanotra S, Gupta R, Kumar R. (2020) Influence of climate change on cocoon crop loss under subtropical conditions. International Journal of Current Microbiology and Applied Sciences. 9(5):167-171.

Singh RK, Saratchandra B. (2012) Climate Change and Sustainable Agriculture. Journal of Environmental Science and Engineering. 54(2):161-174

Subedi B, Poudel A, Aryal S. (2023)The impact of climate change on insect pest biology and ecology: implications for pest management strategies, crop production, and food security. J Agric Food Res. 14:100733. 23.

Sujatha G, Kumar GA, Teja K, Devi DL, Rupali J, Gautam SK. (2024)A comprehensive review of the effect and mitigation of climate change on sericulture. Int J Environ Clim Change. 14(7):776-788. 6.

Sureshkumar, P., Siva Reddy, G., and Muthulakshmi, M. (2002). Heat stress responses in the silkworm, Bombyx mori: Disruption of protein synthesis and damage to DNA, RNA, and lipids. Journal of Insect Physiology, 48(2), 143-150

Zhang Y. (2018) Determination of optimal temperature for production of quality eri silkworm cocoon and seed. Agricultural Research and Technology: Open Access Journal. 17(3):2-9.



TASAR



CHAPTER 1: IMPACT OF CLIMATE CHANGE ON TASAR CULTURE AND ADAPTATION STRATEGIES

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1.1. INTRODUCTION

India occupies a unique position in the global silk sector as it is the only country producing all five commercially important varieties of silk, namely Mulberry, Tropical Tasar, Oak Tasar, Eri, and Muga silk (Central Silk Board, 2023). Among these, tropical tasar silk produced by the wild silkworm Antheraea *mylitta* is primarily forest-based and deeply associated with the socio-economic and cultural life of tribal populations inhabiting the central and eastern Indian states such as Jharkhand, Chhattisgarh, Odisha, Maharashtra, Telangana, Andhra Pradesh, Bihar, and Madhya Pradesh (Suryanarayana and Srivastava, 2005; Reddy *et al.,* 2013). Tasar culture is mainly practiced on forest tree species such as *Terminalia arjuna*, *Terminalia tomentosa* and *Shorea robusta*, and provides supplementary income and livelihood security to nearly 3.5 lakh tribal families in India (Dash *et al.,* 2011). The industry is considered highly suitable for resource-poor communities due to its compatibility with forest ecosystems, low investment requirement, and potential for generating year-round employment (Nayak *et al.,* 2018).

Climate plays a significant role in determining the productivity and sustainability of tasar culture because the growth, development, and survival of both host plants and silkworms are highly dependent on environmental conditions such as temperature, rainfall, humidity, and photoperiod (Bale *et al.*, 2002; Yamamura and Kiritani, 1998). Climate change, characterized by long-term alterations in temperature, precipitation, atmospheric carbon dioxide concentration, and frequency of extreme weather events, has emerged as one of the most serious global environmental challenges of the twenty-first century (IPCC, 2021). Rising global temperatures and increased climatic variability are expected to influence agricultural and forest ecosystems profoundly, particularly in tropical and subtropical regions (Parry *et al.*, 2007). In India, climate change poses a serious threat to agriculture, biodiversity, and forest-dependent livelihood systems due to increasing incidences of droughts, erratic rainfall, floods, and heat waves (Prasad *et al.*, 2017).

Tasar sericulture is highly vulnerable to climate variability because it relies on open-field rearing systems and natural forest ecosystems (Das *et al.,* 2011). Variations in temperature and rainfall directly affect host plant phenology, leaf quality, pest incidence, silkworm growth, cocoon quality, and survival rates (Coviella and Trumble, 1999; Hunter, 2001). Elevated atmospheric CO_2 may increase plant biomass; however, it often deteriorates leaf nutritional quality by reducing nitrogen content and altering carbon–nitrogen balance, thereby negatively affecting silkworm nutrition and digestibility (Lincoln *et al.,* 1993; Coviella and Trumble, 1999). Similarly, high temperature stress accelerates insect metabolism and developmental rates, increases pest outbreaks, and may result in additional insect generations per year (Bale *et al.,* 2002; Yamamura and Kiritani, 1998). The tasar silkworm is particularly sensitive to thermal stress, which adversely affects fecundity, cocoon formation, silk ratio, and larval survival (Rahmathulla, 2012; Dash *et al.,* 2011).

Recent climatic analyses over India indicate a significant rise in mean temperature, erratic rainfall distribution, increased frequency of droughts, heat waves and extreme precipitation events, all of which directly influence tasar host plants and silkworm performance. The Ministry of Earth Sciences (MoES) reported that the annual mean surface temperature over India increased by approximately 0.7°C during 1901–2018, with a warming trend of nearly 0.15°C per decade during 1986–2015 (Krishnan *et al.,* 2020). India Meteorological Department (IMD) assessments further revealed that annual maximum and minimum temperatures have increased across most parts of central and peninsular India, while annual rainfall variability has intensified during recent decades (Pai *et al.*, 2014; IMD, 2020). Rainfall Atlas of India (1971–2020) highlighted increasing irregularity in monsoon rainfall, higher coefficients of variation, and rising incidences of extreme rainfall events in central Indian regions where tasar culture predominates (IMD, 2022). Such climatic disturbances adversely affect leaf flushing, host plant productivity, silkworm growth, cocoon quality and pest incidence. Studies have shown that a rise of 2°C temperature may result in one to five additional insect generations annually, increasing pest and disease pressure in tasar ecosystems (Yamamura and Kiritani, 1998). Similarly, elevated temperatures above the optimum threshold accelerate respiration and reduce net leaf yield in major host plants such as *Terminalia arjuna* and *T. tomentosa* (Bale *et al.,* 2002; Hunter, 2001). Increased humidity fluctuations and erratic precipitation further enhance outbreaks of fungal diseases, stem borers, uzifly and predators, thereby reducing cocoon productivity and threatening the livelihood security of tribal tasar rearers across India (Coakley *et al.*, 1999; Das *et al.*, 2011).

Climate-induced changes also influence the dynamics of parasitoids, predators, and pathogens associated with tasar ecosystems (Thomas and Blanford, 2003; Thomson *et al.*, 2010). Increased humidity and rainfall variability favour fungal and bacterial diseases, while warmer temperatures enhance the multiplication and distribution of insect pests (Coakley *et al.,* 1999). Forest degradation, biodiversity loss, and habitat fragmentation further aggravate the vulnerability of tasar culture by reducing the availability of quality host plants and disrupting ecological interactions (Schafellner and Schopf, 2008). Therefore, understanding the impact of climate change on tasar host plants, silkworm biology, pest dynamics, and associated ecosystems has become essential for developing sustainable adaptation and mitigation strategies.

In view of the increasing climatic uncertainties, there is an urgent need to develop climate-resilient tasar production systems through integrated approaches such as thermo-tolerant silkworm breeds, drought-resistant host plant accessions, integrated nutrient and pest management, climate-based advisory services, agroforestry models, and biodiversity conservation strategies (Kumar *et al.,* 2002; Das *et al.,* 2004; Nayak *et al.,* 2018). Strengthening scientific research, technological interventions, and policy support will be crucial for ensuring the sustainability and economic viability of tasar sericulture under changing climate scenarios.

1.2. IMPACT OF CLIMATE CHANGE ON TASAR TOOD PLANTS

The association and importance of the weather on the development of plant pest and diseases has been known for over two thousand years. Theophrastus (370-286 B.C.) observed that cereals cultivated in higher altitude regions exposed to the wind had lower disease incidence than cereals cultivated in lower altitude areas. During the eighteenth century and the beginning of the nineteenth century, the effects of factors such as nutrition, air humidity and wind on plant disease occurrence started to be studied (Colhoun, 1973). Now a days, the environment can influence host plant growth and susceptibility; pest reproduction, dispersal, survival and other activities; as well as host-pest/pathogen interaction.

1.2.1. Effect of Enhanced Atmospheric Carbon Dioxide on Plant Growth

Plants grow through the well-known process of photosynthesis, utilizing the energy of sunlight to convert water from the soil and carbon dioxide from the air into sugar, starches, and cellulose the carbohydrates that are the foundations of the entire food chain. CO_2 enters a plant through its leaves. Greater atmospheric concentrations tend to increase the difference in partial pressure between the air outside and inside the plant leaves, and as a result more CO_2 is absorbed and converted to carbohydrates. Crop species vary in their response to CO_2. A plant responds readily to increased CO_2 levels. Higher levels of atmospheric CO_2 also induce plants to close the small leaf openings known as stomata through which CO_2 is absorbed and water vapor is released. Thus, under CO_2 enrichment crops may use less water even while they produce more carbohydrates. This dual effect will likely improve water-use efficiency, which is the ratio between crop biomass and the amount of water consumed. At the same time, associated climatic effects, such as higher temperatures, changes in rainfall and soil moisture, and increased frequencies of extreme meteorological events, could either enhance or negate potentially beneficial effects of enhanced atmospheric CO_2 on plant physiology.

1.2.2. Effect of Elevated Carbon Dioxide on Crop Pest Dynamics

A larger crop canopy and denser foliage resulted from enhanced CO_2 level in the atmosphere will create more relative humidity, thereby making micro-environment more favorable to pests. Increases in food quality, i.e. increase in the nitrogen content of plants due to high temperature, can results in sudden resurgence of population of pests. Moreover under condition of stress, plant defensive systems are less effective and they become more susceptible to pest attack (Coviella and Trumble 1999). Some more findings on effects of enhanced CO_2 on plant pests is given in the table 1. Extinction might occur in some species because of insufficient genetic diversity, but the species might survive in areas that become favorable as a result of change. If climate change is slow, selection might enable the species to adapt. Otherwise, the species may become extinct locally as conditions become more favorable for their competitors.

1.2.3. Effects of Higher Temperature in Tasar food plants

Increased temperatures may accelerate the rate at which plants release CO_2 in the process of respiration, resulting in less than optimal conditions for net growth. When temperatures exceed the optimal for biological processes, crops often respond negatively with a steep drop in net growth and leaf yield. If night time temperature rises and day time temperature falls as is expected from greenhouse warming projections- heat stress during the day may be less severe than otherwise, but increased night time respiration may also reduce potential yields. Another important effect of high temperature is accelerated physiological development, resulting in hastened maturation and reduced leaf yield.

1.2.4. Impact of Enhanced Temperature on Crop Pest Dynamics

Insects are cold-blooded organisms - the temperature of their bodies is approximately the same as that of the environment. Therefore, temperature is probably the single most important environmental factor influencing insect behavior, distribution, development, survival, and reproduction. Some researchers believe that the effect of temperature on insects largely overwhelms the effects of other environmental factors (Bale *et al.,* 2002). It has been estimated that with a 2^{o} C temperature increase, insects might experience one to five additional life cycles per season (Yamamura and Kiritani 1998). Other researchers have found that moisture and CO_2 effects on insects can be potentially important considerations in a global climate change setting (Coviella and Trumble 1999; Hunter 2001). For

every insect species there is a range of temperature within which it remains active from egg to adult stage. Lower values of this range are called 'threshold of development' or 'developmental zero'. Within the favorable range, there is an optimum temperature at which most of the individuals of a species complete their development. Exposure to temperatures on either side of the range exerts an adverse impact on the insect by slowing down the speed of development. Climatic factors that influence the growth, spread, and survival of crop pest /diseases include temperature, precipitation, humidity, dew, radiation, wind speed, circulation patterns, and the occurrence of extreme events. Most analyses conclude that in a changing climate, pests may become even more active than they currently are, thus posing the threat of greater economic losses to farmers (Coakley *et al.,* 1999). Higher temperature, humidity and greater precipitation, on the other hand, are likely to result in the spread of plant diseases, as wet vegetation promotes the germination of spores and the proliferation of bacteria and fungi, besides influencing the life cycle of soil nematodes and other organisms.

Table 1: Impact of Climate Change on Tasar Culture and Adaptation Strategies

Climate Change Factor	Impact on Tasar Food Plants and Silkworm	Adaptation Strategies	Key References
Rising temperature	Accelerated respiration and reduced net leaf yield in host plants; shortened silkworm lifecycle, poor cocoon quality, reduced fecundity, and increased mortality under heat stress	Development of thermo-tolerant silkworm lines, heat-resilient host plant accessions, rescheduling of brushing and pruning dates, microclimate management	Bale *et al.* (2002); Yamamura & Kiritani (1998); Das *et al.* (2011)
Elevated atmospheric CO_2	Increased plant biomass but deterioration in leaf nutritional quality due to lower nitrogen and higher C:N ratio; altered foliar chemistry affects silkworm growth and digestibility	Development of climate-resilient host plants, integrated nutrient management (INM), balanced fertilization, moisture conservation	Coviella & Trumble (1999); Hunter (2001); Chaudhary *et al.* (2002)
Erratic rainfall and rainfall variability	Disturbs leaf flushing and feeding cycles; increased larval mortality; reduced parasitism efficiency and altered predator dynamics	Rainwater harvesting, climate-based advisory services, adjusted rearing schedules, integrated farming systems	Prasad & Bambawale (2010); Coakley *et al.* (1999)
Drought stress	Reduced growth and leaf yield of major tasar host plants such as Terminalia arjuna and Terminalia tomentosa; decline in cocoon productivity	Development of drought-tolerant accessions (e.g., accession 525 and 523), afforestation, soil moisture conservation, alternate host plant identification	Kumar *et al.* (2002); Das *et al.* (2004)
Forest degradation and habitat fragmentation	Reduction in natural habitat of Antheraea mylitta, decline in biodiversity, disruption of forest-based tasar ecosystems	Community forest conservation, agroforestry, habitat restoration, biodiversity conservation	Das *et al.* (2011); Parry *et al.* (1989)

Climate Change Factor	Impact on Tasar Food Plants and Silkworm	Adaptation Strategies	Key References
Increased pest and disease incidence	Increased outbreaks of leaf spot, powdery mildew, gall pests, stem borers, uzifly and predators; higher cocoon loss and reduced silk productivity	Integrated Pest Management (IPM), neem-based biopesticides, pest-resistant host accessions, disease surveillance	Coakley *et al.* (1999); Dhillon & Sharma (2009); Scott *et al.* (1997)
Humidity fluctuation	Abnormal moulting, poor cocoon formation, increased fungal and bacterial diseases in silkworm rearing	Humidity monitoring, improved rearing hygiene, controlled environmental management	Colhoun (1973); Das *et al.* (2011)
Increased pest generations due to warming	Additional insect life cycles per season increase infestation severity and crop damage	IPM, crop monitoring, synchronized pruning and brushing schedules	Yamamura & Kiritani (1998); Bale *et al.* (2002)
Elevated temperature effects on parasitoids and predators	Reduced survival and altered host-searching ability of parasitoids; disruption of tritrophic interactions	Conservation biological control, habitat management, climate-adaptive pest management	Thomas & Blanford (2003); Thomson *et al.* (2010); Skirvin *et al.* (1997)
Extreme weather events (heatwaves, storms)	Damage to host plantations, cocoon loss, livelihood insecurity among tribal rearers	Crop insurance, resilient farming systems, diversified livelihood models, climate advisory services	Das *et al.* (2011); Parry *et al.* (1989)
Declining biodiversity and ecological imbalance	Loss of natural enemies, disruption in ecological stability and forest ecosystem functioning	Indigenous germplasm conservation, eco-restoration, mixed plantation models	Schafellner & Schopf (2008); Thomson *et al.* (2010)
Socio-economic vulnerability of tribal farmers	Income instability, migration, and decline in traditional tasar practices	Integrated farming systems, women SHGs, value-chain strengthening, m-kisan advisory services	Das *et al.* (2011); Kumar *et al.* (2002)
Nutrient depletion and soil degradation	Reduced host plant productivity and lower quality leaves for silkworm feeding	Integrated Nutrient Management (INM), vermicompost, biofertilizers, green manuring, micronutrient application	Chaudhary *et al.* (2002); Kumar *et al.* (2002); Das *et al.* (2004)
Limited host plant adaptability	Reduced resilience of traditional host species under changing climate	Identification of alternate host plants such as Lagerstroemia speciosa with drought tolerance and high leaf yield	Kumar *et al.* (2002); Das *et al.* (2004)

1.3. IMPACT OF CLIMATE CHANGE ON TASAR SILKWORM

The effect of increased CO_2 and temperature on tasar food plants directly affects the lifecycle of silkworm. Although plant biomass increases because of enriched CO_2 but their nutritional quality gets deteriorated such as lower nitrogen (N) content, higher C:N ratio, starch, total soluble sugars and polyphenols that affect insect growth, consumption and digestibility. Changes in foliar chemistry under elevated condition are likely to alter interaction between silkworm and their pests. Alterations of CO_2 level and temperature will affect the silkworm by decreasing their relative growth rate (RGR) and prolonged developmental time, as well as increased abundance and fecundity of food

plant pests. Due to high temperature, large quantity of tasar seed cocoons is affected and it is estimated about 30% of the total stock. The high temperature stress induces the change in the physiology and biochemical composition and in turn the fecundity and other commercial traits in the silkworm.

1.3.1. Impact of climate change on tasar silkworm protection

The impacts of climate change can be positive, negative or neutral, since these changes can decrease, increase or have no impact on insect pests and diseases, depending on specific location of each region or period (Das, *et al.,* 2011). Tasar silkworm pests are mainly damaged parasitoid and predators which are beneficial (natural enemy) for management of agricultural and forest plant protection. Parasites and predators are likely to undergo diverse effects due to changes in atmospheric CO2 levels, increase in temperatures and shifts in precipitation. Among parasitoids, many hymenopteran wasp parasitoids which are relatively host-specific and are considered as specialists are more sensitive to changes in their host emergence times or developmental rates than tachnid flies which feed on several host insects and are likely to be less susceptible to the asynchrony with their hosts induced by climate change. Variability in rainfall reportedly has an adverse influence on parasitism levels of several caterpillar pests (Prasad Y.G and O.M Bambawale 2010).

1.3.2. Effect of elevated temperature on parasitoid and predators

It is predicted that a 1°C rise in temperature would enable species to spread 200 km northwards or 140 m upwards in altitude (Parry *et al.,* 1989). All species will be under strong selection pressures, which may be different from those exerted when the climate is stable. Natural enemies are no exception. Exposure to temperature extremes even for short periods is likely to influence parasitoid survival and host searching ability (Scott *et al.,* 1997). Temperature influenced the fecundity and sex ratio of Campoletischloridae, anichneumonid larval parasitoid of *H. armigera* (Dhillon and Sharma, 2009). Short exposure to higher temperatures can eliminate endosymbiont bacteria like Wolbachia and Buchnera which influence several aspects of parasitoid reproduction (Thomas and Blanford, 2003).

Fluctuations in parasitoid abundance and observed wide ranges in field parasitisation levels may be attributed to climatic conditions. In case of predators, however, it could be different. For example, it has been predicted that coccinellids reduce aphids more strongly in hot summers than in moderate summers (Skirvin *et al.,* 1997). Overall, there is lack of a clear understanding of the dynamics of matching thermal requirements of parasitoids, predators and their hosts as a tritrophic system. It is generally perceived that natural enemies are relatively more sensitive to climatic variability than their herbivore hosts. Perhaps this is explained by higher intrinsic rates of population increases following decimation by herbivores relative to natural enemies (Thomson *et al.,* 2010). Each species has to be analyzed separately to understand and predict the influence of either gradual or abrupt increase in temperatures (Table 1).

1.3.3. Effect of rainfall variability on parasite and predators

The meta-analysis indicated that the variability in precipitation was a key factor influencing parasitism. A higher variability in rainfall led to a decrease in parasitism. Studies carried out till now indicate that the interactive effects of changes in CO_2, temperature and rainfall on natural enemies can be complex and hence it is difficult to predict their combined effects.

1.3.4. Effect of elevated carbon dioxide on Natural predators and parasitoid

The development of the parasitoid wasp, *Glyptapantelesliparidis,* of gypsy moth, Lymantria dispar, feeding on three different tree species fumigated with 540+20 ppm $CO_2$was not adversely affected by changes in food quality when compared to ambient CO_2 (Schafellner and Schopf, 2008). The effects of elevated CO_2 on natural enemies are essentially indirect and mediated through changes in herbivore hosts that feed on plants with altered nutritional quality. The effects are mainly reflected in the form of changes in natural enemy fitness, development, mortality and abundance, and differ between parasitoids and predators. Within the parasitoid category, the specialists that are host-specific are likely to be more adversely affected than generalists that survive on a variety of host insects. Very few research experiments have been conducted under controlled conditions with elevated CO_2 to investigate the effects on tritrophic systems.

1.4. ADAPTATION STRATEGIES FOR MAINTAINING TASAR PRODUCTION UNDER CHANGING CLIMATE

Maintaining or enhancing the tasar cocoon production and income of tasar farmers are challenging tasks for scientists and policy makers under climate change. Mitigation and adaptation are two methods for minimizing the harmful effect of climate change. Options to maintain and enhance tasar cocoon production under climate change and its scenario viz., Climate resilient host plants and silkworm breeds, Rescheduling of pruning and brushing date, Integrated farming, Integrated Nutrient Management, Integrated pest management, Crop insurance, Improved weather based tasar advisory, Relocation of crop in alternate areas, Use of indigenous technical knowledge. Adaptation against the climate change is the best policy to minimize the harmful effect in tasar culture. In adaptation, there are several options to maintain and enhance tasar cocoon production under climate change and its scenario. This Institute has developed several technologies against the climate change for host plant and silkworm to maintain or enhance the production of tasar cocoons.

In host plants, development of drought tolerant, pest & disease resistant accessions, rescheduling of pruning date, integrated nutrient management, integrated pest management, host plant advisory services through m-kisan. Whereas, in silkworm strategies are development of thermo-tolerant line, rescheduling of brushing date, integrated pest management and silkworm advisory through m-kisan for enhancing the cocoon production under the impact of climate change.

Table 2: Adaptation Strategies in Tasar food plants and silkworm

Sl.No.	Tasar food plants	Tasar silkworm
1	Development of drought tolerant,	Development of thermo-tolerant line.
2	Pest & disease resistant accessions,	Rescheduling of brushing date.
3	Identification of alternate host for silkworm rearing	Integrated pest management.
4	Rescheduling of pruning date,	Silkworm advisory through m-kisan.
5	Integrated farming	
6	Integrated nutrient management	
7	Integrated pest management,	
8	Host plant advisory services through m-kisan.	

1.4.1. Adaptation Strategies in Tasar food plants

1.4.1.1. Drought tolerant tasar food plants

The study was conducted with two different soil moisture regimes i.e. non-stress and stress in selected accessions. Results revealed that accession 525-showed higher growth in terms of plant height

followed by accession 523 under moisture stress condition. Similarly, physiological parameters (Relative water content, water saturation deficit, relative saturation deficit and excised leaf water loss) and biochemical characters (total proline and chlorophyll content) were higher with accession 525 followed by 523 under moisture stress condition. Two accessions were identified for drought condition. Among the accessions, accession no.525 and 523 of *T. arjuna* were found superior in terms of plant growth, physiological and biochemical characters and leaf yield. Further, accessions 525 and 523 are having higher value for stress tolerant index, drought resistance index and yield index but accessions 123 and 135 showed better yield stability index. Leaf yield of accession 525 and 523 was found to be higher in water stress and control treatment, respectively. Result further showed that among various drought tolerant indices, stress tolerant index, drought resistance index and yield index were higher in accessions 525 and 523.

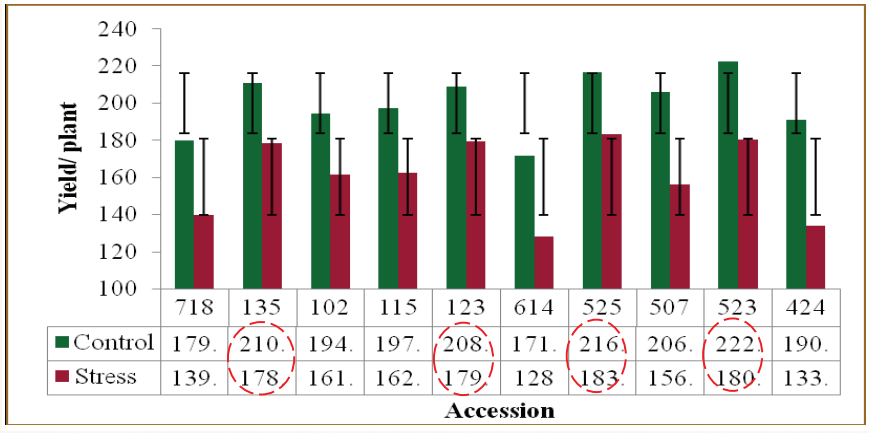


Figure 1: Drought tolerant tasar food plants accession

1.4.1.2. Selection of Pest & disease resistant tasar food plant accessions

An experiment was conducted to assess the Pest & disease resistant plant accessions from field Gene bank that was established with 314 accessions of tasar host plants. 140 accessions of Arjun (83) & Asan (57) were screened for their tolerance against Leaf spot, Black nodal girdling and Powdery mildew diseases, 78 accessions -resistant to black nodal girdling , 68 accessions-moderately resistant to powdery mildew and Percent Disease Index for foliar diseases: Asan > Arjun accessions, due succulence and pubescence of leaves. Thirty three accessions of *T. arjuna* and *Twenty seven* accessions of *T. tomentosa* have been identified as tolerant ones for major foliar diseases. Accessions 533, 615, 701 and 702 of *T. arjuna* and acc 501 and 533 of T. tomentosa which were tolerant to the major fungal foliar diseases.

Leaf anatomical characters	Correlation with leaf spot
Cuticle thickness + Upper epidermis (µm)	-0.859**
Cuticle thickness (µm)	-0.494**
** Significant at 1% level.	
Genotypes with high cuticle & upper epidermis having low PDI for leaf spot	

1.4.1.3 Identification of alternate host plant (*Lagerstroemia speciosa)* A potential tasar host plant for Tasar silkworm

Propagation through cuttings showed that days taken for rooting varies in different season and maximum days taken for rooting was 45 days in *L. speciosa* and 60 days in T.arjuna in the cuttings planted during December. Height of one year old saplings of L. speciosa was more (80.13 cm) in

comparison to *T. arjuna* (59.10 cm). Overall growth performance along with total leaf yield/plant of two year old plants of L. speciosa was higher than *T. arjuna* under 10' x 5' spacing. First crop silkworm rearing results show that larval duration was slightly higher in *L.speciosa* (35 days) as compared to *T.arjuna* and *T.tomentosa* (32 days). Similar trend was observed in second crop of both the year (52 and 45 days in *L.speciosa* and *T.arjuna*, respectively). ERR (%) was almost at par in all the three plants in both the crops. Silk ratio was in the range of 11.71 in *T.arjuna* 13.11 in *L.speciosa* in first crop. However, silk ratio was higher in second crop during both years in all the three species studied. Filament length varied 630.40 m in T.arjuna to 695m in *L.speciosa* in first crop of year 2014. Filament length was higher in second crop (887 and 940m in *T.tomentosa* and *L.speciosa*, respectively). Denier of the filament was almost similar in all the three species. Grainage behavior in *L. speciosa* was at par with *T. arjuna*.

Salient features of *Lagerstroemia speciosa* :	
Low gestation period (2-3 y)	
Fast growing	
Two crops/year	
Drought tolerant	
Wide adaptation	

Advantage:

1) Developed package of cultivation for Tasar silkworm rearing
2) Clonal propagation is simple and rapid as compared to *T. arjuna*.
3) Overall growth performance along with total leaf yield/plant (36%) in *L. speciosa* was higher than *T. arjuna*
4) Silkworm rearing and Grainage performance is at par with *T. arjuna,* (3-7 days higher larval duration).

1.4.1.4. Rescheduling of pruning date

The occurrence of pest is mainly governed by three components (called triangle concept) viz., host, pest and environment. These three components are determining success of food plant quality leaf production. When all three components are presence in favorable condition resulted in high pest severity which consider peak period caused maximum crop loss. Among three components, if any one of the components is absent or prevailing unfavorable condition resulted in minimum crop loss. There is less amenable to change host and pest during rearing period and modification of micro climate is possible through altering pruning date. Based on the historical research on selection of pruning date for quality leaf production were identified recommendation first week of March for first crop and last week of April for second crop for low pest infestation and quality leaf production.

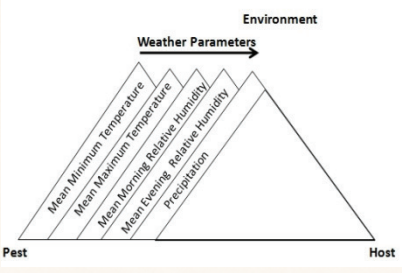




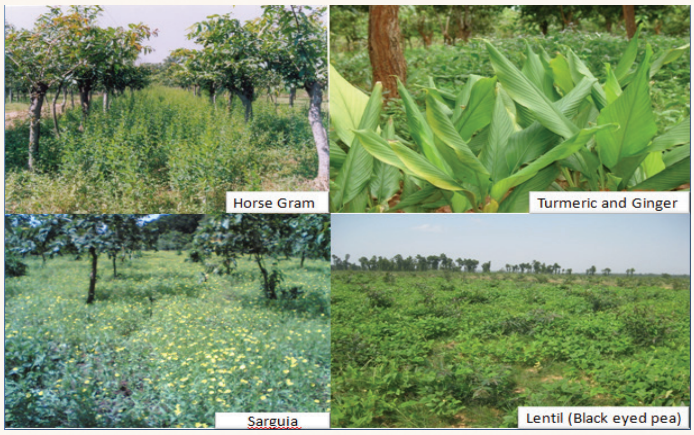


Table 3: Recommendation of pruning date in major tasar growing state.

Agro-climatic Zone	Districts cum under Agro-climatic zone	Recommendation
Jharkhand State		
Western Plateau Zone	Bokaro, Latehar, Lohardanga ,Gumla, Hazaribagh, Palamau, Ranchi, Simdega, Chatara, Garhwa	1 March (for I crop) 30 April (for II crop)
Central and North Eastern Plateau Zone	Jamtara, Koderma,Pakur, Dhanbad, Dumka, Sahebganj	1 March (I crop) 15 April (II crop)
South Eastern Plateau Zone	East Singbhum, Saraikela/Kharsawan, West Singhbhum	15 February (I crop) 1 April (II crop)
Chhattisgarh State		
C.G. Plains (15 Distt)	Raipur, Gariyaband, Balodabazar, Mahasamund, Dhamtari, Durg, Balod, Bemetara, Rajnandgaon, Kabirdham, Bilaspur, Mungeli, Korba, Janjgeer, Raigarh& a part of Kanker Districts (Narharpur& Kanker Block)	15 February (I crop) 15 March (II crop)
Plateau (7 Distt)	Jagdalpur, Narayanpur, Beejapur, Kondagaon, Dantewada, Sukma and the remaining part of Kanker Districts	1 March (I crop) 1 April (II crop)
Northern Hills (5 Distt)	Sarguja, Surajpur, Balrampur, Koria, Jashpur&Dharamjaigarh Tehsil of Raigarh Districts	15 Feb (I crop) 15 March (II crop)
Odisha State		
North Western Plateau	Sundargarh, parts of Deogarh, Sambalpur & Jharsuguda	1 March (I crop) 1 April (II crop)
North Central Plateau	Mayurbhanj, major parts of Keonjhar, (except Anandapur&Ghasipura block)	15 Feb (I crop) 15 March (II crop)

1.4.1.5. Integrated farming/ Intercropping

Integrated farming / Intercropping is a key component for maintain / enhances farmer income under climate change and its scenario. Under 10 X 6 feet tasar food plantation farmers can easily grow horse gram, turmeric, ginger, surguja and lentil etc to earn the additional income along with tasar cocoons. Integrated farming system not only enhances the income of farmers but also create a resilient environment against the climate change.





Model 1

Integrated farming system for augmenting the income of farmers

Salient Features

1) Tasar host plant based integrated farming system comprising of leguminous and other cash crops is effective
2) It will offer sustainable utilization of available land resources.
3) Integrated farming is more suitable under wider spaced plantation like 12' x 6', 10' x 5'. The system has been found economically viable and remunerative for tasar growers.
4) Net income from integrated farming ranges from Rs. 23,000 to 41,000/ha.

Usage

1) Plough the land thoroughly at the onset of monsoon.
2) After necessary cultural operations, apply farm yard manure @ 600cft/ha and chemical fertilizers @100N:50P:50K as recommended for full-grown tasar food plantation.
3) Sow locally grown agricultural crops like Green Gram (*Phaseolus aureus*), Black Gram (*Phaseolus mungo*), and Cow pea (*Vigna sinensis*) @ 16 – 20 kg/ha in the first week of July, and crops like horse gram (Dolichos biflorus @ 24-30 kg/ha) and Niger (Guizotiaabyssinica @ 6-8 kg/ha) during third/fourth week of August. In winter vegetables like spinach, fenugreek, carrot, reddish etc can grow.

Expenditure: 10000-17000/hac.

Cost Benefit Ratio: 1:3.8 to 1:4.6 depending upon intercrops.

Model 2

Tasar cocoon Production on bunds with Paddy to enhance the income of the farmers

Salient Feature

1) Tasar culture along with paddy crop increase the income of the farmers with an environment friendly balance approach.
2) Can avoid deforestation by meeting fuel wood requirements with possibility of Briquettes making.

Usage

1) In one hectare paddy field 80 Arjun or Asan food plant can be planted maintaining 15 feet plant to plant distance on four sides bunds for tasar silkworm rearing.
2) 160 dfls can be reared from 5th year onwards and 8000 cocoons may be produced.
3) The farmers can earn additional income Rs.13500.00 net profit after reducing the expenditure of Rs. 10500.00 on Tasar culture.
4) Additional 40 plants in backyard as chawki garden (8' x 8' spacing) has to be maintained.

1.4.1.6. Integrated Nutrient Management

The basic concepts of INM is the maintenance or adjustment of soil fertility and supply of plant nutrients to an optimum level for sustaining desired crop productivity through optimization of benefits from all possible sources of plant nutrients in an integrated manner. INM is ecologically, socially and economically viable and environment friendly which can be practiced by farmers to derive higher productivity with simultaneously maintaining soil fertility. Integrated nutrient management encourages the use of on-farm organics, thus it saves on the cost of fertilizers for crop

production. It involves proper combination of chemical fertilizers, organic manure, crop, residues, N2~fixing crops (like pulses such as rice bean, Black gram, other pulses and oilseeds such as soybean and bio-fertilizers suitable to the system of land use and ecological, social and economic conditions.

Components of INM:

1. Integration of soil fertility restoring crops like green manures, legumes etc.
2. Recycling of crop residues
3. Use of organic manures like FYM, compost, vermicompost, biogas, slurry, poultry manure, bio-compost, press mud cakes, phosphocompost
4. Utilization of Bio fertilizers
5. Balanced use of fertilizer nutrients as per the requirement and target yields.

Advantages

1. Enhances the availability of applied as well as native soil nutrients
2. Synchronizes the nutrient demand of the crop with nutrient supply from native and applied sources.
3. Provides balanced nutrition to crops and minimizes the antagonistic effects resulting from hidden deficiencies and nutrient imbalance.
4. Improves and sustains the physical, chemical and biological functioning of soil.
5. Minimizes the deterioration of soil, water and ecosystem by promoting carbon sequestration, reducing nutrient losses to ground and surface water bodies and to atmosphere.

Recommendations by CSB-CTRTI, Ranchi Application of NPK fertilizers

- The recommended dose of NPK is 150-50-50 kg ha^{-1} $year^{-1}$ to be added to the soil.
- NPK application is 48 g Urea (3 split doses) + 46 g SSP + 12 g MOP $plant^{-1}$ $year^{-1}$.
- FYM @ 1kg $plant^{-1}$ $year^{-1}$should also be applied.

Foliar application of micronutrients mixture

- A mixture of six micronutrients viz. [Manganese sulphate ($MnSO_4$) 4.6 kg + zinc sulphate ($ZnSO_4$) 1.09 kg + Cupric sulphate (CuSO4) 0.2 kg + Ferrous sulphate ($FeSO_4$) 0.25 kg + Borax ($Na_2 B_4 O_7$) 0.5 kg + Ammonium molybdate $\{(NH_4)_6 Mo_7O_{24}\}$ 0.0036 kg.] per hectare per crop may be applied on *Terminalia arjuna* plants with 4' x 4' spacing by dissolving the above said mixture in 1000 liter of water and spraying 3 – 4 weeks before commencement of the rearing. For the plants with 6' x 6' spacing the amount of micronutrients should be halved and dissolved in 500 liters of water (Chaudhary *et al.*, 2002).

Foliar application of NPK fertilizers

- In a bid to reduce the quantity of NPK fertilizers that should be added to the soil, aqueous solution of 1% Urea + 1% DAP + 1% MOP may be sprayed on *Terminalia arjuna* plants with the application of half of the recommended basal dose of NPK i.e. 150-50-50 kg ha^{-1} $year^{-1}$ (Das *et al*, 2004).

Use of organic manure

- To improve the soil fertility 12 mt vermicompost along with 75-25- 25 kg ha^{-1} $year^{-1}$ (50

  % of the recommended dose) is advisable to be added to the soil (Kumar *et al.*, 2002).

Use of biofertilizers

- Combined application of *Azotobactor*+ *Azospirillum* + *phosphobacterin*@ 20 kg each is recommended to improve leaf yields and soil fertility (Kumar *et al.*, 2002).

Incorporation of green manure

- Sowing of Sunnhemp or Daincha seeds @ 50 kg ha^{-1} during the onset of monsoon and incorporates the biomass after 45 days or before flowering initiation can be practiced for improving crop yield and soil fertility (Kumar *et al.*, 2002).

In-situ soil health and nutrient management

- Conservation of rainwater through small catchments (i.e. circular basin trenches of size 6′×2′×1′ (lxbxd) across land for plain land and semicircular for slop land) along with growing & incorporation of *Cassia tora*and inoculation of Phosphate Solubilizing Bacteria (PSB) in plantation sites showed average content of N, P and K in leaf of *T. tomentosa* were increased by 24.08, 30.00 and 28.57%, respectively than control.
- Soil N, P and K content increased by 28.48, 23.93 and 24.65%, respectively.
- Similarly, the above treatment had recorded higher leaf yield, cocoon yield and S.R% as compared to control with the tune of 25.41%, 20.29% and 7.36%, respectively.
- Hence, development of *in-situ* soil health and nutrient management by adopting rain water management along with green manuring and PSB is beneficial and eco friendly for tasar host plantation to produce good quality cocoons.

1.4.1.7. Integrated Pest management

Integrated pest management practices are cost effective and eco-friendly technology, which is, not only reduces the cost of protection but also reduces the pollution load from tasar ecosystem and enhances the farmers' income.

(i) IPM for Gall pest

1) Delay in pruning by a month i. e. last week of April to minimize the gall infestation.
2) Mechanical
3) Collection and destruction of gall infested leaves and pruning waste.
4) Bio-pesticides:
5) Soil application of neem cake @ 150 kg per hectare in two split doses before the onset of monsoon (15^{th} May and 30^{th} May)
6) Three Consecutive foliar sprays of 15ppm azadirachtin (Vanguard 1500ppm) at an interval of 15 days after sprouting of leaves (10ml/lit-5 litres per hectare). Or
7) Three Consecutive foliar sprays of Neem Based Pesticides at an interval of 15 days after sprouting of leaf.

Chemical:

1) Acetamiprid 20% SP, at @ 0.2gm/ liter of water spray at an interval of 15 days after sprouting of leaf.

Waiting period: 7days.

(ii) IPM for Defoliators

Cultural:

Two times deep ploughing after silkworm rearing rearing Nov.-Dec. and March-April is to be done.

Mechanical:

Collection and destruction of different developmental stages of insect such as eggs, grubs/larvae, pupae and adults of coleopteran and lepidopteran pests during morning and evening hours twice a week from the month of May to July.

Botanical:

Soil application of neem cake (dried and fine meshed @ 60 kg per acre in two split doses at 15 days interval before the onset of monsoon (1st dose – 15th May & 2nd dose-30th May).

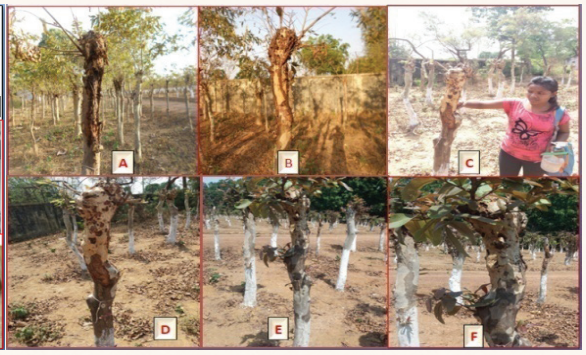
Foliar application of 15 ppm Azadirachtin once after 15 days of soil application of neem cake (15th June). Or

Three Consecutive foliar sprays of Neem Based Pesticides at an interval of 15 days after sprouting of leaf

(iii) Neem based technology for management of bark eater in tasar food plants



Figure. Preparation procedure of Neem based pesticides. A: Collection of neem leaf (1kg), B & C: Washing of neem leaves, D: addition of butter milk (2.5L) to the leaves, E: Mixing of butter milk and neem leaves and stored in earthen pot, F: covering with the pot with J: Dilution of the neem pesticide. Lid and muslin cloth, G: grinding of the leaves after 15 days, H: Resultant paste, I: mother solution.



Effect of *Neem* based pesticides on bark eater control and rejuvenation of damage part in tasar food plants

Preparation of Neem based pesticide.

Preparation

- One kg of crushed neem leaf is mixed with 2 litres of butter milk and stirred thoroughly.
- The mixture is transferred to an earthen pot, covered with lid and muslin cloth and stored in a dark place for 15 days.
- After fifteen days, the solution is mixed thoroughly and filtered through muslin cloth.
- This solution can be used as a base solution for preparation of active pesticides.

Application:

- The base solution is diluted to 10 times with water (1:10 ratio) and sprayed on bark eater infested part of the trees.
- Before spraying the solution the bark eater infested part of the plant should be cleaned, web/ litter should be removed with the help of knife, larvae & pupae present in the hole should be killed with the help of aluminium or iron wire.
- Spray the diluted neem solution on bark eater infested parts in a week for three to four times.

(iv) IPM package for management of stem borer in tasar food plants

1. Practices for avoid the egg laying of stem borer in tasar food plants

i. Scrubbing the bark + Spray Neem based pesticide at 1:10 ratios (two times spry after monsoon at 20-25 days interval)

ii. Scrubbing the bark + Spray or painting lime 10% with 2ml/liter Fevicol (one time spry/ painting after monsoon)

2. Practices for management of stem borer at grubs' level in tasar food plants

i. Clean hole with knife and aluminum wire / cycle spoke (during October – April)

ii. Clean hole with knife and aluminum wire / cycle spoke + Insert cotton wool soaked in emulsion of 1:5 Neem based pesticide + water(during October – April)

iii. Clean hole with knife and aluminum wire / cycle spoke + Insert cotton wool soaked in emulsion of Kerosin /Petrol (during October – April)

3. Practices for management of stem borer at adults' level in tasar food plants

1. Manual collection and killing of stem borer during rainy season
2. Collection and killing of stem borer with the help of light trap during rainy season.

1.4.1.8. Host plant advisory services through m-kisan.

Host plant advisory services, provides basic, timely and accurately pre-information of different climate and weather conditions host plant production and protection. It ishelpful to farmers for increase interest, knowledge, adoption and impact of climate changes on tasar culture practices. Timely and accurately information share to farmers regarding food plant schedules viz., pruning, application of fertilizers and forewarning of pest and disease in host plant are not only help to reduces the cost of input in tasar host plant production but also enhances the income of tasar farmers.



1.4.2. Adaptation Strategies in Tasar Silkworm

1.4.2.1. Development of thermo-tolerant line.

1) The thermo-tolerant moths of Daba BV have been isolated. Selection 1 (S1) and Selection 2 (S2) generation has been generated.
2) S1 and S2 thermo-tolerant line cocoons have been harvested and post cocoon parameters have been assessed. The Shell weight, S.R.%, filament length, breakage number, NBFL and silk weight of S1 thermo-tolerant line cocoons have been found to be superior than Daba BV control cocoons.
3) The RAPD based analysis of polymorphic bands between thermo susceptible-pupae and thermo-tolerant moths have been analysed for the development of SCAR based molecular marker for the identification of thermo-tolerant line.
4) Three SCAR markers (TT-PB1, TT-PB2 and TT-PB3) have been developed. Among these, TT-PB1 showed more specificity towards thermo-tolerant lines.
5) Heat shock proteins and factors responsible for thermo-tolerance in thermo-tolerant line have been analysed. HSP70 and HSP21 have found to be up-regulated in thermo-tolerant lines of Daba.

1.4.2.2. Rescheduling of brushing date for higher crop yield

The occurrence of pest (parasite & predator) is mainly governed by three components (called triangle concept) *viz*., host, pest and environment. During the period of silkworm rearing, silkworm acting as host, endo-parasitoids & predator acting as pest and weather during rearing period as environment. These three components are determining success of tasar cocoon production. When all three components are presence in favorable condition resulted in high pest severity, which consider peak period caused maximum crop loss. Among three components, if any one of the components is absent or prevailing unfavorable condition resulted in minimum crop loss. There is less amenable to change host and pest during rearing period and modification of microclimate is possible through altering brushing date, brushing direction, density of leaf canopy and suitable agronomical practices.

Agro-climatic Zone	Districts cum under Agro-climatic zone	Recommendation
Jharkhand State		
Western Plateau Zone	Bokaro, Latehar, Lohardanga ,Gumla, Hazaribagh, Palamau, Ranchi, Simdega, Chatara, Garhwa	5 July (I crop) 20 September (II crop)
Central and North Eastern Plateau Zone	Jamtara, Koderma,Pakur, Dhanbad, Dumka, Sahebganj	15 July (I crop) 20 September (II crop)
South Eastern Plateau Zone	East Singbhum, Saraikela/Kharsawan, West Singhbhum	10 July (I crop) 15 September (II crop)
Chhattisgarh State		
C.G. Plains (15 Distt)	Raipur, Gariyaband, Balodabazar, Mahasamund, Dhamtari, Durg, Balod, Bemetara, Rajnandgaon, Kabirdham, Bilaspur, Mungeli, Korba, Janjgeer, Raigarh& a part of Kanker Districts (Narharpur& Kanker Block)	10 July (I crop) 25 September (II crop)

Agro-climatic Zone	Districts cum under Agro-climatic zone	Recommendation
Plateau (7 Distt)	Jagdalpur, Narayanpur, Beejapur, Kondagaon, Dantewada, Sukma and the remaining part of Kanker Districts	10 July (I crop) 25 September (II crop)
Northern Hills (5 Distt)	Sarguja, Surajpur, Balrampur, Koria, Jashpur&Dharamjaigarh Tehsil of Raigarh Districts	10 July (I crop) 25 September (II crop)
Odisha State		
North Western Plateau	Sundargarh, parts of Deogarh, Sambalpur & Jharsuguda	15 July (I crop) 15 September (II crop)
North Central Plateau	Mayurbhanj, major parts of Keonjhar, (except Anandapur&Ghasipura block)	10 July (I crop) 25 September (II crop)

1.4.2.3 IPM PACKAGE FOR THE CONTROL OF UZIFLY, *BLEPHARIPA ZEBINA* WALKER

Mechanical:

- Uzi fly infested / dead silkworm larvae should be collected and destroyed.
- Uzi fly maggots / Pupae should be collected from rearing field / grainage house and destroyed.
- Flimsy and uzi fly infested cocoons should be harvested early and stifled or sun dried.
- Sticky trap (Lassa - adhesive) should be used for collecting and killing the adult uzi flies.

Chemical:

- Bleaching powder solution (2%) as an ovicide can be applied on silkworm body to kill uzi fly eggs. This treatment has to be repeated four to five times.

Control measures for predators:

1) Use of nylon net (mesh size 2 mm), especially during chawki rearing to prevent silkworm from the attack of predators.
2) Mechanical collection and destruction of of predators in the rearing field throughout rearing period and especially at the time of incidence of the predator by using sticky country made adhesive (lassa) glued to bamboo pole or other sticks.
3) Collection and destruction of egg mass/ oothecae/ nests/nymphs and adults of predators.
4) The rearing trees should be cleaned of ants and nests of ants before brushing or transfer of silkworm on it.
5) The base of the trees should be dusted with an insecticide (Methyl- parathion 2% dust) to prevent ant attack.

1.4.2.4 Tasar silkworm advisory services through m-kisan.

Tasar silkworm advisory services, provides basic, timely and accurately pre-information of different climate and weather conditions silkworm protection. It ishelpful to farmers for increase interest, knowledge, adoption and impact of climate changes on tasar culture practices. Timely and accurately information share to farmers regarding tasar silkworm schedules viz., brushing schedule and forewarning of pest and disease in tasar silkworm not only help to reduces the cost of input silkworm production but also enhances the income of tasar farmers.

1.5. CONCLUSION

Climate change has emerged as one of the most significant challenges affecting tasar culture, particularly in tropical and subtropical regions where tasar sericulture is closely linked with forest ecosystems and tribal livelihoods. Variations in temperature, rainfall, humidity, and atmospheric carbon dioxide directly and indirectly influence the growth and productivity of tasar host plants as well as the survival, development, and commercial traits of the tasar silkworm, Antheraea mylitta. Elevated temperatures accelerate respiration and physiological development in host plants, reducing leaf yield and quality, while altered foliar chemistry under elevated CO_2 conditions adversely affects silkworm nutrition and cocoon productivity. Climate variability also enhances pest and disease outbreaks, increases the number of insect generations, and disturbs the ecological balance among pests, parasitoids, and predators. Consequently, cocoon yield, silk quality, and farmer income are increasingly becoming vulnerable under changing climatic conditions.

However, several adaptation and mitigation strategies have shown promising results in improving resilience in tasar culture. Development of drought-tolerant and disease-resistant host plant accessions, thermo-tolerant silkworm lines, integrated nutrient and pest management, rescheduling of pruning and brushing dates, integrated farming systems, and weather-based advisory services through m-kisan are effective climate-smart interventions. Identification of alternate host plants such as Lagerstroemia speciosa also offers opportunities for sustainable tasar production under stress conditions. Therefore, climate-resilient technologies, combined with ecological conservation and farmer-centered extension services, are essential for sustaining tasar sericulture under future climate scenarios.

1.6. FUTURE PROSPECTS

Future development of tasar culture requires climate-resilient, sustainable, and farmer-centric approaches to minimize the adverse impacts of climate change. Scientific innovations, ecological conservation, and policy support will play a crucial role in ensuring long-term sustainability and livelihood security in tasar sericulture. The below listed future prospect is highly required towards development of climate resilient tasar silk production:

1. Development of thermo-tolerant and drought-resistant races of *Antheraea mylitta* through advanced breeding, molecular markers, and genomic approaches.
2. Identification and promotion of climate-resilient host plants with better adaptability, improved leaf quality, and resistance to drought and diseases.
3. Expansion of long-term ecological and climate studies to understand host plant silkworm pest parasitoid interactions under changing environmental conditions.
4. Development of climate prediction models and decision-support systems for timely weather advisories and risk management in tasar-growing regions.
5. Promotion of integrated farming systems, agroforestry, and intercropping models to enhance farmer income and climate resilience.
6. Strengthening of rainwater harvesting, soil moisture conservation, and organic nutrient management practices for sustainable host plant productivity.
7. Conservation of biodiversity and restoration of degraded forest ecosystems to maintain ecological balance and natural habitats for tasar culture.
8. Adoption of digital technologies such as m-kisan, mobile-based advisories, remote sensing, and GIS-based monitoring for real-time climate and pest management support.
9. Enhancement of integrated pest management (IPM) strategies using eco-friendly biopesticides, biological control agents, and climate-smart crop protection practices.

10. Strengthening policy support, crop insurance, women participation, tribal empowerment, and value-chain development for sustainable and economically viable tasar sericulture under climate change scenarios.

1.7. REFERENCES

Anonymous, 2020. *Functioning of Central Silk Board and Performance of Silk Industry*. Bengaluru: Ministry of Textiles, Government of India. Available at: Central Silk Board [Accessed 14 May 2026].

Bale, J.S., Masters, G.J., Hodkinson, I.D., Awmack, C., Bezemer, T.M., Brown, V.K., Butterfield, J., Buse, A., Coulson, J.C., Farrar, J. and Good, J.E., 2002. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. *Global Change Biology*, 8(1), pp.1–16.

Benchamin, K.V. and Jolly, M.S., 1986. Principles of silkworm rearing. In: *Proceedings of Seminar on Problems and Prospects of Sericulture*, pp.63–106.

Central Silk Board, 2023. *Note on Sericulture and Silk Industry Statistics*. Bengaluru: Central Silk Board, Government of India.

Chaudhary, S.K. *et al.*, 2002. Micronutrient management in tasar host plants. *Indian Journal of Sericulture*, 41(2), pp.123–128.

Coakley, S.M., Scherm, H. and Chakraborty, S., 1999. Climate change and plant disease management. *Annual Review of Phytopathology*, 37, pp.399–426.

Colhoun, J., 1973. Effects of environmental factors on plant disease. *Annual Review of Phytopathology*, 11, pp.343–364.

Coviella, C.E. and Trumble, J.T., 1999. Effects of elevated atmospheric carbon dioxide on insect–plant interactions. *Conservation Biology*, 13(4), pp.700–712.

Das, K., Singh, P.K. and Reddy, R.M., 2004. Integrated nutrient management in tasar host plants. *Indian Journal of Sericulture*, 43(2), pp.145–150.

Das, P.K. *et al.*, 2004. Foliar fertilization studies in *Terminalia arjuna*. *Sericologia*, 44(3), pp.411–417.

Das, R. *et al.*, 2011. Climate change and its impact on tasar culture. *Indian Silk*, 50(5), pp.20–27.

Datta, R.K. and Nanavaty, M., 2005. *Global Silk Industry: A Complete Source Book*. New Delhi: Universal Publishers.

Dhillon, M.K. and Sharma, H.C., 2009. Effects of temperature on parasitoids of insect pests. *Biological Control*, 48, pp.222–231.

Gargi, Rajendra Kumar, S.K., Sinha, P.S., 2009. *Screening of the Germplasm of Terminalia arjuna and T. tomentosa for Tolerance against Three Major Foliar Diseases*. Central Silk Board funded project (PRP-4667), Bengaluru.

Gedam, P.C., Bawaskar, D., Chowdary, N.B. and Venugopal, A., 2023. Perception of tasar silkworm rearers about the climate change impact on the tasar silk production of Maharashtra. *Asian Journal of Agricultural Extension, Economics & Sociology*, 41(7), pp.153–164.

Hariharan, S., Monisha, U., Logeshwari, S.M., Mounisha, K., Mohana, J. and Kumar, A.S.K., 2024. Impact of climate change on sericulture: adaptation strategies and future directions. *Uttar Pradesh Journal of Zoology*, 45(16), pp.570–580.

Hunter, M.D., 2001. Effects of elevated atmospheric carbon dioxide on insect–plant interactions. *Agricultural and Forest Entomology*, 3(3), pp.153–159.

IMD (2020) Climate of India. Pune: India Meteorological Department, Ministry of Earth Sciences, Government of India.

IMD (2022) Rainfall Atlas of India (1971–2020). Pune: India Meteorological Department, Ministry of Earth Sciences, Government of India.

IPCC, 2018. *Summary for Policymakers*. In: *Global Warming of 1.5°C: An IPCC Special Report*. Geneva: World Meteorological Organization.

IPCC, 2021. *Climate Change 2021: The Physical Science Basis*. Cambridge: Cambridge University Press.

Karur, A.S. and Narmada, M., 2026. Climate change impacts on sericulture: evidence from mulberry physiology, silkworm biology and northeast Indian Muga ecosystems. *International Journal of Environment and Climate Change*, 16(4), pp.281–291.

Kaushik, A., Borah, G., Saikia, S., Kaushiki, B. and Phukan, T., 2025. Climate-resilient sericulture: strategies for sustainable silk production in a changing climate. *International Journal of Advanced Biochemistry Research*, 9(8), pp.891–897.

Krishnan, R., Shrestha, A.B., Ren, G., Rajbhandari, R., Saeed, S., Sanjay, J., Syed, M.A., Vellore, R., Xu, Y. and You, Q. (2020) Assessment of Climate Change over the Indian Region. Singapore: Springer Nature for Ministry of Earth Sciences, Government of India.

Krishnaswami, S., 1978. *New Technology of Silkworm Rearing*. Bangalore: CSR&TI.

Kumar, R. *et al.*, 2002. Integrated nutrient management in tasar host plantations. *Indian Journal of Forestry*, 25(4), pp.451–457.

Kumar, R., Sinha, A.K. and Saha, L.M., 2002. Drought management in tasar host plantations. *Indian Silk*, 41(8), pp.9–13.

Lincoln, D.E., Fajer, E.D. and Johnson, R.H., 1993. Plant–insect herbivore interactions in elevated CO_2 environments. *Trends in Ecology & Evolution*, 8(2), pp.64–68.

Nayak, B.K., Dash, R. and Sahu, A.K., 2018. Tasar culture and tribal livelihood in India. *International Journal of Tropical Agriculture*, 36(2), pp.367–375.

Pai, D.S., Sridhar, L., Badwaik, M.R. and Rajeevan, M. (2014) 'Analysis of the daily rainfall events over India using a new long period high resolution gridded rainfall data set', MAUSAM, 65(1), pp. 1–18.

Pandiyaraj, T. and Yadav, H., 2018. *Screening of Fast Growing Drought Tolerant Terminalia arjuna Accessions for Raising Block Plantation*. Central Silk Board funded project (AIP-4711), Bengaluru.

Parry, M.L., Carter, T.R. and Konijn, N.T., 1989. *The Impact of Climatic Variations on Agriculture*. Dordrecht: Kluwer Academic Publishers.

Parry, M.L., Carter, T.R. and Konijn, N.T., 2007. *Climate Change and World Agriculture*. London: Earthscan.

Prasad, P.V.V., Bheemanahalli, R. and Jagadish, S.V.K., 2017. Field crops and the fear of heat stress. *Plant Science*, 260, pp.34–45.

Prasad, Y.G. and Bambawale, O.M., 2010. Climate change and insect pest management. *Indian Journal of Plant Protection*, 38(1), pp.1–7.

Rahmathulla, V.K., 2012. Management of climatic factors for successful silkworm crop and higher silk production: a review. *Psyche*, 2012, pp.1–12.

Ram, R.L., 2016. Impact of climate change on sustainable sericultural development in India. *Journal of Environmental Biology and Agricultural Sciences*, 7(Special Issue), pp.1–8.

Reddy, R.M., 2010. Prospects of sericulture in India. *Indian Silk*, 49(3), pp.5–9.

Reddy, R.M., Sinha, A.K. and Dash, R., 2013. Tasar culture in tribal economy. *Journal of Rural Development*, 32(4), pp.421–430.

Saha, S. and Mondal, R., 2026. *Sustainable Sericulture in India: Climate Change Impacts and Mitigation Strategies*. Singapore: Springer Nature.

Schafellner, C. and Schopf, A., 2008. Development of parasitoids under elevated CO_2 conditions. *Agricultural and Forest Entomology*, 10(1), pp.1–8.

Scott, J.A. *et al.*, 1997. Climate change and parasitoid survival. *Ecological Entomology*, 22, pp.325–335.

Sengupta, K., Ghosh, A. and Das, P., 2014. Sericulture as an employment generating household industry in India. *Asian Journal of Agricultural Extension*, 2(1), pp.45–52.

Shepherd, J.M., Shindell, D. and O'Carroll, C.M., 2005. What's the difference between weather and climate? NASA. Available at: NASA Climate Article [Accessed 14 May 2026].

Singh, J. and Baig, M.M., 2019. *Studies of Population Dynamics of Stem Borers in Tasar Host Plants and their Management through IPM Approaches*. Central Silk Board funded project report, Bengaluru.

Singh, J., Kumar, A., Mukherjee, S., Singh, G.P., Ray, S., Rawat, K.S. and Sinha, A.K., 2017. Assessment of brushing date and direction on tasar silkworm (*Antheraea mylitta* D.) production and protection. *International Journal of Current Microbiology and Applied Sciences*, 6(10), pp.4853–4859.

Singh, J., Rawat, K.S., Kumar, A., Mukherjee, S., Singh, G.P., Ray, S., Pandiaraj, T. and Sinha, A.K., 2018. Weather based forewarning of predators in tasar silkworm (*Antheraea mylitta* D.) at Kathikund, Dumka (Jharkhand, India). *International Journal of Current Microbiology and Applied Sciences*, 7(2), pp.633–638.

Sinha, A.K., Mittal, V., Pandey, J.P. and Singh, G.P., 2018a. Integrated management of leaf gall in *Terminalia* plants. In: *Tasar Technology Compendium: Tropical and Temperate Tasar Culture*, p.7.

Sinha, A.K., Mittal, V., Pandey, J.P. and Singh, G.P., 2018b. Neem based pesticide for management of bark eating caterpillar in *Terminalia* plants. In: *Tasar Technology Compendium: Tropical and Temperate Tasar Culture*, p.8.

Skirvin, D.J., Perry, J.N. and Harrington, R., 1997. The effect of climate warming on aphid predators. *Global Change Biology*, 3, pp.1–10.

Suryanarayana, N. and Srivastava, A.K., 2005. *Monograph on Tropical Tasar Silkworm*. Ranchi: Central Tasar Research and Training Institute.

Sustainability Study, 2025. Predicting potential habitats and the conservation of the tasar silkworm (*Antheraea mylitta*) in the Similipal Biosphere Reserve, Odisha, India. *Sustainability*, 17(13), p.5824.

Theophrastus, 370–286 BC. Early observations on plant diseases and environmental influences.

Thomas, M.B. and Blanford, S., 2003. Thermal biology in insect–parasite interactions. *Trends in Ecology & Evolution*, 18(7), pp.344–350.

Thomson, L.J., Macfadyen, S. and Hoffmann, A.A., 2010. Predicting the effects of climate change on natural enemies of agricultural pests. *Biological Control*, 52(3), pp.296–306.

Yamamura, K. and Kiritani, K., 1998. A simple method to estimate the potential increase in the number of generations under global warming in temperate zones. *Applied Entomology and Zoology*, 33(2), pp.289–298.

CHAPTER 2: SHIFT IN PHENOLOGICAL PATTERNS IN TASAR (*Antheraea mylitta* D.) IN RELATION TO CHANGING CLIMATE WITH REFERENCE TO CHHATTISGARH

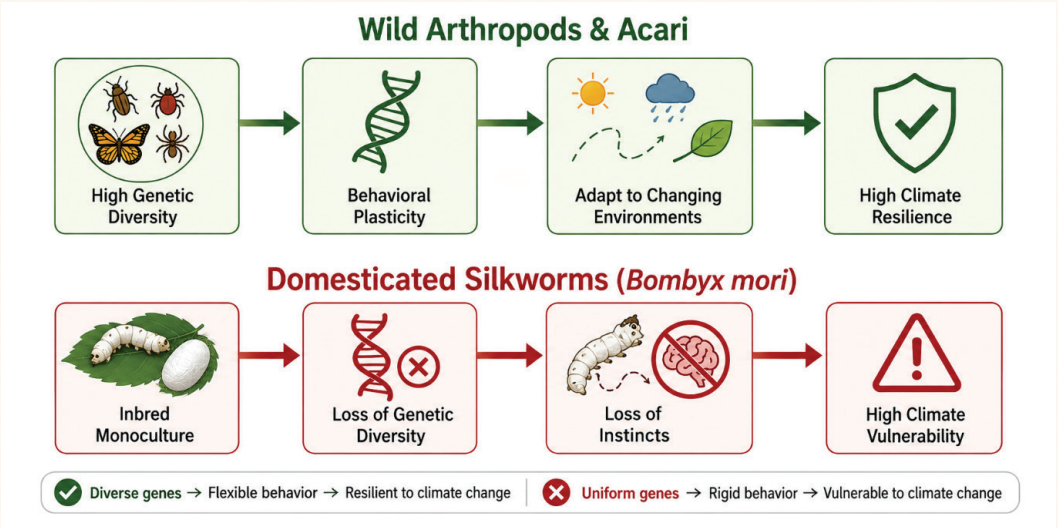
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2.1. INTRODUCTION

Insects are believed to have originated nearly 480 million years ago and subsequently diversified through continuous evolutionary adaptation to changing environmental conditions. Their evolution and distribution have been shaped by a wide range of abiotic and biotic factors, including temperature, humidity, rainfall, photoperiod, wind patterns, topography, soil characteristics, microbial interactions, predators, parasitoids and host plant availability. Such adaptive responses improve survival, reproduction and long-term fitness under varying ecological conditions (Triplehorn & Johnson, 2005; Chapman, 2013). Host plant specificity also strongly influences the distribution of herbivorous insects. Monophagous insects generally exhibit restricted distribution due to dependence on a single host species, whereas polyphagous insects possess broader ecological adaptability and greater colonization potential (Bernays & Chapman, 1994).

Climate change has emerged as a major ecological driver influencing insect biodiversity, dispersal and population dynamics. Rising global temperatures are expected to alter species distribution, migration patterns and colonization success. Enhanced dispersal capacity may allow insects to track favorable environmental conditions and expand beyond their existing geographical ranges. Advances in molecular biology and genetic markers have further improved understanding of insect dispersal, migration and population structure (Hill *et al.,* 2011). Since insect growth and reproduction are closely linked to environmental conditions, fluctuations in temperature, humidity, rainfall and photoperiod can substantially affect their survival and phenology. One of the most important adaptive mechanisms evolved by insects to overcome unfavorable environmental conditions is diapause, a hormonally regulated state of suspended development characterized by reduced metabolism and arrested growth. Diapause enables synchronization of insect life cycles with favorable seasons, thereby ensuring survival and reproductive continuity (Tauber *et al.,* 1986).



The tropical tasar silkworm, *Antheraea mylitta*, is an economically important wild sericigenous insect widely distributed across India. It plays a significant role in tribal livelihood security and forest-based sericulture through the production of tasar silk, a valuable natural fiber recognized for its texture, durability and eco-friendly characteristics. Unlike domesticated mulberry silkworms, *A. mylitta* possesses greater ecological adaptability and survives under natural forest ecosystems. Its life cycle is strongly regulated by environmental factors such as temperature, humidity, rainfall and host plant phenology. Therefore, synchronization of developmental stages with seasonal environmental conditions is essential for successful growth, development and reproduction.

Phenology, which refers to the seasonal timing of biological events in relation to environmental conditions, is a critical component in understanding insect ecology and climate interactions. In insects, phenological events such as egg hatching, larval development, pupation, adult emergence and reproduction are highly sensitive to climatic variables. Alterations in environmental conditions due to climate change may disrupt these synchronizations, leading to phenological mismatches, reduced survival and altered population dynamics. In sericigenous insects, such disturbances may directly affect cocoon productivity, voltinism and seed availability.

In *A. mylitta*, diapause serves as an important ecological adaptation enabling synchronization of developmental stages with favorable environmental conditions. During adverse climatic periods, particularly under extreme temperatures or unsuitable seasonal conditions, the insect enters diapause mainly at the pupal stage to enhance survival until favorable conditions return. The initiation, maintenance and termination of diapause are regulated by complex interactions among genetic, physiological and environmental factors, especially temperature and photoperiod (Denlinger, 2002). Recent climatic variability, including increasing temperatures, delayed monsoon onset, irregular rainfall and shifting seasonal patterns, may significantly affect diapause behavior and phenological synchronization in tasar silkworms. Variations in diapause duration and intensity can alter adult emergence, voltinism patterns and reproductive success, ultimately influencing tasar silk productivity and sustainability of forest-based sericulture systems. Understanding the relationship between climatic factors, diapause regulation and insect phenology is therefore essential for developing adaptive management strategies for sustainable tasar culture under changing climatic scenarios.

Chhattisgarh is one of the major tasar silk-producing states in India and has recently experienced prolonged summers, delayed monsoon onset and elevated temperatures during grainage seasons. These climatic abnormalities are increasingly affecting tasar silkworm seed production and are suspected to influence diapause termination, moth emergence, flight period, fecundity and egg hatching behavior in *A. mylitta*. The present study was therefore undertaken to investigate climate-induced shifts in phenological patterns of *A. mylitta* across different climatic regions of Chhattisgarh, with special emphasis on the DBV and DTV races, and to evaluate their implications for sustainable tasar sericulture.

2.2. SPATIAL TEMPERATURE ANOMALY IN MAJOR TASAR SILKWORM REARING AREAS IN CHHATTISGARH

The annual maximum temperature anomaly map indicated that several central districts of Chhattisgarh experienced higher daytime temperatures compared with the long-term normal. Elevated maximum temperatures are known to adversely affect larval growth, feeding efficiency and cocoon formation in Antheraea mylitta. Tasar silkworm larvae are highly sensitive to heat stress, and prolonged exposure to elevated temperatures may reduce food intake, increase metabolic expenditure and accelerate larval development. Such physiological stress can ultimately result in

poor cocoon quality, reduced silk productivity and increased larval mortality. Higher temperatures may also enhance susceptibility to pathogens and other stress-related disorders in silkworm populations (Rahmathulla, 2012; Neven, 2000).

The annual minimum temperature anomaly map further revealed pronounced positive anomalies in northern and central regions of Chhattisgarh, indicating that nighttime temperatures were substantially above the normal average. Elevated minimum temperatures are ecologically important because they may interfere with diapause regulation and seasonal synchronization in *A. mylitta*. Diapause is an adaptive physiological mechanism that enables the insect to survive unfavorable environmental conditions and synchronize adult emergence with suitable climatic periods and host plant availability. Warmer night temperatures may disrupt diapause induction, maintenance or termination, leading to altered emergence timing and phenological mismatches with host plants. Such disturbances can negatively influence voltinism, reproductive success and population stability in tasar silkworms (Denlinger, 2002; Tauber *et al.*, 1986).

The observed warming trends may significantly influence voltinism patterns, developmental duration and reproductive performance of tasar silkworm populations. Changes in thermal regimes can accelerate insect development and modify the duration of different life stages, thereby disturbing the natural seasonal cycle of the species. Since tasar culture in Chhattisgarh is largely dependent on forest ecosystems and climatic suitability, fluctuations in temperature and rainfall anomalies may adversely affect egg hatching, larval survival, pupal development and adult emergence. Climatic variability may also indirectly affect major tasar host plants such as Terminalia arjuna, Terminalia tomentosa and Shorea robusta by altering leaf moisture content, nutritional quality and flushing patterns. Reduced synchronization between silkworm developmental stages and host plant phenology may consequently compromise cocoon productivity and seed availability. Regions exhibiting persistent positive temperature anomalies may therefore become increasingly vulnerable to climate-induced stress affecting tasar sericulture systems.

2.3. BIOLOGICAL SIGNIFICANCE OF TEMPERATURE AND RAINFALL TREND IN CHHATTISGARH

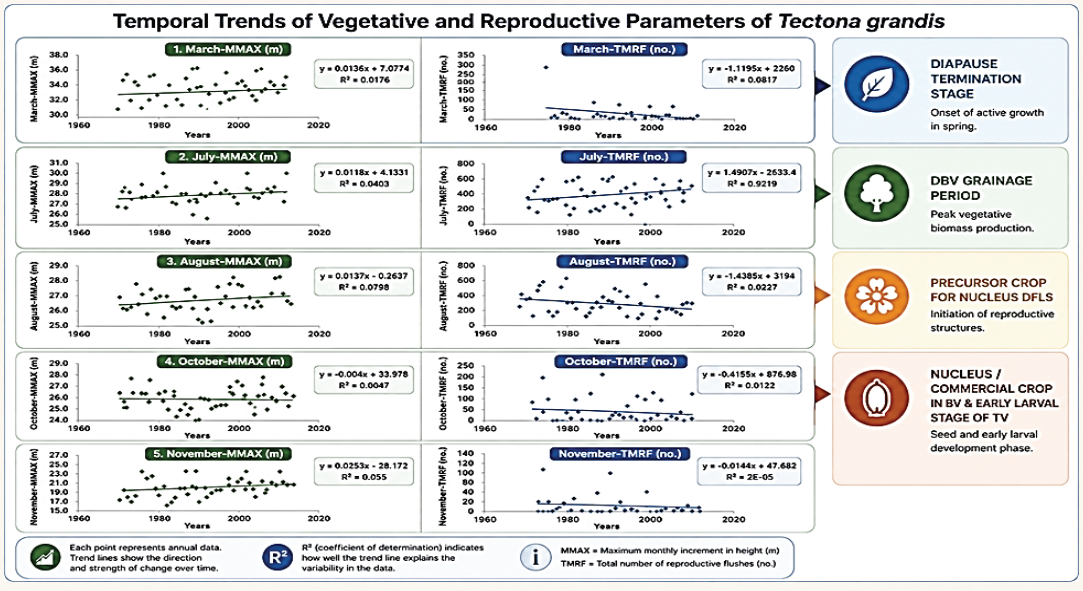


Figure 1 The figure illustrates long-term temporal trends in maximum temperature (MMAX) and minimum rainfall (TMRF) across different biologically critical stages of tropical tasar silkworm seed production and rearing. Scatter plots with regression equations and coefficient of determination (R^2)

values indicate climatic variability from approximately 1970–2015. The data reveal that maximum temperature during most crop stages shows a gradual increasing trend, whereas rainfall exhibits inconsistent fluctuations with both increasing and decreasing tendencies depending on the season. However, the very low R^2 values in most plots indicate weak correlations, suggesting high inter-annual climatic variability.

Analysis of long-term climatic trends during critical stages of tropical tasar silkworm seed production from 1970 to 2015 revealed gradual changes in seasonal temperature and rainfall patterns across tasar-growing regions of Chhattisgarh. Scatter plot analysis of maximum temperature (MMAX) and total monthly rainfall (TMRF) indicated a progressive increase in temperature across most crop seasons, whereas rainfall exhibited irregular and inconsistent fluctuations. Although the relationships showed relatively low coefficients of determination (R^2), the cumulative climatic variability reflects increasing environmental instability within tasar sericulture ecosystems. Similar long-term warming trends and rainfall irregularities have been reported to influence insect phenology, host plant dynamics and sericultural productivity under changing climatic conditions (IPCC, 2021; Rahmathulla, 2012).

During the diapause termination period in May, maximum temperature exhibited a gradual increase while rainfall showed a declining tendency. Rising temperature combined with reduced pre-monsoon rainfall may accelerate premature diapause termination, disrupt synchronization of larval emergence and affect scheduling of seed crops in Antheraea mylitta. Temperature is a critical environmental cue regulating diapause induction and termination, and abnormal warming can alter developmental timing and seasonal adaptation (Denlinger, 2002).

The DBV grainage period during July showed a marginal increase in temperature along with moderately variable rainfall. Elevated temperature during grainage may adversely affect seed preservation efficiency and embryonic development, whereas excessive rainfall and humidity may promote microbial contamination, reduce egg quality and ultimately affect Disease-Free Laying (DFL) productivity. Similar observations have been reported in sericulture systems where high temperature and humidity adversely influenced silkworm egg viability and disease incidence (Benchamin & Jolly, 1986).

During August, corresponding to the precursor crop period for nucleus DFL production, increasing temperature and declining rainfall trends were observed. Such climatic conditions may negatively influence larval feeding efficiency, cocoon formation and overall silkworm performance. Reduced rainfall can induce moisture stress in host plants, thereby lowering leaf succulence, nutritional quality and feeding suitability for tasar larvae. Climatic stress affecting host plant physiology has been shown to directly influence silkworm growth, survival and cocoon productivity (Scriber & Slansky, 1981).

October exhibited declining trends in both temperature and rainfall, which may adversely affect larval survival and cocoon productivity during late crop stages. In contrast, November showed a relatively stronger increase in temperature that could disturb larval development, pupation and physiological synchronization. Variations in thermal regimes are known to alter insect metabolic activity, developmental duration and reproductive performance, particularly in poikilothermic organisms such as silkworms (Chapman, 2013).

Tasar silkworm rearing is highly dependent on natural forest ecosystems and the availability of healthy host plants. Adequate rainfall is essential for vegetative growth, leaf moisture content and maintenance of host plant quality required for larval feeding and development. Districts receiving moderate and well-distributed rainfall, particularly in southern Chhattisgarh, may therefore provide

favorable ecological conditions for tasar silkworm growth and survival. However, excessive or prolonged rainfall can negatively affect tasar culture by promoting fungal and bacterial diseases, increasing larval mortality and reducing cocoon quality. Moderate rainfall is beneficial, whereas abnormal rainfall intensity and uneven seasonal distribution may create ecological stress within tasar ecosystems (Rahmathulla, 2012).

Conversely, districts experiencing declining rainfall trends may face moisture stress, reduced host plant productivity and poor larval feed efficiency. Rainfall variability may further influence the phenology and diapause behavior of *A. mylitta*, affecting egg hatching, larval emergence and synchronization with host plant availability. Irregular rainfall distribution may disrupt this synchronization, resulting in phenological mismatches and reduced reproductive success. Climate change impacts on tasar culture are therefore likely to vary regionally across Chhattisgarh, with some areas becoming increasingly vulnerable to drought-related stress while others may experience higher disease prevalence and ecological instability. Adoption of climate-resilient rearing practices, conservation of adaptable silkworm ecotypes and continuous environmental monitoring are therefore essential for sustainable tasar silk production under changing climatic conditions.

The long-term trends indicate progressive warming, irregular rainfall patterns and high climatic variability across different tasar silkworm crop seasons. These changes substantially influence diapause regulation, larval development, cocoon formation and reproductive physiology in *A. mylitta*. In addition to temperature and rainfall, other environmental parameters such as relative humidity and host plant condition also play crucial roles in determining silkworm performance. Climatic anomalies were associated with unusual biological events in tasar silkworm populations, including irregular moth emergence, increased pupal mortality, altered adult morphology, reduced fertilization and decreased fecundity. Climatic stress may further reduce sperm viability, mating efficiency and egg viability, thereby affecting fertilization and hatching percentage. Similar reproductive impairments under thermal stress have been documented in several insect species (Neven, 2000). These observations indicate that climate variability is increasingly affecting the phenology, physiology and reproductive biology of tropical tasar silkworms, thereby threatening the sustainability of tasar sericulture. Development of climate-resilient silkworm breeds, modification of crop calendars and implementation of climate monitoring systems are therefore essential for sustaining tasar culture under future climatic scenarios.

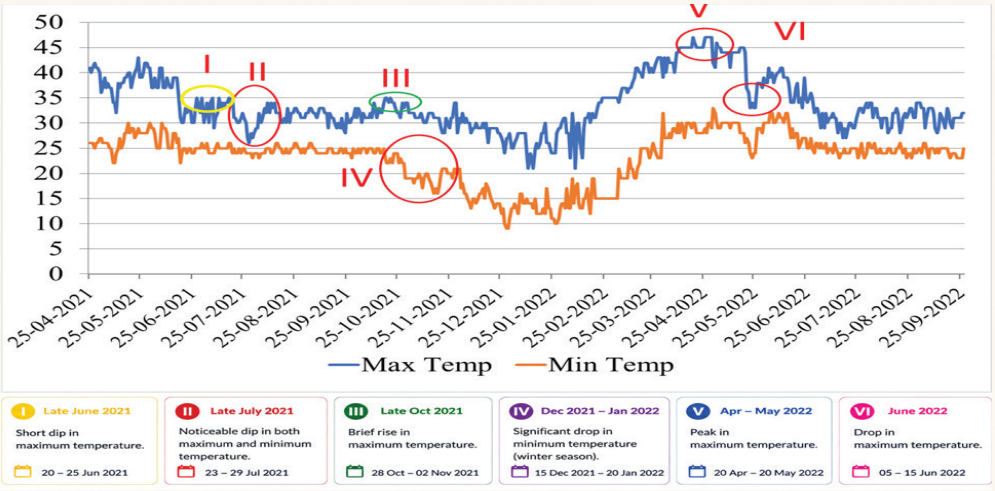


Figure 2 Temporal changes in maximum and minimum air temperatures recorded in Bilaspur from April 2021 to September 2022.

The data reveal distinct seasonal fluctuations corresponding to monsoon, winter and summer climatic conditions. During the initial period (April–June 2021), maximum temperatures remained high, ranging between 38–42°C. A gradual decline in maximum temperature was observed during June–July 2021 (Region I), likely associated with monsoon onset, increased cloud cover and rainfall activity. Minimum temperatures remained relatively stable around 24–26°C during this phase. In Region II (July–August 2021), sudden fluctuations in maximum temperature indicated atmospheric instability and intermittent rainfall associated with active monsoon conditions. Subsequently, a slight increase in maximum temperature occurred during October 2021 (Region III) following monsoon withdrawal. A pronounced decline in minimum temperature was observed from November 2021 to January 2022 (Region IV), reaching approximately 10–15°C and reflecting winter cooling conditions. Maximum temperatures also decreased moderately during this period. From February 2022 onward, both maximum and minimum temperatures gradually increased. The highest maximum temperatures were recorded during March–April 2022 (Region V), reaching 45–47°C and indicating severe summer heat stress. Pre-monsoon fluctuations observed during May–June 2022 (Region VI) were likely associated with convective atmospheric activity and changes in moisture conditions preceding monsoon onset. Overall, substantial seasonal temperature variability in Bilaspur, which has significant implications for tropical tasar silkworm rearing. Temperature fluctuations directly influence silkworm growth, cocoon quality, host plant health and disease incidence. Extreme summer and winter temperatures may therefore adversely affect seed crop performance.

2.4. PHENOLOGICAL VARIATION IN DTV (A) & DBV (B) IN RELATION TO STANDARD BRUSHING SCHEDULE

The tasar silkworm, *Antheraea mylitta* D., is an exothermic wild sericigenous insect characterized by distinct seasonal life-history events. Recent climatic fluctuations have altered phenological patterns and ecological interactions associated with this species. A pronounced plastic response in fecundity, development and survivorship in relation to temperature was evident in *A. mylitta* populations (Kumar *et al.*, 2012). Analysis of climatic data from the past three decades indicated a progressive increase in temperature and annual rainfall across several tasar sericulture-practicing regions (Sinha *et al.*, 2014). Since tasar seed production activities are concentrated between May and December, fluctuations in abiotic factors substantially influence silkworm development and ultimately cocoon yield. Moreover, the parental stocks of DABA BV and TV presently utilized for commercial rearing were originally derived from wild populations through selection and mass multiplication. Consequently, these populations are adapted to a relatively narrow range of climatic conditions (Reddy *et al.*, 2017).

Observations also identified a clear cyclic pattern in moth emergence and brushing schedules, with two peak periods in DBV and three in DTV annually. Graphical analysis showed high synchronization between moth emergence and brushing schedules in DBV, while DTV had slight temporal deviations. This led to a lack of disease-free layings (DFLs) during scheduled brushing in some areas. Diapause breakdown in DBV caused off-season moth emergence, resulting in a loss of breeding stock. Extreme heat events post-diapause caused severe pupal mortality, weak moths and other abnormalities in DTV. Dry spells and low rainfall during the active rearing phase of the precursor seed crop intensified viral incidence in the first DBV crop. Increased temperatures disrupted diapause in DBV populations, leading to off-season moth emergence and loss of breeding stock (Singh and Srivastava, 2011). Tasar sericulture seed production requires timely decision-making for superior yield and quality. Prolonged summers due to climate change have affected tasar-growing regions, causing abnormalities in moth emergence and grainage behavior. These

abnormalities include high pupal mortality, weak moths, altered sex ratios and reduced reproductive success. Higher post-diapause temperatures are likely responsible for these abnormalities, with malformed moths often resulting from desiccation during emergence. Asynchronous mating and reduced reproductive success were also observed due to males emerging earlier than females (Kumar *et al.*, 2012).

Temperature is one of the most critical abiotic factors affecting tasar silkworms, particularly in relation to reproduction and seed production. Elevated temperatures influence male pheromonal signaling and female receptivity, often resulting in reduced mating success and inadequate production of disease-free layings (DFLs). High temperature stress during summer preservation also contributes to male sterility and reduced female mating thresholds, thereby limiting silkworm seed production. Moreover, elevated temperature combined with high relative humidity favors viral infections in silkworm populations. Temperature stress during the spinning stage can produce irregular silk filament size, while improper handling and moisture loss during DFL transport may lead to poor embryonic development and egg depression. Therefore, maintaining optimal temperature conditions is essential throughout all developmental stages of tasar silkworm rearing (Jolly *et al.*, 1974).

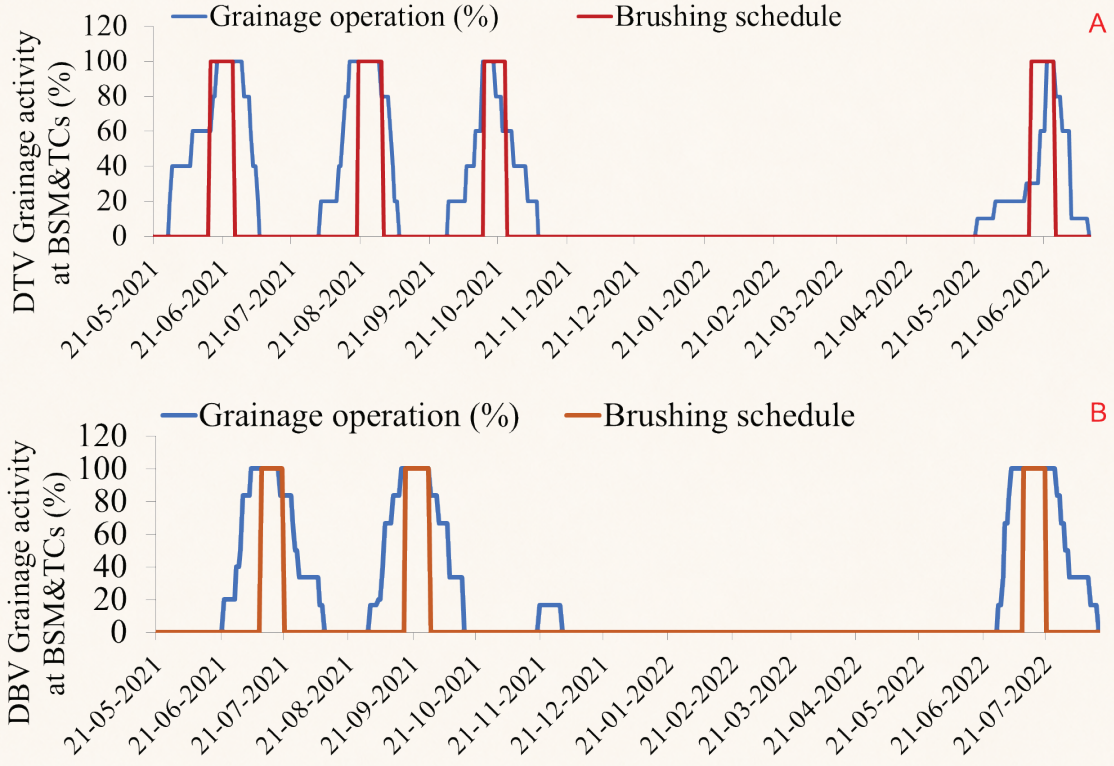


Figure 3. DTV (A) and DBV (B) moth emergence and brushing schedules during different seasonal flight period.

Synchronization of the silkworm life cycle with seasonal environmental conditions and host plant availability is fundamental for sustainable tasar silk production (Jolly *et al.*, 1974). Environmental fluctuations associated with climate change have disrupted the annual rhythm and developmental phases of *Antheraea mylitta* D. (Kumar *et al.*, 2012). Several abnormalities have been reported, including off-season moth emergence during periods when host plants are unavailable, altered emergence and mating behaviour, multiple or erratic emergence peaks, and disruption of the normal protandrous emergence cycle between male and female moths (Singh and Srivastava, 2011).

Climatic variations have also affected voltinism patterns, with shifts from bivoltine or multivoltine to univoltine behaviour observed in higher elevation regions (Reddy *et al.*, 2017). Additionally, premature winter conditions often prolong larval duration, thereby increasing rearing costs for stakeholders involved in tasar sericulture (Sinha *et al.*, 2014).



Figure 4. Normal moth emergence behavior was observed when the moth secreted sufficient cocoonase enzyme, enabling it to dissolve the cocoon structure and emerge successfully. However, insufficient production of cocoonase enzyme during periods of high temperature resulted in rapid drying of the enzyme, thereby hindering normal moth emergence from the cocoon.

The graph presents year-wise deviation (%) in cocoon yield across bivoltine (BV) and trivoltine (TV) tasar silkworm crops in Chhattisgarh during 2010–2021. The data are categorized into five crop groups, namely I BV, II BV, I TV, II TV and III TV, representing different seasonal crops. Positive deviation values indicate above-average cocoon yield, whereas negative values denote reduced productivity compared to the overall mean yield of the study period. The I BV crop exhibited relatively stable performance with moderate positive deviations during 2011–2020; however, a sharp decline was observed in 2021, indicating unfavorable climatic conditions affecting spring–summer brood productivity. In contrast, the II BV crop showed substantial positive deviations during the initial years (2010–2012), followed by alternating fluctuations with significant negative deviations in 2013, 2015, 2020 and 2021, reflecting increased variability in autumn brood performance. Among trivoltine crops, I TV recorded notable positive deviations during 2013 and 2017, suggesting favourable environmental conditions during spring rearing seasons, whereas several other years showed moderate negative deviations. The II TV crop demonstrated comparatively balanced fluctuations with positive peaks during 2013, 2014 and 2016–2017, indicating better resilience under rainy season conditions. The III TV crop displayed high inter-annual variability, with strong positive deviations in 2012, 2020 and 2021, while negative deviations predominated during 2014–2019.



Figure 5. Abnormalities associated with exposure to higher temperatures during the post-diapause period are illustrated in the figure. Malformed moths were observed due to desiccation during emergence, resulting in improper wing expansion and spreading. In some cases, moths were unable to emerge completely from the cocoon. Certain pupae successfully transformed into moths but died within the cocoon because of inadequate secretion of cocoonase enzyme, which prevented successful emergence.

The graph presents year-wise deviation (%) in cocoon yield across bivoltine (BV) and trivoltine (TV) tasar silkworm crops in Chhattisgarh during 2010–2021. The data are categorized into five crop groups, namely I BV, II BV, I TV, II TV and III TV, representing different seasonal crops. Positive deviation values indicate above-average cocoon yield, whereas negative values denote reduced productivity compared to the overall mean yield of the study period (Sinha *et al.*, 2014). The I BV crop exhibited relatively stable performance with moderate positive deviations during 2011–2020; however, a sharp decline was observed in 2021, indicating unfavorable climatic conditions affecting spring–summer brood productivity (Kumar *et al.*, 2012). In contrast, the II BV crop showed substantial positive deviations during the initial years (2010–2012), followed by alternating fluctuations with significant negative deviations in 2013, 2015, 2020 and 2021, reflecting increased variability in autumn brood performance (Singh and Srivastava, 2011).

Among trivoltine crops, I TV recorded notable positive deviations during 2013 and 2017, suggesting favourable environmental conditions during spring rearing seasons, whereas several other years showed moderate negative deviations. The II TV crop demonstrated comparatively balanced fluctuations with positive peaks during 2013, 2014 and 2016–2017, indicating better resilience under rainy season conditions. The III TV crop displayed high inter-annual variability, with strong positive deviations in 2012, 2020 and 2021, while negative deviations predominated during

2014–2019. These variations collectively indicate the increasing influence of climatic instability on seasonal tasar cocoon productivity and highlight differential crop sensitivity to changing environmental conditions (Reddy *et al.*, 2017; Suryanarayana and Srivastava, 2015).

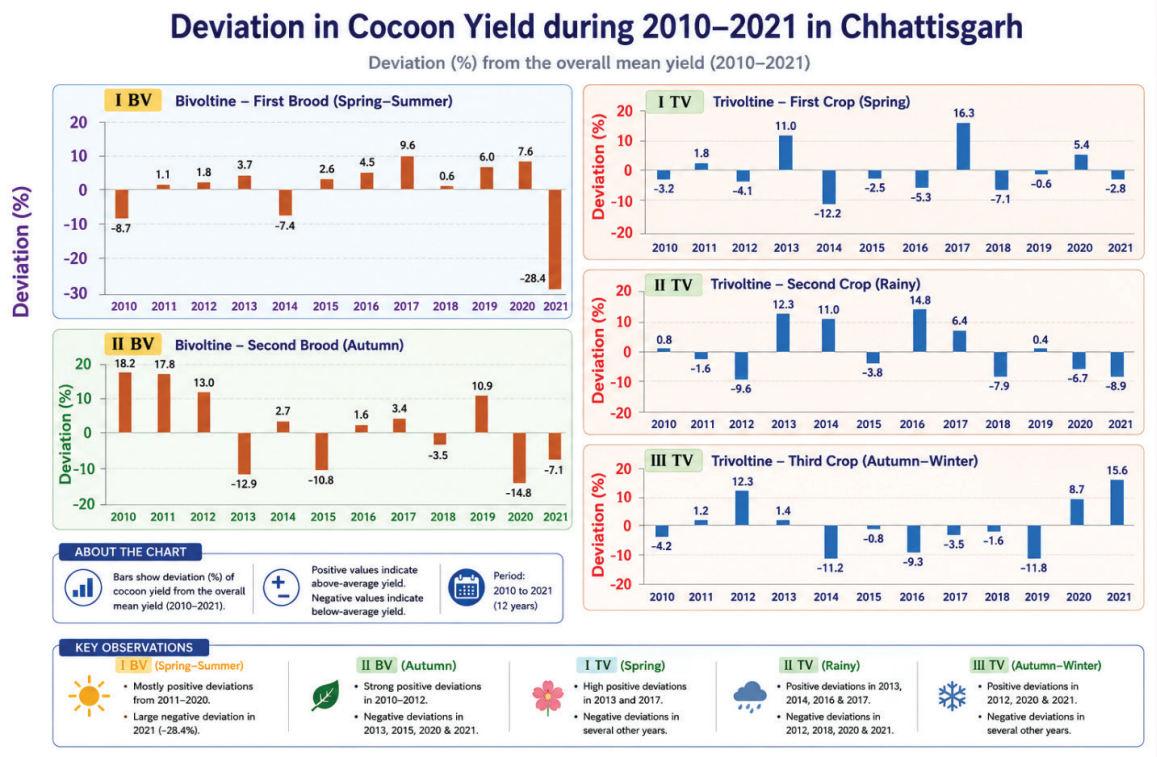


Figure 6. Deviation in the cocoon yield during 2010 to 2021 in Chhattisgarh

The graph presents year-wise deviation (%) in cocoon yield across bivoltine (BV) and trivoltine (TV) tasar silkworm crops in Chhattisgarh during 2010–2021. The data are categorized into five crop groups, namely I BV, II BV, I TV, II TV and III TV, representing different seasonal crops. Positive deviation values indicate above-average cocoon yield, whereas negative values denote reduced productivity compared to the overall mean yield of the study period (Sinha *et al.*, 2014). The I BV crop exhibited relatively stable performance with moderate positive deviations during 2011–2020; however, a sharp decline was observed in 2021, indicating unfavorable climatic conditions affecting spring–summer brood productivity (Kumar *et al.*, 2012). In contrast, the II BV crop showed substantial positive deviations during the initial years (2010–2012), followed by alternating fluctuations with significant negative deviations in 2013, 2015, 2020 and 2021, reflecting increased variability in autumn brood performance (Singh and Srivastava, 2011).

Among trivoltine crops, I TV recorded notable positive deviations during 2013 and 2017, suggesting favourable environmental conditions during spring rearing seasons, whereas several other years showed moderate negative deviations. The II TV crop demonstrated comparatively balanced fluctuations with positive peaks during 2013, 2014 and 2016–2017, indicating better resilience under rainy season conditions. The III TV crop displayed high inter-annual variability, with strong positive deviations in 2012, 2020 and 2021, while negative deviations predominated during 2014–2019. These variations collectively indicate the increasing influence of climatic instability on seasonal tasar cocoon productivity and highlight differential crop sensitivity to changing environmental conditions (Reddy *et al.*, 2017; Suryanarayana and Srivastava, 2015).

2.5. CONCLUSION

The present compilation clearly demonstrates that climate variability has significantly influenced the phenology, reproductive biology and grainage performance of the tropical tasar silkworm, *A. mylitta* in Chhattisgarh. Rising temperature trends, irregular rainfall distribution and prolonged seasonal extremes have altered the synchronization between silkworm developmental stages and favorable environmental conditions, resulting in noticeable shifts in moth emergence, diapause termination, flight period and voltinism patterns in both Daba Bivoltine (DBV) and Daba Trivoltine (DTV) races.

Spatial and temporal analyses of climatic parameters revealed progressive warming trends across major tasar-growing districts, particularly during biologically sensitive crop stages. Elevated maximum temperatures and warmer night temperatures adversely affected larval development, cocoon formation, diapause regulation and reproductive efficiency. Climatic anomalies were associated with several abnormal biological responses, including off-season moth emergence, malformed moths, incomplete emergence from cocoons, reduced fecundity, poor hatching percentage and increased seed cocoon loss. Extreme heat stress during the post-diapause period particularly disrupted cocoonase activity, leading to impaired moth emergence and reduced grainage success.

Long-term analysis of cocoon yield deviation indicated substantial inter-annual variability among different crop groups. Early seasonal crops such as I BV and I TV were more vulnerable to climatic stress, exhibiting higher fluctuations in cocoon productivity, reproductive instability and cocoon loss. In contrast, II BV, II TV and III TV crops showed relatively greater stability, better fecundity and improved hatching performance, suggesting comparatively higher ecological adaptability under changing environmental conditions. These findings indicate that climatic suitability and seasonal synchronization strongly determine the success of tasar seed production systems. The diapause, an important adaptive survival mechanism in *A. mylitta*, is highly sensitive to changing thermal and rainfall regimes. Disturbance in diapause induction, maintenance and termination may ultimately alter voltinism behavior, emergence periodicity and population sustainability. Such phenological disruptions not only affect silkworm biology but also influence host plant synchronization, seed availability and overall tasar silk productivity.

Overall, the increasing vulnerability of tropical tasar sericulture to climate change and emphasizes the urgent need for climate-resilient management strategies. Development of thermotolerant and adaptable silkworm races, climate-based crop scheduling, improved grainage preservation techniques, real-time environmental monitoring and conservation of genetically diverse wild populations are essential for sustaining tasar sericulture under future climatic scenarios. This compilation provides an important ecological insight into climate-induced phenological shifts in *A. mylitta* and contribute toward strengthening sustainable forest-based sericulture in India.

2.6. REFERENCES

Benchamin, K.V. & Jolly, M.S. (1986). Principles of silkworm rearing. *Proceedings of Seminar on Problems and Prospects of Sericulture*, S. Mahalingam (Ed.), Vellore, India, pp. 63–106.

Bernays, E.A. & Chapman, R.F. (1994). *Host-Plant Selection by Phytophagous Insects*. Chapman & Hall, New York.

Chapman, R.F. (2013). *The Insects: Structure and Function* (5th ed.). Cambridge University Press.

Denlinger, D.L. (2002). Regulation of diapause. *Annual Review of Entomology*, 47: 93–122.

Hill, J.K., Griffiths, H.M. & Thomas, C.D. (2011). Climate change and evolutionary adaptations at species' range margins. *Annual Review of Entomology*, 56: 143–159.

IPCC (2021). *Climate Change 2021: The Physical Science Basis*. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Jolly, M.S., Sen, S.K. & Ahsan, M.M. (1974). *Non-mulberry silks*. FAO Agricultural Services Bulletin.

Khavse *et al.* (2015). IMD (2022). India Meteorological Department reports on temperature and rainfall patterns.

Kumar, N.S., Basavaraja, H.K. & Datta, R.K. (2012). Effect of climatic factors on growth and reproductive performance of tasar silkworm *Antheraea mylitta* D. *Indian Journal of Sericulture*, 51(2), 120–126.

Neven, L.G. (2000). Physiological responses of insects to heat. *Postharvest Biology and Technology*, 21: 103–111.

Rahmathulla, V.K. (2012). Management of climatic factors for successful silkworm (*Bombyx mori* L.) crop and higher silk production: A review. *Psyche*, 2012: 121234.

Reddy, R.M., Suryanarayana, N. & Sarkar, A. (2017). Genetic variability and adaptation in tropical tasar silkworm populations. *Asian Journal of Biological and Life Sciences*, 6(1), 347–357.

Singh, G.P. & Srivastava, A.K. (2011). Influence of seasonal climatic variation on diapause and moth emergence in tropical tasar silkworm. *Journal of Insect Science*, 24(3), 145–152.

Sinha, A.K., Sahu, A.K. & Prasad, B.C. (2014). Climate variability and its impact on tasar sericulture in central India. *Indian Journal of Agricultural Sciences*, 84(9), 1092–1098.

Suryanarayana, N. & Srivastava, S.K. (2015). Seasonal variability and cocoon productivity in tropical tasar silkworm under changing climatic conditions. *Sericologia*, 55(4), 215–223.

Tauber, M.J., Tauber, C.A. & Masaki, S. (1986). *Seasonal Adaptations of Insects*. Oxford University Press, New York.

Triplehorn, C.A. & Johnson, N.F. (2005). *Borror and DeLong's Introduction to the Study of Insects* (7th ed.). Thomson Brooks/Cole.

CHAPTER 3: CLIMATE CHANGE AND EMERGING PEST DYNAMICS IN TASAR SERICULTURE

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3.1. INTRODUCTION

Tasar sericulture is a climate-sensitive agroforestry-based enterprise practiced largely under natural outdoor conditions. Unlike mulberry sericulture, where silkworm rearing is conducted under controlled environments, tropical tasar silkworm (*Antheraea mylitta* Drury) is reared directly on host plants growing in forest and block plantations (Shivakumar and Shamitha, 2013). As a result, both the silkworm and its host plants remain continuously exposed to fluctuating environmental conditions and diverse biological stresses (Gathalkar and Barsagad, 2016; Mathur and Shukla, 1998). Among these, insect pests have emerged as one of the major constraints affecting sustainable tasar cocoon production.

Climate change has become an increasingly important factor influencing insect pest incidence, distribution, survival and seasonal abundance across agricultural and forest ecosystems (Skendžić *et al.*, 2021; Subedi *et al.*, 2023). Rising temperature, irregular rainfall, prolonged dry spells, changes in relative humidity and shifting seasonal patterns are altering the ecological balance between insect pests, host plants, silkworms and natural enemies. These climatic disturbances often create favourable conditions for rapid multiplication of pests, extension of pest activity periods, increased number of generations and expansion into newer geographical regions.

In tasar ecosystems, such changes are becoming increasingly evident during recent years. Several insect species that were previously considered sporadic, localized, or minor pests are now emerging as economically important pests of both tasar host plants and silkworms. Simultaneously, some traditionally important pests are exhibiting changes in their seasonal incidence, severity and geographical distribution (Gadad *et al.,* 2023). These changing pest dynamics are posing serious challenges to tasar rearers, particularly under rainfed and forest-based rearing conditions where environmental regulation is difficult.

The major pests associated with tasar sericulture include defoliators, sap feeders, stem borers, predators, and parasitoids. Among silkworm pests, parasitoids such as *Blepharipa zebina* and *Xanthopimpla pedator* have long been recognized as serious constraints in tasar rearing. Similarly, predatory insects including reduviid bugs, predatory stink bugs, ants, wasps and praying mantids contribute significantly to larval mortality under field conditions (Chandrashekharaiah *et al.*, 2018; Selvaraj *et al.*, 2020). However, recent field observations indicate the emergence of several new pests such as leaf webbers, bagworms, shoot borers, soldier beetles, and predatory wasps, whose incidence and damage potential are gradually increasing in different tasar-growing regions.

Climate-induced stress may also weaken host plant vigour and reduce the defensive capacity of silkworms, thereby increasing their susceptibility to pest and disease attack. In addition, ecological disturbances caused by changing climate may disrupt the activity of natural enemies and alter the predator–prey balance within tasar ecosystems. Such changes ultimately favour pest establishment and outbreak situations.

Considering the growing influence of climate variability on pest ecology, understanding the emergence and changing behaviour of pests in tasar sericulture has become increasingly important. Continuous monitoring of pest dynamics, documentation of emerging pests and development of climate-resilient integrated pest management strategies are therefore essential for sustaining tasar silk production under future climatic scenarios.

This chapter highlights the emerging pests associated with tasar host plants and silkworms, their nature of damage, seasonal incidence and possible relationship with changing climatic conditions in tropical tasar ecosystems.

3.2. HOST PLANT PESTS

Healthy host plants form the foundation of successful tasar silkworm rearing, as the growth, survival and cocoon productivity of *Antheraea mylitta* are directly dependent on the quality and availability of foliage. In tropical tasar sericulture, host plants such as *Terminalia arjuna,* and *T. tomentosa* are cultivated under natural environmental conditions where they are continuously exposed to a wide range of insect pests throughout the year. Infestation by these pests not only reduces leaf biomass but also deteriorates foliage quality, thereby adversely affecting silkworm growth, larval health, cocoon formation and ultimately cocoon yield.

Insect pests associated with tasar host plants constitute one of the major biotic constraints in tasar ecosystems. Depending on the pest species, severity of infestation, plant age and prevailing environmental conditions, foliage loss may range from moderate damage to severe defoliation leading to substantial reduction in leaf availability for silkworm rearing. Under heavy infestation conditions, losses ranging from 15–90% have been reported in tasar plantations.

The pest complex associated with tasar host plants is highly diverse and includes defoliators, sap feeders, stem feeders, bark feeders, leaf miners, and borers. Major established pests include gall insect (*Trioza fletcheri* minor), vapourer tussock moths, May–June beetle (*Anomala blanchardi*), ash weevils (*Myllocerus viridanus*, *M. undecimpustulatus* and *M. transmarinus*), red beetles (*Tricliona picea* and *T. variabilis*), stem borers (*Psiloptera fatuosa, Sphenoptera koenbierensi and Aeolesthes holosericea*), bark-eating caterpillars (*Indarbela* spp.) and termites (Table 1). In addition, sucking pests such as thrips, leaf hoppers, and spittlebugs are frequently observed infesting tasar food plants in different agroclimatic regions (Jolly *et al.*, 1974; Singh *et al.*, 1992, Thangavelu and Singh, 1991, Thangavelu, 2000; Chandrashekharaiah *et al.*, 2018 and Preeti Tirkey *et al.*, 2019).

Table 1: Seasonal abundance and extent of damage of major pests of tasar food plants

S.N.	Common Name	Scientific name	Seasonal Abundance	Extent of damage (%)	
				Low	High
Leaf feeders (Sucking pests and defoliators)					
1.	Gall Insect	*Trioza fletcheri*	Mar – Nov (Jul-Sep)*	10-20	80-90
2.	Vapourer Tussock Moth	*Notolophus antiqua*	April – Nov (Jul – Sep)	8-10	70 - 90
3.	May-June Beetle	*Anomala blanchardi*	Mar – Aug (May–June)*	8-10	35 - 40
4.	Ash weevil	*Myllocerus viridanus*, *M. Undecim-pustulatus*, *M. transmarinus*	June – Oct (Jul-Sep)*	5-7	15 - 20

S.N.	Common Name	Scientific name	Seasonal Abundance	Extent of damage (%)	
				Low	High
5.	Red Beetle	*Tricliona picea* & *T. variables*	May – Oct (Jul-Aug)*	5-7	30-35
Stem feeders					
7.	Stem Borers	*Psiloptera fatuosa, Sphenoptera koenbierensi* & *Aeolesthes holosercea*	Jan – Dec	8-10	60 80
8.	Bark eating caterpillars:	*Indarbela quadrinotata* & *I. tetraonis*	Jan- Dec (April – Sep.)*	5-10	40-60
9.	Termites	*Odontoterme sparvidens, O. obesus, O. proformosanus, O. latiguloides, O. ganpati, O. redemanni Microtermes obesi* & *Coptoterme sheimi*	Throughout the year	5-10	50-60

Note: ** Indicates peak incidence*

Traditionally, many of these pests remained seasonal or localized in occurrence and were effectively regulated by environmental conditions and natural enemies. However, recent years have witnessed considerable changes in the pest scenario of tasar host plants. Several insect species that were previously considered minor, sporadic, or of negligible economic importance are now emerging as serious pests in tasar plantations. Increasing incidence of leaf webbers, hairy caterpillars, leaf miners, leaf-rolling weevils, bagworms, and shoot borers has been reported from different tasar-growing regions, indicating a gradual shift in pest dynamics (Table 2).

Table 2: Seasonal abundance and nature of damage of emerging pests of tasar food plants

Sl. No.	Common Name	Biological Name	Seasonal incidence	Nature of damage
	Leaf webber	*Chalcidoptera appensalis Othaga sp Nycelotala ravana Cyptoblabes sp* Torticidae moth Twirler moth	April to Nov. (June -July)*	Webbing and defoliating of leaves
	Hairy caterpillar	*Selepa celtis*	June to August	Defoliation
	Leaf miner	-	May to Dec. (Sept-Nov)*	Defoliating the leaves by means of mining
	Leaf Rolling Weevil	*Apoderus tranquebaricus* & *Paramecolabus discolor*	May to Sept (Jun-July)*	Rolling of the leaves for egg laying and feeding the chlorophyll of the leaves by scraping
	Bagworm	*Acanthopsyche bipar* & *Mahasena* sp.	April-Dec. (June-Aug)*	Defoliation and also feeding on the bark

Sl. No.	Common Name	Biological Name	Seasonal incidence	Nature of damage
	Shoot borer	-	Jun- Oct (July-Aug)*	Boring the tender shoots

Note: ** Indicates peak incidence*

Climate variability appears to play a significant role in the emergence and increasing severity of these pests. Rising temperature, erratic rainfall distribution, prolonged dry periods, delayed monsoon and fluctuations in relative humidity create favorable conditions for rapid pest multiplication and prolonged activity. Warmer environmental conditions may accelerate insect development, increase reproductive potential and permit multiple generations within a single season. Simultaneously, irregular climatic conditions may weaken host plant vigour, making plants more susceptible to pest infestation.

Changes in climatic conditions may also influence the synchronization between pests and their natural enemies. In many ecosystems, environmental disturbances alter predator–prey and host–parasitoid relationships, thereby reducing the effectiveness of natural biological control mechanisms. Such ecological imbalances may contribute to the outbreak potential of emerging pests in tasar plantations.

Defoliators constitute one of the most destructive groups among host plant pests because they directly reduce the photosynthetic area available for plant growth and leaf production. Repeated defoliation weakens plants, delays regeneration of foliage, and reduces the carrying capacity of plantations for silkworm rearing. Young plantations are particularly vulnerable because severe defoliation adversely affects plant establishment and branching pattern.

Stem borers and bark feeders further aggravate the problem by damaging the vascular tissues of host plants. Infestation by these pests disrupts nutrient translocation, weakens structural integrity, and predisposes plants to secondary infections and environmental stress. Similarly, leaf miners and sap feeders reduce plant physiological efficiency by damaging internal leaf tissues and extracting plant sap, ultimately affecting foliage quality.

Among the emerging pests, leaf webbers and bagworms have gained particular importance in recent years due to their increasing incidence and widespread occurrence. Their concealed feeding behaviour often delays detection during the early stages of infestation, allowing the population to build up rapidly before visible symptoms appear. Likewise, the increasing incidence of shoot borers in young plantations has become a matter of concern because repeated attack on terminal shoots adversely affects plant architecture and foliage production.

The emergence of new pests and the changing status of existing pests highlight the dynamic nature of tasar ecosystems under changing climatic conditions. These developments necessitate regular pest surveillance, documentation of pest diversity, and ecological studies on pest biology, seasonal incidence, and environmental adaptability.

Management of host plant pests in tasar sericulture requires an integrated and eco-friendly approach because indiscriminate chemical pesticide application may adversely affect silkworm health and disrupt the ecological balance of tasar ecosystems. Therefore, emphasis should be given to integrated pest management strategies involving field sanitation, mechanical removal of infested plant parts, conservation of natural enemies, use of botanical pesticides, timely monitoring, and need-based application of safer insecticides in non-rearing periods.

Development of climate-resilient pest management strategies and strengthening of pest forecasting systems will become increasingly important for sustaining tasar host plant productivity under future climate change scenarios. Continuous monitoring of emerging pest trends and understanding their ecological relationship with changing climatic factors will be essential for minimizing crop losses and ensuring sustainable tasar silk production.

3.2.1. LEAF WEBBERS (Crambidae, Pyralidae, Tortricidae, Gelechiidae: Lepidoptera)

It has been observed that here are 6 species of leaf webbers which are known to infest the *Terminelia arjuna* (Fig 1). However, among these *Chalcidoptera appensalis* is most commonly occurring species. Whereas remaining are considered to be minor and negligible.

3.2.1.1 Identifying Characteristics of Insect Pest:

Eggs are laid in masses after incubation period larvae hatches from egg and they will feed gregariously on the epidermis of the leaves. Early instar larvae are with transparent body with brown head capsule. Late instar larvae are with white and dark stripes with black head capsule. Adults are medium in size with different colour patterns (Fig 2).



Figure 1: Developmental satges and damaging symptoms of *Chalcidoptera appensalis* a: Egg Mass b: Early instars feeding on epidermis c: Late instar instar larvae d: Pupae e: Adult moth f: Damaged plant



Chalcidoptera appensalis



Othaga sp



Nycelotala ravana



Cyptoblabes sp



Torticidae moth



Twirler Moth

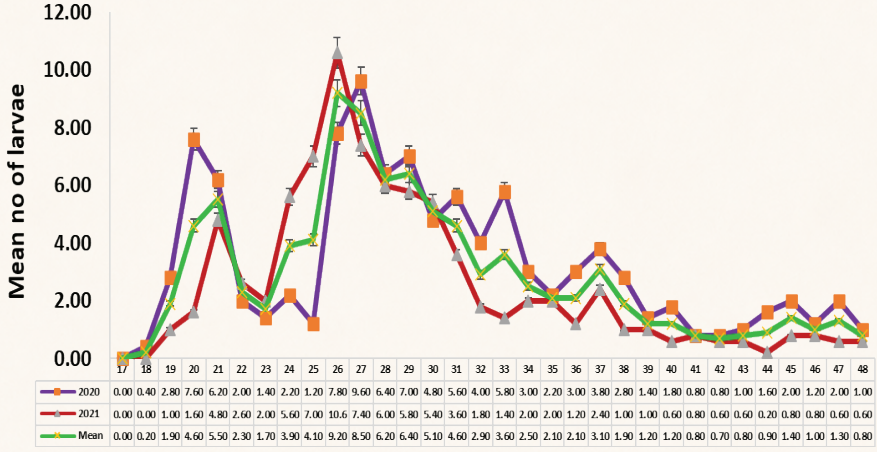
Figure 2: Different species of leaf Webber's observed on tasar food plants

3.2.1.2 Damaging symptoms:

Larvae web the leaves together with a silken thread and feeds on the webbed leaves. Incidence was only observed in arjun plants.

3.2.1.3 Period of occurrence

Incidence was observed from the month April to November with a peak incidence during June -July (Fig 3).



	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
2020	0.00	0.40	2.80	7.60	6.20	2.00	1.40	2.20	1.20	7.80	9.60	6.40	7.00	4.80	5.60	4.00	5.80	3.00	2.20	3.00	3.80	2.80	1.40	1.80	0.80	0.80	1.00	1.60	2.00	1.20	2.00	1.00
2021	0.00	0.00	1.00	1.60	4.80	2.60	2.00	5.60	7.00	10.6	7.40	6.00	5.80	5.40	3.60	1.80	1.40	2.00	2.00	1.20	2.40	1.00	1.00	0.60	0.80	0.60	0.60	0.20	0.80	0.80	0.60	0.60
Mean	0.00	0.20	1.90	4.60	5.50	2.30	1.70	3.90	4.10	9.20	8.50	6.20	6.40	5.10	4.60	2.90	3.60	2.50	2.10	2.10	3.10	1.90	1.20	1.20	0.80	0.70	0.80	0.90	1.40	1.00	1.30	0.80

Figure 3: Seasonal incidence of leaf webbers on *Terminalia arjuna*

3.2.1.4 Natural enemies of leaf webbers

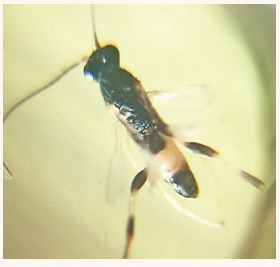
During the regular monitoring it has been observed that different larval parasitoids like *Baryscapus sp., Diolcogaster sp., Therophilus sp.* and parasitic mermithid nematodes known to attack leaf webber complex in tasar ecosystem (Fig 4).



Baryscapus sp.



Diolcogaster sp.



Therophilus sp.



Parasitic mermithid nematode

Figure 4: Natural enemies complex associated with leaf webbers infesting tasar food plants

Control measures

- Collection and destruction of egg masses and larvae from infested leaves
- In new plantations where rearing of silkworm is not yet started in such plantation this pest may be managed by spraying Fenvalrate 20 EC @ 1.0 ml/l or Emamectin benzoate 5 SG @ 0.5 g/l or Indoxacarb 14.5 SC @ 0.8 ml/l.

3.2.2. HAIRY CATERPILLAR- *Selepa celtis* (Nolidae: Lepidoptera)

3.2.2.1 Identifying Characteristics of Insect Pest

Eggs are laid in masses and freshly laid eggs will be yellowish and translucent with round shape with reticulate markings on chorion. The larvae of this defoliator are highly active, hairy, and yellowish with black dots on the 2nd, 7th, 8th and 9th abdominal tergites. Moths are medium size with pale brown color (Fig 5).

3.2.2.2 Damaging symptoms

The larvae of *S. celtis* are voracious leaf defoliators of *Terminelia arjuna*. Larvae cause damage by defoliating the leaves. Early instar larvae cause damage by feeding the epidermal layer of the leaves by scraping. However late instars larvae cause the defoliation/skeletisation of the leaves. Incidence was only observed in arjun plants.



Figure 5: a: Egg mass b: Damage by early instar larvae c: Late instar larvae defoliating the leaves d: pre pupal stage e: Pupae f: Adult moth

3.2.2.3 Period of occurrence: June to August

3.2.2.4 Control measures

- Collection and destruction of egg masses and larvae from infested leaves
- In new plantations where rearing of silkworm is not yet started in such plantation this pest may be managed by spraying Fenvalrate 20 EC @ 1.0 ml/l or Emamectin benzoate 5 SG @ 0.5 g/l or Indoxacarb 14.5 SC @ 0.8 ml/l.

3.2.3. LEAF MINERS

3.2.3.1 Identifying Characteristics of Insect Pest

Larvae are very small in size with creamy or pale-yellow color body. After completion of the larval stage, it pupates inside the leaf mines. Adults are very small in size with light brown color wings with white spots (Fig 6).

3.2.3.2 Damaging symptoms

These tiny insects eats the inside of host plant leaves which leads to brown colouring with see-through patches and can leave the whole tree looking severely damaged (Fig 6).

3.2.3.4 Period of occurrence

Incidence was observed from the month of May with peak incidence during Nov-Dec.

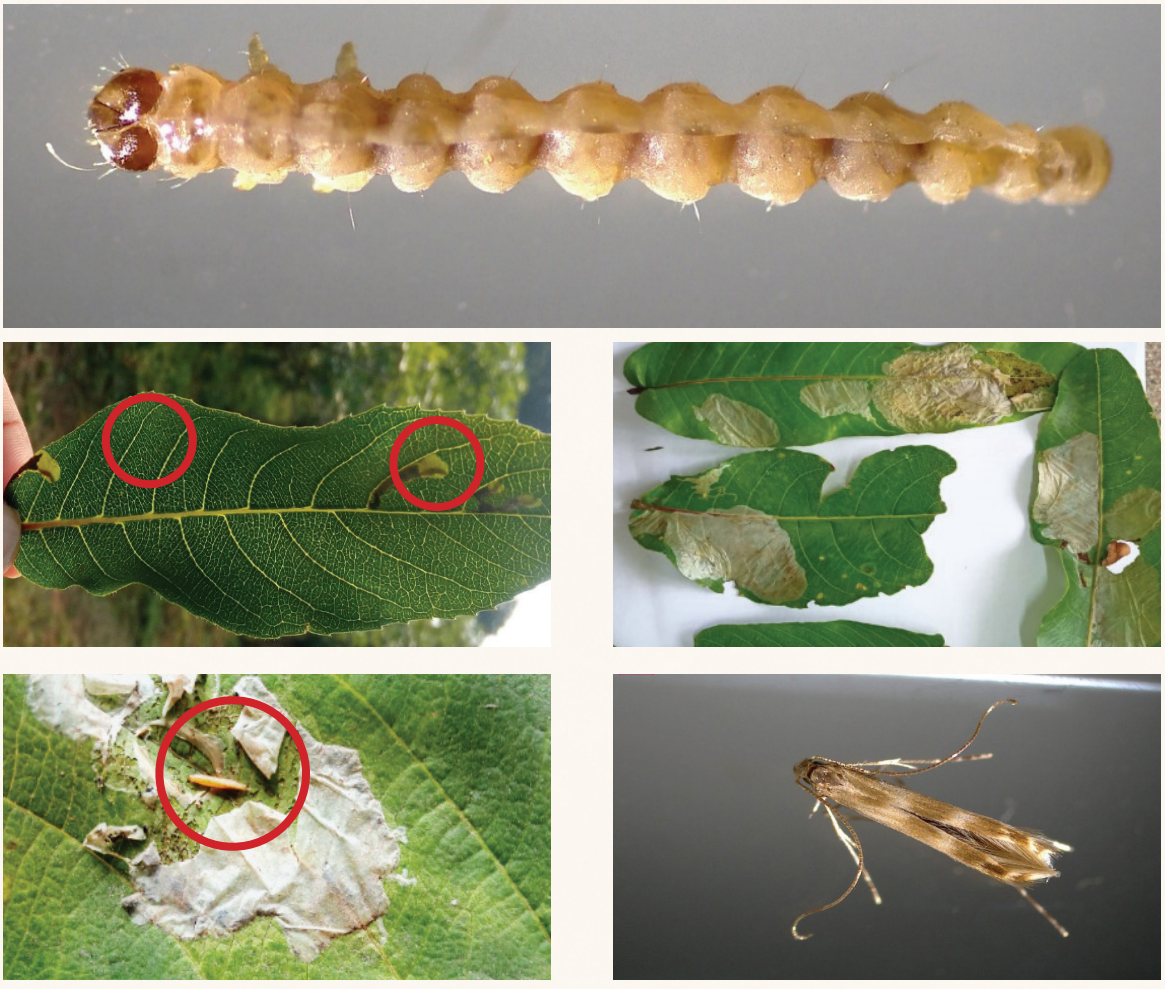


Figure 6: a: Larvae of leaf miner b: Larvae feeding by mining the leaf c: Leaves showing damaging symptoms d: Pupa e: Adult

3.2.3.5 Control measures

- Removal and destruction of mined leaves can reduce pressure
- Spraying of neem-based insecticides 5 ml per liter with the waiting period of 10 days
- In new plantations insecticides like Spinosad (0.2 ml/l) or Chlorantraniliprole-18.50 SC (0.5 ml/l)

3.2.4. LEAF ROLLING WEEVILS- *Apoderus tranquebaricus & Paramecolabus discolor* (Attelabidae: Coleoptera)

3.2.4.1 Identifying Characteristics of Insect Pest

Eggs are spherical and yellowish; Females typically deposit a single egg into each roll. Occasionally, more than one egg may be laid, especially when tender leaves are in short supply. Larvae develop in and feed upon leaf rolls. Larvae are legless, C-shaped, and grub-like. Adults are strikingly-colored weevils. The body is red with black compound eyes and fore legs is well developed with robust femur. Fore wings (Elytra) are shiny porcelain-like finish with yellow spots (Fig 7).

3.2.4.2 Damaging symptoms

Adults feed by skeletonizing or chewing small holes in the leaves of arjuna plants. Portions of some leaves are damaged by construction of leaf rolls. Female weevil lays a single egg on young oak leaves at the terminal end, then scores the leaf and tightly rolls it up into a little incubator to protect it. Once a leaf roll has aged a couple days, the leaf tissue dries into a hard casing around the egg. These leaf rolls may be severed from their point of attachment to a leaf and fall to the ground; area under tree canopy may contain numerous detached leaf rolls. Some leaf rolls may remain attached. Incidence was only observed in arjun plants.

3.2.4.3 Period of occurrence

Activity of this pests can be noticed between May to Sept and there after its incidence usually declines drastically

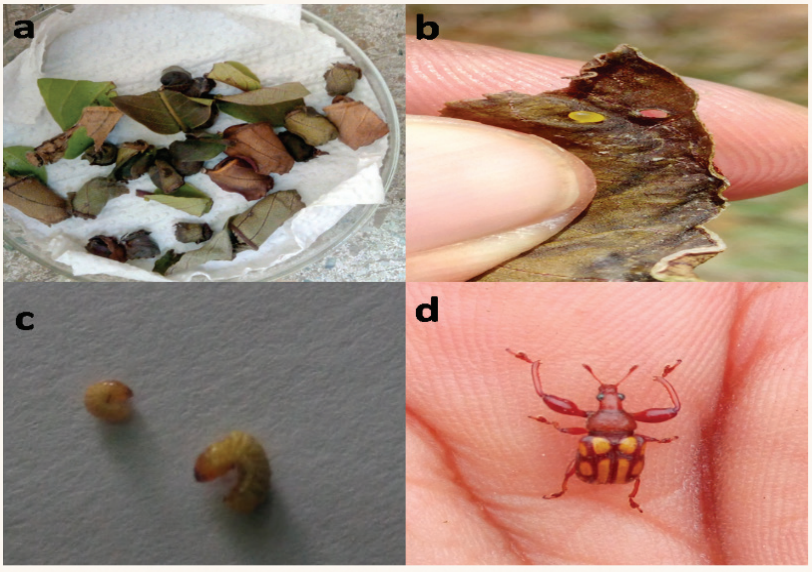


Figure 7: a: Leaf rolls containing eggs/grubs b: Egg inside leaf roll c: Grub inside the rolls d: Adult

3.2.4.4 Control measures

- Collection and destruction of leaf rolls which will be containing eggs and grubs
- Foliar application of neem based insecticides
- In new plantations insecticides like Roket (Profenofos 40% + Cypermethrin 4% EC) at the rate of 2 ml/l

3.2.5. BAGWORMS *Acanthopsyche bipar* and *Mahasena* sp (Psychidae: Lepidoptera)

3.2.5.1 Identifying Characteristics of Insect Pest:

The first identification characteristic of pest was observed with the visibility of bags which attached upright at the lower thin branches, side of leaf, mid rib of leaf, under the branch canopy and abaxial surface between the mid vein. The bags were constructed with the leaves of host plant one above the other with the help of silk. The silk ejected from the bagworm to create the bag were incredibly tough and very difficult to break open. Fragments of plant material in the cases as opposed to silk only or other materials are characteristics of the macro-moth family Psychidae. The cases will be having two small opening at the anterior and posterior end. The caterpillar comes out from the top opening to feed and ejects waste from the bottom end. The bottom opening is also acting as the exit path for the emerging male adult. It was also observed that when the worm feels threatened it shrinks body and hide inside the case without any movement as defensive behavior. On tasar host plants two types bagworms are seen. One constructs the case using leaf materials and other one is by sticks (Fig 8).

Eggs: eggs are creamish in color, generally they are laid within bag and after hatching neonates comes out of bag and starts feeding on host plants and simultaneously prepare the protective case or bag (Fig 10).

Larva: The larvae is eruciform with a well-developed and scleritonized head and thoracic legs. Larval body color found to be creamy to light brown in color with body length of 2 – 2.5 cm. Similar to cases 2 different larvae of bagworms known to infest tasar food plants (Fig 10).

Pupa: Male pupa was dark brown in color with the size of 1.8cm in length with clear visibility of wing pads. Female pupa was reddish brown in colour measuring 2.3cm in length with no antennae or wing pad formation (Fig 10).

Adults: Male moths will be light brown in color, bigger in size with body length of 1.5 cm, forewings measure 1.5 cm horizontally and 0.6 cm vertically. The hind wings are 1.0 cm horizontally and 0.6 cm vertically, possesses bipectinate antennae which measures 0.7cm in length. The adult females are sac-like wingless, their eyes, antennae and mouth-parts being atrophied measuring 2.3cm (Fig 10).

3.2.5.2. Damaging symptoms: Damage symptom sometimes overlooked by other general defoliators like beetles and caterpillars of tasar host plant. However It was notice that larvae only expel the head and thorax part from the bag for eating and moving, while the rest part remain inside the case).The initial appearance of damage mostly appeared at the lower surface of leaves both in *T. arjuna* and *T. tomentosa*, the young larva stick at the centre of the leaves with the help of gluey substance ejected from mouth, feeds on the leaves exhibiting irregular holes at the centre and full grown larvae causes the damage by feeding from the leaf margin irregularly leaving midrib (Fig 10 &11).

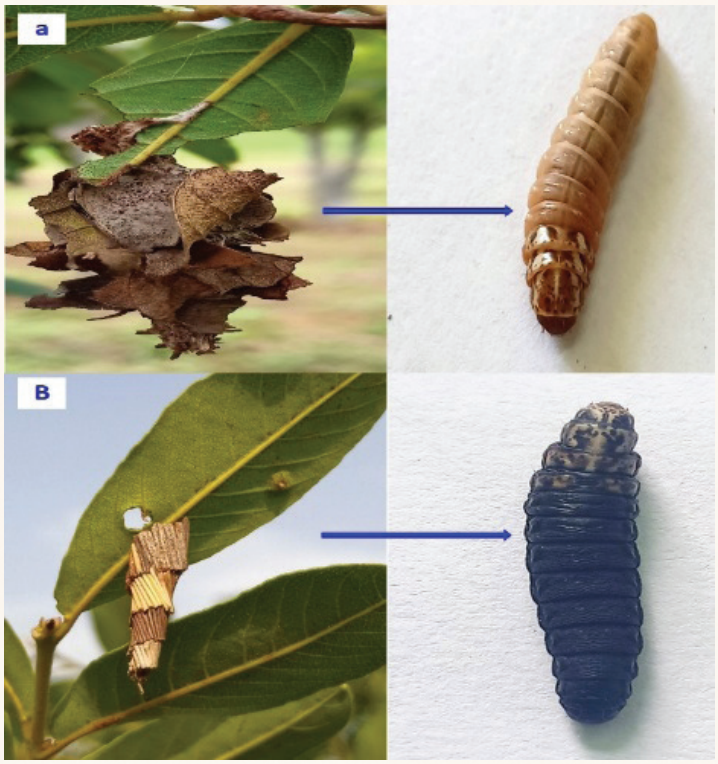


Figure 8: Types of bagworms infesting tasar food plants a) Larval case made by sticks b) Larval case made by leaf bits

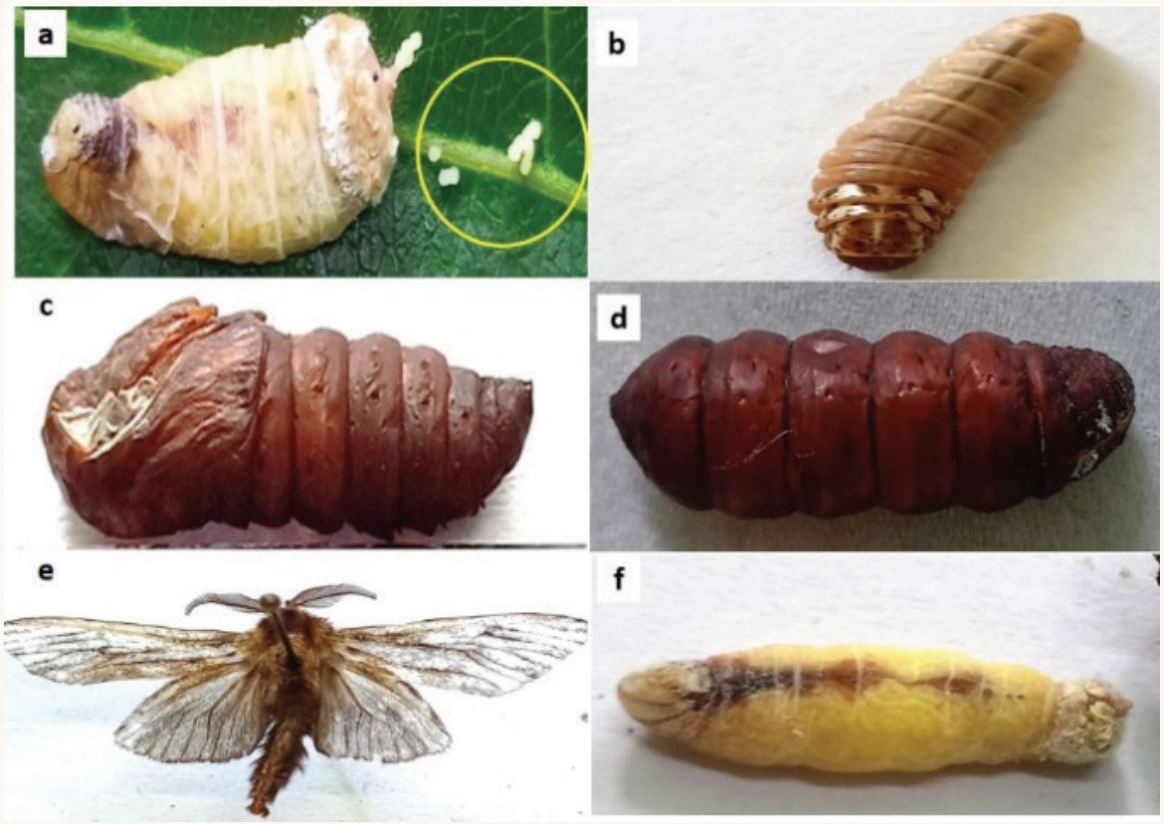


Fig 9: Developmental stages of bagworm which makes its cage using leaf bits a) Eggs b) Larva, c) Male pupa d) Female pupa e) Male adult f) Female adult



Figure 10: Damaging symptoms of bagworms on *Terminalia arjuna*



Figure 11: Damaging symptoms of bagworms on *Terminalia tomentosa*

3.2.5.3 Natural enemies

During the study larval parasitoid belonging to tachinid family (Unidentified) was observed and it was noticed that there were 3 to 4 puparia were found in single bag (Figure 12). This indicates that a single parasitoid lay 3 to 4 eggs in one single larva, however detailed study requires about its identification and percent parasitization (Bhagat *et al.*, 2022).

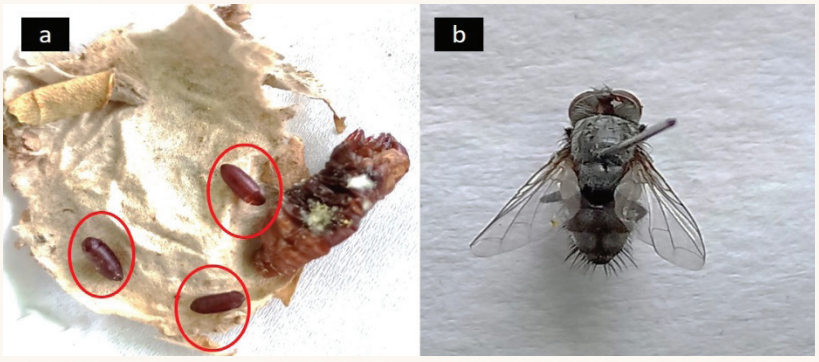


Figure 12: Tachinid parasitoid recorded from bagworm infesting tasar food plant a) dead bagworm larvae along with the pupae of parasitoid b) adult tachinid fly

3.2.5.4 Control measures

- Mechanical Hand Picking- If the bags are few in number and easily reached, they may be picked off the plant and squashed.
- Conservation of natural enemies

3.2.6. SHOOT BORER

Incidence of this pest is being from past two years and its damage is comparatively higher in asan plants than the arjuna plants. Detailed study about this pest is underway, however nature of damage is described below.

3.2.6.1 Damaging symptoms

Larvae of shoot borer burrow in to the tender shoot and feeds on the internal content. Which results in the drying and wilting of terminal shoots. If damaged shoot is dissected larvae with its excreta can be seen. Further damaged shoots also shows the bore holes on the shoots (Fig 13).



Figure 13: a) Bore hole on the damaged shoot b) drying of the affected shoot c) larvae fed on the internal content of the shoot d) larvae of the shoot borer recorded from tasar food plants

3.2.6.2 Control measures

- Early detection and clipping of infected shoots remove the pest from the plant
- If the incidence is high insecticides like Chlorantraniliprole-18.50 SC (0.5 ml/l)

3.3. SILKWORM PESTS

Protection of tasar silkworms from insect pests continues to be one of the most critical challenges in tropical tasar sericulture. Unlike mulberry sericulture, where silkworms are reared under controlled indoor conditions, tasar silkworms are reared entirely under open field and forest environments. Consequently, the silkworms remain continuously exposed to fluctuating climatic conditions and a wide range of natural enemies throughout their larval and spinning stages. These adverse conditions often result in heavy crop losses and reduced cocoon productivity.

Among the various biotic constraints, insect predators and parasitoids play a major role in limiting successful silkworm rearing. Under severe infestation conditions, pest-associated crop losses may reach 40–45%, particularly during unfavourable climatic periods characterized by high temperature, irregular rainfall, prolonged humidity, or dry weather stress. Such environmental conditions not only favour pest multiplication but also weaken silkworm vigour and increase their susceptibility to predation and parasitization.

The pest complex associated with tasar silkworms is broadly categorized into parasitoids and predators. Among the parasitoids, the uzi fly, *Blepharipa zebina* and the ichneumon fly, *Xanthopimpla pedator* are recognized as the most destructive species in tasar ecosystems (Marepally and Benarjee, 2016, 2017). *B. zebina* parasitizes late instar larvae, resulting in poor cocoon formation and mortality

during spinning and pupation stages. Similarly, *X. pedator* attacks the pupal stage by ovipositing through freshly spun cocoons, causing severe damage to seed and commercial cocoon crops.

Predatory insects constitute another major group of pests affecting tasar silkworms. Predatory stink bug, *Eocanthecona furcellata*, and reduviid bug, *Sycanus collaris*, are among the most destructive predators commonly encountered in tasar fields. These predators mainly attack early instar larvae by piercing the body wall and sucking haemolymph, often causing immediate larval mortality. In addition to predatory bugs, several other natural enemies such as predatory wasps, red ants (*Oecophylla smaragdina* and *Myrmicaria brunnea*) and praying mantids (*Hierodula bipapilla*) also contribute significantly to silkworm mortality during outdoor rearing (Table 3).

In recent years, noticeable changes have been observed in the pest dynamics of tasar silkworms across major tasar-growing states including Jharkhand, Odisha, Chhattisgarh, and West Bengal. Several insect species that were previously considered secondary, seasonal, or minor pests are now emerging as economically important threats. Altered climatic conditions, especially rising temperature, irregular precipitation patterns, prolonged dry spells, and increased atmospheric humidity, appear to have created favourable ecological conditions for pest establishment, survival, and rapid multiplication.

One of the important recent observations in tasar ecosystems is the increasing incidence of predatory wasps. Earlier, wasp predation was considered sporadic and localized, mainly involving Vespa orientalis. However, field observations conducted during recent years have revealed the occurrence of additional predatory wasp species such as *Polistes olivaceus*, *P. stigma tamulus* and *P. strigosus attratus* actively feeding on tasar silkworm larvae. In some rearing fields, these wasps have emerged as serious pests during chawki and early larval stages, causing substantial crop loss.

Similarly, the occurrence of soldier beetles (*Ichthyurus antheraeanus*) as predators of first instar tasar larvae represents another emerging concern (Reddy *et al.*, 2026). These beetles have been increasingly observed in tasar plantations during brushing periods, where they attack and feed upon newly hatched larvae. Though detailed ecological studies are still underway, their repeated occurrence indicates a possible shift in pest status under changing environmental conditions.

Another important development is the gradual expansion of the geographical distribution of ichneumon fly infestation. Earlier, severe infestation by *Xanthopimpla pedator* was mostly confined to relatively warmer tasar-growing zones. However, recent observations suggest that the parasitoid is spreading into newer regions with increasing frequency and intensity. Such expansion may be linked with climatic warming and changes in seasonal weather patterns that favour parasitoid survival and activity.

The changing pest scenario in tasar sericulture highlights the growing influence of climate variability on pest ecology and silkworm health. Climatic stress not only favours pest multiplication but may also disrupt the activity of natural biological control agents, thereby disturbing ecological balance within tasar ecosystems. In addition, stress-induced weakening of host plants and silkworms may further aggravate pest incidence and crop vulnerability.

These emerging challenges emphasize the need for continuous pest surveillance, ecological monitoring, and development of climate-resilient pest management strategies. Adoption of integrated pest management approaches, conservation of natural enemies, timely field sanitation, use of protective rearing practices, and region-specific pest forecasting systems will play an important role in minimizing pest-associated crop losses in tasar sericulture under changing climatic conditions.

Table 3. Major Parasitoids and Predators of tasar silkworm, *A. mylitta*

S.N.	Scientific Name	Common Name	Seasonal Abundance/Period of Occurrence	Economic Loss in Cocoon production (%)	Susceptible Stage
Parasitoids					
1.	*Blepharipa zebina*	Uzifly	Aug. – Feb. (Oct.- Jan.)*	10 – 40	3rd, 4th & 5th instar larvae
2.	*Xanthopimpla predator*	Ichneumon Fly	July - Jan. (Oct. –Dec.)*	10 – 30	Spinning stage larvae
Predators					
1.	*Eocanthecona furcellata*	Stink Bug	June – Jan. (Sep. - Dec.)*	10 -15	1st, 2nd & 3rd instar larvae
2.	*Sycanus collaris*	Reduviid Bug	Aug. – Nov. (Sep. - Oct.)*	10 -30	1st, 2nd & 3rd instar larvae
3.	*Vespa orientalis*	Wasp	Throughout year (July – Nov.)*	10 -15	1st, 2nd & 3rd instar larvae
5.	*Oecophylla smaragdina*	Red Ants	Throughout year (July – Feb.)*	5 – 7	1st, 2nd & 3rd instar larvae
6	*Hierodula bipapilla*	Praying Mantis	Throughout year (Aug. – Oct.)*	5 – 7	1st, 2nd & 3rd instar larvae

Note: ** Indicates peak incidence*

Table 4. Emerging pests of tasar silkworm

S.N.	Scientific Name	Common Name	Seasonal incidence	Susceptible Stage
1.	*Belotus sp.*	Soldier Beetle	July-August	1st instar larvae
2.	*Polistes olvaceous, P. stigma tamulus, and P. strigosus attratus.*	Predatory wasps	Jun-Oct (Jun-Aug)*	1st, 2nd & 3rd instar larvae
3.	*Sarcophaga (Sarcorohdendorfia) hiromui*	Flesh fly	Sept-Dec. (Oct-Nov)*	3rd, 4th & 5th instar larvae

Note: ** Indicates peak incidence*

3.3.1. SOLDIER BEETLE *Ichthyurus antheraeanus* (Coleoptera: Cantharidae)

3.3.1.1 Identifying Characteristics of Insect Pest

These are medium sized narrow elongated beetles with black and yellow colored body. Head is commonly bent downward. The antennae are 10-11 segmented, threadlike, and generally held forward of the body. Pronotum is wider and longer than the head. Fore wings are leathery and smaller in size, which covers only thoracic segments. Whereas, hindwings are membranous and bigger in size and they cover entire thoracic and abdominal segments.

3.3.1.2 Damaging symptoms

It has been observed that they damage to tasar silkworms only in first instar by biting and feeding the larvae (14).

3.3.1.3 Period of occurrence

Incidence of this pest has been recorded in some of the tasar practicing regions during last 3-4 years and activity of this pest was noticed in the month of July which coincides with the brushing of silkworm.

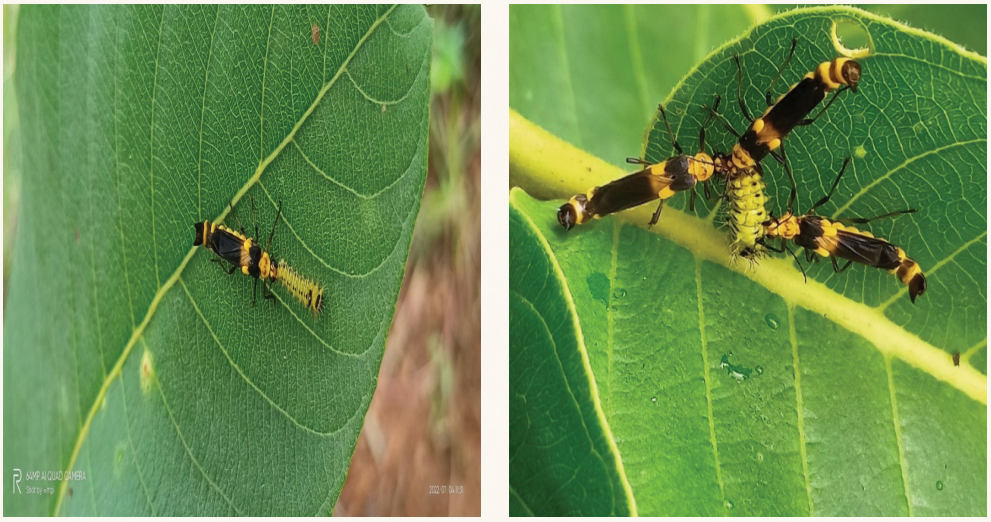


Figure 14: Soldier beetles feeding on the first instar tasar silkworm

3.3.2. PREDATORY WASPS

Predatory wasp like *Vespa orientalis* is reported to predate on tasar silkworm since long time ago but its incidence in current scenario is very negligible. However, from past few years scenario has changed drastically as per as wasps as a pests of tasar silkworm. It has been noticed that apart from *V. orientalis* at least 3 species other species of wasps known to predate on tasar silkworms. Which includes *Polistes olvaceous, P. stigma tamulus, and P. strigosus attratus* (Figure 15).

3.3.2.1 Damaging symptoms

Nature of damage by wasps to tasar silkworm is that after catching the host larvae, they cut the larvae and feeds on them and some species of wasps are also known to carry the larvae to their nests to feed the young ones.



Figure 15: Different wasp species feeding on tasar silkworms a) *Polistes strigosus attratus* b) *P. stigma tamulus* c) *P. olvaceous*

3.3.2.2 Period of occurrence

Activity of predatory wasps can be observed March to August with peak incidence during Jun-August

3.3.2.3. Control Measure:

- Destruction of wasps nests preset in and around the rearing site
- Rearing of silkworms under nylon net during Chawki stage

3.3.3. FLESH FLY (*Sarcophaga (Sarcorohdendorfia) hiromui*)

It has been noticed that some of the flesh flies are also known to parasitize the tasar silkworm. As it has been observed that magots emerging out of the harvested cocoons in the grainage. Generally, flesh flies are not true parasitoids like tachinids, however they might have parasitized weak, diseased or wounded insect larvae or pupae. Incidence of this pest was more during the year 2021 and it was quite less in the year 2022. Further detailed studies are required about its morphology, parasitization potential, biology, seasonal incidence and its management.

3.3.3.1 Nature of damage

Damaged larvae spins flimsy cocoon and those cocoons exhibits presence of maggots exit hole on the middle and posterior region of the cocoons (Figure 16).

3.3.3.2. Control measures

- Collection and destruction of maggots and pupae in the grainage
- Sorting out and stifling of flimsy cocoons



Figure 16: Flesh fly a) Maggots b) Pupae c) Adult fly d) Damaged tasar cocoons

3.4. CONCLUSION

Tasar sericulture is highly vulnerable to changing climatic conditions because both host plants and silkworms are maintained under open environmental conditions. Recent years have witnessed significant changes in the pest scenario of tasar ecosystems, including the emergence of several new pests and increased severity of previously minor pests.

Emerging pests such as leaf webbers, bagworms, shoot borers, soldier beetles, predatory wasps and flesh flies are gradually becoming important constraints to sustainable tasar production. Climatic variability, ecological disturbances, and changing agroecosystem conditions appear to be major factors driving these changes.

The increasing incidence of these pests emphasizes the importance of regular pest surveillance, early detection, ecological studies and integrated pest management approaches. Conservation of natural enemies, adoption of eco-friendly management practices and development of climate-

resilient rearing strategies will be essential for sustaining tasar sericulture under future climatic scenarios.

Further research is required to understand the biology, ecology, seasonal dynamics, and climate adaptability of emerging pests in order to develop scientifically sound and sustainable pest management strategies for tasar ecosystems.

3.5. REFERENCES

Bhagat, A., Sharma, N., Gadad, H., Reddy, T., Singh, J., Mittal, V., & Kutala, S. (2022). Incidence and nature of damage of bagworms on tasar silkworm food plants. *Plant Archives, 22*(Special Issue VSOG), 17–21.

Chandrashekharaiah, M., Mohanraj, S. S., Rathore, M. S., Nadaf, H. A., Vishaka, G. V., & Sathyanarayana, K. (2022). Infestation potential of *Xanthopimpla konowi* on tropical tasar silkworm cocoons and its management using nylon net. *International Journal of Tropical Insect Science, 42*, 2103–2112.

Chandrashekharaiah, M., Rathore, M. S., Sinha, R. B., & Alok, S. (2018). Status of sucking pests on *Terminalia arjuna*: An indication of changes in pest status and implication for tasar sericulture. *Research Journal of Agricultural Sciences, 9*(5), 1078–1080.

Gadad, H., Bhagat, A, Singh., J, Shreyansh, Mittal, V., Prabhu,D.I.G., Binkadakatti., J., and Pandey J. P. (2023). EmergingPests in Tasar Sericulture (Ed. Sathyanarayana, K.), CTRTI,Central Silk Board, Ranchi pp 1-20.

Gathalkar, G. B., & Barsagade, D. D. (2016). Parasites–predators: Their occurrence and invasive impact on the tropical tasar silkworm *Antheraea mylitta* (Drury) in the zone of central India. *Current Science, 111*(10), 1649–1657. https://doi.org/10.18520/cs/v111/i10/1649-1657

Jolly, M. S., Sen, S. K., & Ahsan, M. M. (1974). *Tasar culture*. Bombay, India: Ambika Publishers.

Marepally, L., & Benarjee, G. (2016). Identification and behavioral evaluation of sex pheromone in *Xanthopimpla pedator* (Fabricius): A serious pupal parasitoid of tropical tasar silkworm *Antheraea mylitta* Drury. *Hayati Journal of Biosciences, 23*, 185–190.

Marepally, L., & Benarjee, G. (2017). Studies on various factors affecting female sex pheromone release in *Xanthopimpla pedator*: A pupal parasitoid of tasar silkworm. *International Journal of Biosciences, 11*(3), 126–134.

Mathur, S. K., & Shukla, R. M. (1998). Rearing of tasar silkworm. *Indian Textile Journal, 86*, 68.

Preeti Tirkey, M., Chandrashekharaiah, M. S., Rathore, R. K., Singh, R. B., Sinha, & Alok Sahay, S. (2019). Studies on level of infestation of flat headed borer and bark eating caterpillar on *Terminalia arjuna* and their management using insecticides. *International Journal of Current Microbiology and Applied Sciences, 8*(1), 598–605.

Reddy, K. M., Biffi, G., Gadad, H., Bhagat, A., Chowdary, N. B., Sushil, S. N., & Sreedevi, K. (2025). A new species of *Ichthyurus* (Coleoptera: Cantharidae: Chauliognathinae) preying on tasar silkworm, *Antheraea mylitta* (Drury) from India. *Zootaxa, 5729*(2), 383–393. https://doi.org/10.11646/zootaxa.5729.2.9

Selvaraj, C., Bawaskar, D. M., Chandrashekharaiah, M., Nadaf, H., Rathore, M. S., & Srinivas, C. (2020). Damage potential of *Eocanthecona furcellata* on *Antheraea mylitta*. *Journal of Experimental Zoology India, 23*, 1213–1217.

Shivakumar, G., & Shamitha, G. (2013). Studies on larval mortality: Diseases, pest and predator menace in outdoor and indoor reared tasar silkworm, *Antheraea mylitta* Drury (Daba TV). *Research Journal of Animal, Veterinary and Fishery Sciences, 1*(4), 1–7.

Singh, R. N., Goel, A. K., & Thangavelu, K. (1992). Succession of insect pests in tasar ecosystem in Bihar. *Indian Journal of Ecology, 19*, 177–182.

Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., & Lemić, D. (2021). The impact of climate change on agricultural insect pests. *Insects, 12*(5), 440. https://doi.org/10.3390/insects12050440

Subedi, B., Poudel, A., & Aryal, S. (2023). The impact of climate change on insect pest biology and ecology: Implications for pest management strategies, crop production, and food security. *Journal of Agriculture and Food Research, 14*, 100733. https://doi.org/10.1016/j.jafr.2023.100733

Thangavelu, K. (2000). *Lessons on tropical tasar*. Ranchi, India: Speed-O-Print.

Thangavelu, K., & Singh, R. N. (1991). Integrated pest management in tasar culture. *Annals of Entomology, 92*, 52–65

CHATPER 4: IMPACT OF SEASONAL FLUCTUATIONS ON THE EMERGENCE OF *Antheraea* spp (LEPIDOPTERA: SATURNIIDAE)

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4.1. INTRODUCTION:

Climate warming has emerged as one of the most significant environmental challenges affecting natural ecosystems worldwide. Rising global temperatures influence biological systems at multiple organisational levels, ranging from individual physiological responses to large-scale alterations in community structure and ecosystem functioning (Guo *et al.,* 2011). Both plants and animals exhibit measurable responses to warming, including changes in growth, reproduction, phenology, species interactions, and geographical distribution. Among animals, insects are considered particularly vulnerable and responsive to climate change because they are poikilothermic organisms whose body temperature, metabolism, and developmental processes are directly regulated by ambient environmental conditions.

Over the last century, Earth's average surface temperature has risen markedly by 0.5 ºC to 0.6 ºC (*Menéndez, 2007; Ubukata, 2000*). The most pronounced warming occurred during the 1990s. The magnitude of this warming has not been uniform worldwide. Higher latitudes have experienced stronger temperature increases. Seasonal variation shows that colder months are warming more rapidly than warmer months. Scientific evidence strongly indicates that the accumulation of atmospheric greenhouse gases is the primary driver of these climatic changes. In particular, carbon dioxide released through human activities plays a central role. Climate projections further suggest that global temperatures may continue to rise substantially throughout the twenty-first century. Increases of several degrees Celsius are possible by the year 2100. Growing concern over these environmental changes has stimulated extensive ecological research. Over the past few decades, numerous studies have documented the biological consequences of global warming. These studies cover a wide variety of organisms that differ in habitat, distribution, and life-history characteristics. Observed effects include changes in geographical distribution, seasonal activity, reproductive behaviour, developmental rates, and species interactions. These changes indicate that climate change is already reshaping ecological communities worldwide (*Menéndez, 2007*). Among all organisms, insects are particularly important. They constitute more than half of the known living species and inhabit nearly every terrestrial ecosystem. Insects have short life cycles, high reproductive potential, and a strong dependence on environmental temperature. These traits make them especially sensitive to climatic fluctuations. As a result, insect responses to global warming provide valuable indicators for assessing the broader ecological impacts of climate change on biological systems. The present discussion focuses on the effects of contemporary global warming on insect communities. It emphasises experimentally and observationally documented responses to increasing temperature. Particular attention is given to how temperature-driven changes influence biodiversity, species composition, and community structure in natural ecosystems. The emphasis is primarily on the direct effects of elevated temperature. This aspect has received greater scientific attention and has stronger empirical support than other climatic factors such as precipitation, atmospheric carbon dioxide concentration, and ultraviolet radiation.

4.2. GLOBAL WARMING AND *Antheraea spp.*

The most dominating Indian species within genus *Antheraea* is *Antheraea mylitta*, commonly known as Tasar. Tasar sericulture constitutes an important forest-based livelihood activity for nearly 3.5 lakh tribal farmers distributed across approximately 44.50 million hectares of forested regions in India (Mazumdar *et al.*, 2023). The natural ecological distribution of tasar silkworms extends across a broad geographical range between 72–96°E longitude and 12–31°N latitude, encompassing diverse climatic and vegetation zones suitable for wild silkworm propagation (Jolly *et al.*, 1974). Wild silkworms complete the critical phases of their life cycle, including adult emergence, mating, and oviposition, under natural outdoor environmental conditions during the months of May to November for bivoltine and trivoltine *Antheraea mylitta* (Tasar silkworm) across the states of tropical and sub-tropical states of India, where commercial exploitation of Tasar silkworm is practised (Yamazaki, 1954, Mazumdar *et al.*, 2023; 2024). Among the various eco-races of *Antheraea mylitta* available in India, the commercially most important and extensively exploited race is the DABA ecotype, which occurs in both bivoltine and trivoltine forms. Successful tasar silk production depends greatly on the proper synchronization of essential biological and sericultural activities such as adult emergence, mating, oviposition, larval rearing, and cocoon formation (Jolly *et al.*, 1979). Any disruption in the timing of these developmental and reproductive events can adversely affect cocoon yield, seed production, and overall crop performance. Unlike the domesticated mulberry silkworm *Bombyx mori*, one of the major biological constraints in *A. mylitta* culture is the occurrence of irregular and erratic adult emergence throughout different seasons of the year. Emergence in this species has been recorded not only during the normal pre-monsoon and monsoon periods but also during post-monsoon months and even during diapause phases, indicating a comparatively unstable and environmentally sensitive developmental pattern (Shapiro, 1993; Sharma and Ali, 2013). Such irregular emergence often creates serious difficulties in maintaining synchronized mating and rearing schedules under field conditions. The role of bioclimatic factors in regulating insect emergence and developmental physiology is well established. Environmental parameters such as temperature, relative humidity, rainfall, and photoperiod strongly influence insect metabolism, diapause regulation, pupal development, and adult eclosion (Messenger, 1958). Previous studies have demonstrated that erratic and non-seasonal emergence in *A. mylitta* is closely associated with fluctuations in humidity and rainfall patterns (Siddaiah *et al.*, 2014). Messenger (1958) further emphasized that specific stages of insect development are critically dependent upon one or more climatic variables, which collectively determine the timing and success of developmental transitions. Similarly, the emergence pattern of *A. mylitta* is largely governed by environmental conditions, particularly temperature, humidity, and precipitation (Jolly *et al.*, 1974; Shapiro, 1993). These climatic factors regulate pupal metabolism and adult emergence, thereby influencing voltinism and seasonal crop cycles. Under normal conditions, adult emergence in bivoltine populations of *A. mylitta* generally occurs between June and October, which is regarded as the principal seasonal period for tasar silkworm activity and commercial rearing. Any deviation in climatic conditions during this period may alter emergence behaviour and subsequently affect the productivity and sustainability of tasar sericulture. Since the rearing of Tasar silkworms is mostly practised by marginal farmers, the use of sophisticated tools and techniques is very limited. Since these physiological and reproductive processes take place under natural outdoor conditions, they are greatly influenced by variations in ambient temperature (Jolly *et al.*, 1971). During this transitional season, daytime temperatures may remain favourable, whereas night-time and early morning temperatures often decline sharply, sometimes approaching levels detrimental to insect metabolism and reproductive efficiency. Consequently, low temperature becomes one of the most important ecological factors regulating the successful completion of the life cycle in wild silkworms.

Temperature influences several biological processes such as pupal development, adult activity, wing expansion after emergence, mating responsiveness, sperm transfer, and egg-laying behavior (Mazumdar *et al.*, 2024). In particular, insufficient thermal conditions may delay emergence, reduce mating success, suppress oviposition, or even cause mortality during vulnerable developmental stages. Therefore, understanding the minimum thermal requirements for these activities is essential for clarifying the ecological adaptation and seasonal biology of wild silkworm species such as *Antheraea mylitta and Antheraea assamensis*. Experiments conducted during May 1954 by Yamazaki (1954) using approximately 500 pupae of the univoltine wild silkworm *Antheraea pernyi* demonstrated a significant influence of low temperature on adult emergence, mating, and oviposition under natural environmental conditions. Continuous observations revealed that these physiological and reproductive activities were strongly associated with ambient temperature fluctuations prevailing during the experimental period. Adult emergence was successfully observed at temperatures around 10.5°C, indicating that this temperature represents the minimum threshold required for normal emergence activity. Mating behaviour was recorded at temperatures near 8.0°C, whereas successful copulation was markedly reduced or absent below this level. Oviposition activity occurred at comparatively lower temperatures, with egg laying being observed at approximately 7.5°C, although the number of eggs laid decreased considerably under colder conditions. The study further demonstrated that reduced night-time and early morning temperatures adversely affected the frequency and efficiency of these biological processes. Correlation of behavioural observations with environmental temperature records established distinct thermal threshold values essential for emergence, copulation, and oviposition in *A. pernyi*. These findings indicate that low temperature is a critical ecological factor regulating the reproductive success and seasonal life cycle of the species under natural conditions. The results also provide important insights into the ecological physiology, seasonal adaptation, and reproductive biology of wild silkworms, particularly in relation to environmental stress caused by low temperature exposure.

4.3. EFFECT OF ABIOTIC FACTORS AND WARMING ON SEASONAL AND NON-SEASONAL EMERGENCE

The emergence dynamics of *Antheraea mylitta* were analysed to distinguish the seasonal and non-seasonal patterns of moth emergence across different months of the year (Mazumdar *et al.*, 2023). The clustering approach was based on dissimilarities in the total number of emerged moths, estimated using Euclidean distance and Ward's linkage method, which is widely recognized for minimizing intra-cluster variance and generating biologically meaningful groupings (Legendre and Legendre, 1998). The Agglomerative Hierarchical Clustering (AHC) analysis clearly resolved three major clusters corresponding to distinct emergence patterns. The first cluster comprised the principal seasonal months, namely June, July and September, characterized by synchronized and abundant moth emergence. The second cluster represented non-seasonal months showing irregular or erratic emergence, particularly March, April and May. The third cluster consisted of months with either negligible or complete absence of emergence, including November, December, January and February. Such clustering patterns strongly indicate that emergence in *A. mylitta* is not random but is strongly governed by prevailing environmental conditions and seasonal rhythms.

Mazumdar et al (2023) segregated the months into distinct emergence groups further enabling comparative evaluation of meteorological variables influencing adult emergence. Descriptive statistical analysis demonstrated substantial variation between seasonal and non-seasonal periods. Seasonal months recorded considerably higher rainfall (221.43 ± 26.47 mm), relative humidity (79.91 ± 2.92%), temperature (30.79°C), and moth emergence (46808 ± 10574.68 individuals) compared to non-seasonal months, which exhibited much lower rainfall (16.14 ± 5.31 mm), humidity (55.39

± 2.66%), and emergence (96.00 ± 26.31 individuals). These observations clearly suggest that favourable hydro-climatic conditions are strongly associated with synchronized mass emergence of adult moths. The substantial reduction in emergence during non-seasonal periods further indicates that diapause termination and adult eclosion are highly dependent upon environmental cues, particularly moisture-related parameters. The comparative box plot analyses of rainfall, humidity, temperature and emergence further highlighted the pronounced distinction between seasonal and non-seasonal phases. Seasonal emergence exhibited relatively narrow and consistent distributions of humidity and rainfall, indicating stable environmental conditions during the normal emergence period. In contrast, non-seasonal months showed greater variability and unpredictability, reflecting the erratic nature of emergence during these periods. Such variability may be linked to sporadic fluctuations in atmospheric moisture, which can occasionally trigger premature or delayed emergence of pupae outside the normal reproductive cycle. Correlation analysis provided additional insight into the relative contribution of different climatic variables influencing emergence. Pearson's correlation coefficients demonstrated that rainfall ($r = 0.810$, $p < 0.01$) and relative humidity ($r = 0.750$, $p < 0.0001$) had strong positive associations with annual emergence, whereas temperature showed comparatively weak and statistically non-significant correlation ($r = 0.210$, $p > 0.05$). These findings emphasize the predominant role of moisture-related factors in regulating emergence behaviour of *A. mylitta*. The strong association of rainfall and humidity with emergence is ecologically logical because these parameters directly influence microclimatic conditions surrounding pupae, including moisture balance, soil humidity, and atmospheric saturation, all of which are critical for successful pupal development and adult emergence.

The tasar silkworm inhabits tropical and subtropical forests where seasonal rainfall patterns largely determine host plant phenology, larval growth and pupal survival. Hence, synchronized emergence during monsoon months may represent an adaptive evolutionary strategy ensuring the availability of suitable environmental conditions for mating, oviposition and larval establishment. Similar observations have been reported by Shapiro (1993), who demonstrated that elevated humidity and favourable climatic conditions promote emergence in *A. mylitta*. However, the present study extends previous observations by demonstrating that humidity and rainfall together act as the ultimate triggering factors for emergence rather than temperature alone. Interestingly, the influence of rainfall and humidity differed between seasonal and non-seasonal emergence periods. During seasonal emergence, humidity ($R^2 = 0.64$) and rainfall ($R^2 = 0.41$) both significantly influenced moth emergence, suggesting a coordinated interaction between atmospheric moisture and precipitation. In contrast, erratic emergence during non-seasonal periods was more strongly dependent on humidity ($R^2 = 0.76$) than rainfall ($R^2 = 0.32$), especially during cooler months associated with overwintering diapause. This differential response suggests that while rainfall serves as an important seasonal synchronizer during the normal emergence period, atmospheric humidity alone may occasionally become sufficient to trigger sporadic emergence during diapause. The quasi-independent relationship between rainfall and humidity during non-seasonal months provides further support for this interpretation. During seasonal months, humidity and rainfall exhibited positive correlation (0.31), indicating that both parameters increased simultaneously under monsoon conditions. Conversely, during non-seasonal periods, humidity showed negative correlation with rainfall (-0.49), suggesting that elevated humidity may occur independently of actual precipitation events. Such conditions may arise due to localized atmospheric moisture accumulation, dew formation or transient climatic fluctuations, which can create favourable microclimatic conditions sufficient to stimulate emergence in certain pupae even in the absence of substantial rainfall. The relatively minor influence of temperature observed in the present study deserves special attention. Temperature is widely recognized as an important regulator of

insect metabolism, development and diapause termination. Nevertheless, its weak association with emergence in *A. mylitta* indicates that this species may possess broader thermal tolerance under tropical and subtropical conditions. The average temperature difference between seasonal (30.8°C) and non-seasonal months (26.9°C) was only approximately 4°C, which may be insufficient to significantly alter developmental physiology. Rogers and Westbrook (1985) reported that emergence in several insects, including *Homoeosoma electellum*, may require temperature differences approaching 10°C to produce substantial developmental delays. Therefore, the relatively narrow thermal fluctuations characteristic of tropical regions may explain the negligible influence of temperature observed in the present investigation. The reduced importance of temperature also supports the hypothesis that seasonal emergence in *A. mylitta* is an imprinted or genetically programmed behaviour modulated primarily by environmental moisture cues. Morohoshi (2001) suggested that emergence behaviour in silkworms is evolutionarily synchronized with seasonal environmental rhythms to maximize reproductive success. In the present context, rainfall and humidity likely provide the final physiological signals necessary for diapause termination and adult eclosion. Such synchronization ensures that emerging adults coincide with favourable ecological conditions including host plant availability, optimal atmospheric moisture, and reduced desiccation risk. The findings of the Principal Component Analysis (PCA) further validated the dominance of rainfall and humidity in influencing emergence dynamics. Eigenvalue analysis indicated that the first two principal components explained most of the observed variance, while factor loading values identified rainfall (0.901) and humidity (0.867) as the most influential environmental variables. The strong loading values emphasize that these factors collectively explain much of the seasonal variability in emergence patterns. PCA therefore corroborates the observations obtained through correlation analyses and hierarchical clustering, thereby strengthening the reliability of the conclusions. From an ecological perspective, the observed seasonal emergence pattern reflects the adaptive life history strategy of *A. mylitta* in tropical forest ecosystems. Successful emergence during monsoon periods ensures that larvae encounter young and nutritionally suitable host foliage necessary for rapid growth and cocoon formation. Moreover, high atmospheric humidity reduces water loss and physiological stress in both adults and immature stages. Conversely, emergence during dry non-seasonal months may expose moths to harsh environmental conditions, resulting in reduced survival, unsuccessful mating and poor reproductive performance. Therefore, diapause regulation mediated by humidity and rainfall likely represents a crucial survival adaptation.

The occurrence of erratic emergence during March to May also possesses considerable economic significance in tasar sericulture. Premature or delayed emergence can disrupt synchronized egg laying and brushing schedules, thereby affecting crop planning and seed production. Since tasar silk production largely depends upon timely emergence and coordinated rearing operations, irregular emergence patterns may negatively influence cocoon productivity and seed availability. The present study therefore provides important insights for improving grainage management practices under changing climatic conditions. The role of grainage microclimate becomes particularly important in this context. The study indicates that fluctuations in humidity within grainage houses may substantially influence diapause duration and emergence behaviour. Excessive or uncontrolled humidity may induce premature emergence, whereas inadequate humidity may prolong diapause or increase pupal mortality. Therefore, maintenance of stable humidity conditions within grainage facilities is essential for ensuring synchronized emergence and maintaining seed quality. The use of automated humidifiers, silica gel, lime stacks and proper ventilation systems may help regulate internal humidity and reduce erratic emergence. Such interventions may prove particularly useful for private graineurs and decentralized seed producers engaged in commercial tasar sericulture.

The findings also gain added importance under the present scenario of climate variability and changing monsoon patterns. Alterations in rainfall distribution, humidity levels and seasonal climatic rhythms may directly affect the emergence biology of *A. mylitta* and consequently influence tasar silk productivity. Increasing climatic unpredictability may intensify erratic emergence, disrupt diapause regulation and alter the synchronization between silkworm life cycle and host plant phenology. Therefore, long-term monitoring of climatic variables and their relationship with emergence behaviour is essential for developing adaptive management strategies in tasar sericulture. Although earlier studies have investigated life table parameters and developmental biology of *A. mylitta* (Bajpeyi *et al.*, 1995), comprehensive field-based assessments integrating meteorological variables with emergence dynamics remain limited. The present investigation therefore contributes significantly toward understanding the ecological physiology of tasar silkworm emergence under natural subtropical conditions. By combining hierarchical clustering, correlation analysis and PCA, the study provides a robust statistical framework for interpreting the influence of climatic factors on emergence behaviour.

Overall, the present study conclusively demonstrates that humidity and rainfall are the principal environmental determinants regulating emergence of *A. mylitta*, whereas temperature plays comparatively limited role under tropical and subtropical conditions. Seasonal emergence appears to be a genetically synchronized phenomenon fine-tuned by moisture-related environmental cues, while erratic non-seasonal emergence is predominantly associated with fluctuations in atmospheric humidity. The results highlight the importance of maintaining controlled humidity conditions in grainage systems to minimize irregular emergence and improve seed management practices. Furthermore, the findings provide valuable ecological and practical insights for enhancing tasar silkworm production under increasingly variable climatic conditions.

4.4. IMPACT OF TEMPERATURE AND HUMIDITY ON PEST AND PREDATOR OF SILK-WORM

4.4.1. *Eocanthecona furcellata*

Temperature markedly influenced the development, survival, fecundity, and predatory efficiency of *Eocanthecona furcellata*, thereby affecting its suitability as a biological control agent and its potential for mass rearing (Wang *et al.*, 2013). Adult longevity decreased with increasing temperature, a trend similarly reported in other predatory insects (Aksit *et al.*, 2007; Wang *et al.*, 2013). Maximum fecundity of *E. furcellata* was recorded at 29 °C, whereas the lowest fecundity occurred at 32 °C, and no oviposition was observed at 20 °C or 35 °C. Egg hatchability was also highest at 26–29 °C and lowest at 35 °C, indicating that extreme temperatures adversely affect reproduction and development. Similar findings were reported for the predatory stink bug *Podisus nigrispinus* (Medeiros *et al.*, 2003a). Chu and Chu (1975) further observed that eggs of *E. furcellata* failed to hatch below 15 °C and above 40 °C, confirming that both low and high temperatures are unsuitable for normal growth and reproduction. Life-table analyses demonstrated a strong relationship between temperature and demographic parameters. The intrinsic rate of increase, net reproductive rate, and shortest doubling time were highest at 29 °C, suggesting this temperature as optimal for population growth. Comparable observations have been reported in other predatory pentatomids such as *P. nigrispinus* (Medeiros *et al.*, 2003b). Prey consumption by adult females increased significantly at higher temperatures, with maximum feeding observed between 29–32 °C and minimum consumption at 20–23 °C, supporting earlier findings (Omkar *et al.*, 2016; Wang *et al.*, 2013). Enhanced feeding at higher temperatures may be associated with increased metabolic activity and the greater nutritional requirement for attaining sexual maturity (House, 1961). The present findings provide important implications for large-scale rearing of *E. furcellata*. The highest

fecundity, reproductive potential, and predation efficiency were achieved at 29 °C, identifying it as the most suitable temperature for mass production. However, other environmental factors such as photoperiod, relative humidity, and prey species also influence predator performance. Previous studies demonstrated the effects of photoperiod on predatory insects (Aksit *et al.*, 2007; Malaquias *et al.*, 2010), humidity on predatory bugs (De Clercq *et al.*, 1990), and prey type on predator efficiency (Ahmadi *et al.*, 2007; Tuan *et al.*, 2016; Wang *et al.*, 2014). Therefore, further investigations integrating these factors are essential for refining rearing protocols and improving field application. The functional response analysis revealed that *E. furcellata* followed the Holling type II model across all tested temperatures. Predation efficiency was highest at 35 °C and lowest at 20 °C, indicating superior predatory performance at elevated temperatures. Similar temperature-dependent functional responses have been documented in *E. furcellata* and other predatory pentatomids against *Spodoptera* species (Chen *et al.*, 2015; Fan *et al.*, 2019; Tang *et al.*, 2019; Wang *et al.*, 2019a,b; Wang *et al.*, 2020). Likewise, third instar nymphs exhibited maximum predation efficiency at 35 °C, followed by 32 °C, whereas lower temperatures significantly reduced feeding activity. These findings collectively demonstrate that warmer temperatures enhance the biological control potential of *E. furcellata*.

4.4.2 Yellow jacket paper wasp

The tropical and sub-tropical Tasar silkworm rearing has been adversely affected by *Pollistes olivaceus, Pollistes stigma*, *Pollistes hebraeus* and *Pollistes striogus*, (Mathur, 1980; Sahay *et al.*, 1994) especially in the states of Bihar (Banka region), West Bengal (Birbhum, Bankura, Jhargram, Purulia), parts of Jharkhand (Dumka region) and Orissa (Mayurbhanj region) where it acts as the dominant pest. Although minor infestations has been observed in Madhya Pradesh, Uttar Pradesh (Renukoot region) and Chhattisgarh. However the distribution, degree day analysis and life-table assessment of the wasp species which has turned into pest is yet to be done from the Indian subcontinent.

Predatory wasps belonging to the genus *Polistes* are considered one of the major biotic constraints in tasar sericulture, causing significant economic losses through predation on tasar silkworm larvae. These social hymenopteran insects, belonging to the family Vespidae under the order Hymenoptera, are highly efficient predators commonly encountered in tropical tasar-growing regions of India. The wasps possess elongated slender bodies with a characteristic narrow “wasp waist,” brightly coloured yellow, reddish-brown, or black markings, long membranous wings, and strong mandibles adapted for prey capture and nest construction. They construct papery comb-like nests from chewed wood fibres mixed with saliva, generally on leaves, branches, or sheltered structures (Spradbery, 1973). Species of *Polistes* are widely distributed in major tasar-producing regions including Jharkhand, West Bengal, Odisha, Chhattisgarh, and Madhya Pradesh, where forest vegetation provides suitable nesting habitats and abundant prey availability. Their activity shows strong seasonal variation, with peak abundance and predatory activity occurring during June and July, coinciding with the active growth period of tasar silkworm larvae (Sengupta *et al.*, 1972). During colder months, fertilized queens undergo diapause in protected shelters such as bark crevices and roof spaces, emerging in favourable seasons to establish new colonies. Colony initiation begins with a single queen constructing a papery nest and laying one egg per hexagonal cell. The developing larvae are provisioned with paralyzed insect prey, including tasar silkworm larvae, which serve as an important protein source for brood development. Following pupation, adult worker wasps emerge and participate in foraging, nest expansion, brood care, and colony defence, resulting in rapid colony growth and increased predatory pressure on silkworm populations (Wilson, 1971). *Polistes* wasps are active diurnal hunters possessing strong visual orientation and prey-detection

abilities. They preferentially attack soft-bodied insects, making tasar silkworm larvae highly susceptible due to their exposed outdoor rearing conditions and comparatively slow movement. The wasps capture larvae using powerful mandibles and venomous stings, either paralyzing or dismembering them before transporting prey fragments to the nest for feeding the brood. Severe wasp infestation can result in substantial larval mortality, reduced cocoon formation, poor cocoon weight, and considerable decline in silk yield, thereby directly affecting the livelihood of rural and tribal farmers dependent on forest-based sericulture (Thangavelu, 1992). Effective management strategies primarily involve mechanical and cultural methods, including regular surveillance and destruction of nests during early colony formation, elimination of potential nesting sites such as cracks, crevices, and tree hollows, maintenance of field sanitation, and use of protective netting around rearing areas. Community-based nest removal programmes are also effective because these wasps forage over wide areas, and coordinated management can substantially reduce local population density and subsequent crop damage (Sahay *et al.*, 1994).

Although, no studies has been undertaken with respect to silkworm-wasp interaction from the Indian perspective, except a single work by Mazumdar *et al.* (2024) where the diurnal activities of the *Polistes* spp. was observed from Littipara region of the Pakur district of Jharkhand (one of the leading producer of Tasar silk). The present observations on the diurnal activity pattern of predatory insects associated with tasar silkworm rearing revealed distinct temporal variations in the abundance and activity of different predators, with *Polistes* spp. showing a particularly pronounced response to changing environmental conditions throughout the day. The recorded activity of *Polistes* spp. increased progressively from early morning (0.69897 during 6:00–8:00 am) to reach maximum abundance during late morning hours (1.20412 during 10:00 am–12:00 pm), followed by a slight decline during the afternoon (1.113943 during 1:00–3:00 pm) and a sharp reduction during late afternoon hours (0.60206 during 3:00–5:00 pm). This temporal pattern clearly indicates that the predatory efficiency and foraging behaviour of *Polistes* wasps are strongly influenced by prevailing microclimatic factors, particularly temperature and relative humidity. Similar observations have been reported by several workers who demonstrated that the activity of social wasps increases with rising ambient temperature and moderate humidity, which enhance flight efficiency, prey detection, and metabolic activity (Spradbery, 1973; Jeanne, 1975). During the early morning hours, relatively low temperature and high humidity may limit the flight capability and muscular activity of wasps, resulting in reduced predatory movement and foraging intensity. As the day progresses, increasing solar radiation elevates ambient temperature, thereby enhancing wing muscle performance, energy metabolism, and visual orientation necessary for prey searching and capture. Consequently, the activity of *Polistes* spp. reached its peak during the late morning period when temperature conditions were favourable and humidity levels remained moderately supportive for active flight and nest maintenance. The gradual decline in wasp activity during afternoon hours may be associated with excessive heat stress and reduced relative humidity, which can negatively influence foraging behaviour and increase the risk of desiccation. Extreme afternoon temperatures may force wasps to reduce external activity and remain closer to nests for thermoregulation and water conservation (Kovac *et al.*, 2009). The findings therefore suggest that moderate temperature coupled with optimum humidity provides the most suitable environmental conditions for peak *Polistes* activity in tasar ecosystems.

The observed host activity pattern also indicates that *Polistes* spp. synchronize their foraging behaviour with the availability and vulnerability of tasar silkworm larvae. Since tasar silkworms remain comparatively inactive during cooler morning hours and become more exposed on foliage during warmer periods, the wasps may exploit these behavioural changes to maximize hunting success. *Polistes* wasps are visually oriented diurnal predators possessing highly developed compound eyes and strong prey-recognition abilities, enabling efficient localization of soft-bodied

caterpillars under adequate light intensity and favourable weather conditions (Wilson, 1971). The preference of *Polistes* wasps for late morning activity may therefore represent an adaptive behavioural strategy that optimizes prey capture efficiency while minimizing energetic expenditure. The predatory behaviour generally involves rapid inspection of host plants, followed by attack using strong mandibles and venomous stings to paralyze or dismember silkworm larvae before transporting prey fragments to developing brood within the nest. Such intensive predation during favourable climatic periods can substantially reduce silkworm survival and cocoon productivity.

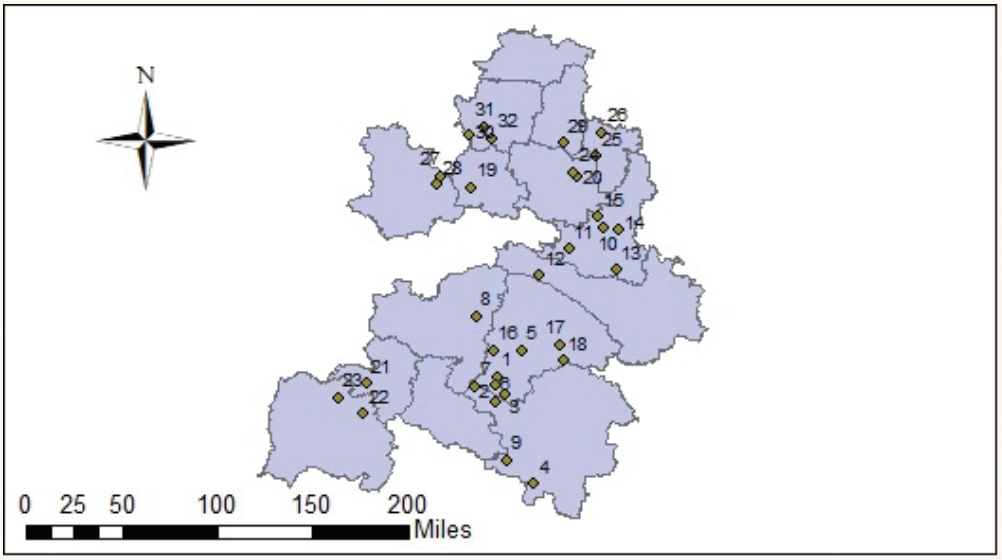


Figure 1. The site of infestation across eastern sub-tropical Indian states where maximum wasp infestation was observed in 2022-23. Site of observation: West Bengal 1. Murkum 2. Barikul 3. Fulkusma 4. Taldangra 5. Sorberia 6. Shyamnagar 7. Neguria 8. Hura 9. Gopiballavpur 10. Patelnagar 11. Dubrajpur 12. Kajora 13. Bolpur 14. Kotasur 15. Dewanganj 16. Baroghutu 17. Bishnupur 18. Peardoba Jharkhand: 19. Madhupur 20. Kathikund 21. Kharsawan 22. Chaibasa 23. Chakradharpur 24. Bajrisol 25. Amrapara 26. Littipara 27. Bansjor 28. Bengabad 29. Jitpur Bihar: 30. Lilabaran 31. Katoria 32. Bhorsar

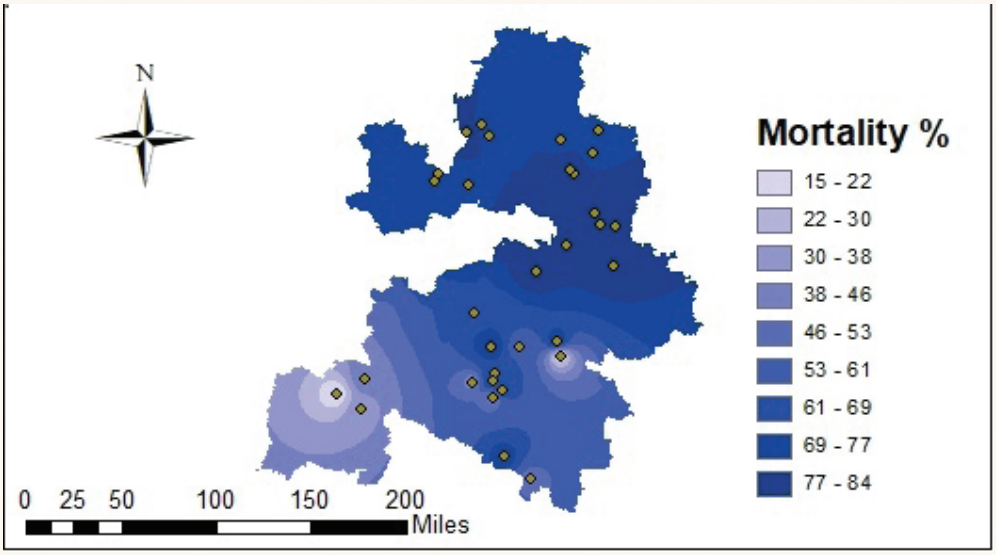


Figure 2. Mortality % as observed in the larval stage due to wasp attack (A cumulative report of mortality across all the instars)

4.4.3 *Sycanus collaris*

Sycanus collaris Fabricius, an important predatory insect belonging to the family Reduviidae under the order Hemiptera, is widely recognized as one of the most destructive natural enemies of tasar silkworms in tropical sericultural ecosystems. Commonly referred to as the assassin bug, *S. collaris* undergoes a hemimetabolous or incomplete metamorphic life cycle in which development proceeds gradually through successive nymphal stages without a pupal stage. The insect is characterized by a robust and elongated body, usually dark brown to black in coloration, with long slender legs adapted for rapid movement and prey capture. One of the most distinctive morphological features of reduviid bugs is the elongated cone-shaped head bearing a strong, curved, piercing-sucking proboscis or rostrum, which functions as the principal feeding organ. This highly specialized rostrum enables the predator to puncture the integument of prey insects and inject toxic salivary secretions that immobilize and digest host tissues before ingestion. The assassin bug also possesses well-developed compound eyes, elongated antennae, and powerful raptorial forelegs that facilitate prey detection and capture, making it an efficient and aggressive predator within forest and agricultural ecosystems (Ambrose, 2003). The life cycle of *S. collaris* begins with the egg stage, during which females initiate oviposition shortly after successful mating. Eggs are generally deposited in clusters or batches containing approximately 50–100 eggs, although the exact number may vary depending on environmental conditions and nutritional status of the female. The eggs are oval or cylindrical in shape and are often coated with protective secretions that reduce desiccation and protect developing embryos from environmental stress and predation. Females strategically place the egg masses in concealed and protected habitats such as bark crevices, beneath leaf litter, within soil cracks, or under loose plant debris to ensure greater survival of the developing embryos. The incubation period usually lasts for 5–7 days, although the duration may fluctuate according to temperature, humidity, and seasonal conditions. Warm and moderately humid environments generally accelerate embryonic development, whereas low temperature and unfavourable humidity may prolong incubation and reduce egg viability (George and Ambrose, 1999). Upon completion of embryonic development, the eggs hatch into first instar nymphs, initiating the active predatory phase of the life cycle. The nymphal stage consists of five distinct instars, each separated by molting events that permit gradual growth and morphological differentiation. Nymphs resemble miniature adults in general appearance but lack fully developed wings and reproductive organs. During each instar, the nymphs actively feed on a wide variety of soft-bodied arthropods, including caterpillars, small insects, spiders, and other invertebrates. Their predatory behaviour is highly aggressive, and both nymphs and adults exhibit similar feeding mechanisms involving prey immobilization through venom injection. The duration of each nymphal instar depends largely on prey availability and environmental factors such as temperature and humidity. Adequate prey supply and favourable climatic conditions accelerate growth and development, whereas nutritional deficiency or environmental stress may prolong the nymphal period and reduce survival. After completion of the fifth instar, the nymph undergoes a final molt and emerges as a fully developed adult possessing functional wings and mature reproductive organs. Adult *S. collaris* attain sexual maturity shortly after emergence and rapidly initiate mating and oviposition activities. The adult lifespan varies considerably depending on climatic conditions, habitat quality, and prey abundance, but individuals generally survive from several weeks to a few months while continuously hunting and reproducing throughout their lifespan (Ambrose, 2003). Spatially and temporally, *S. collaris* is widely distributed throughout tropical and subtropical regions where warm and humid climatic conditions favour its growth and survival. In India, the predator is commonly encountered in forested regions associated with tasar sericulture, particularly in states such as Jharkhand, West Bengal, Odisha, and Chhattisgarh. Its abundance is generally associated with dense vegetation and the availability of suitable prey populations. In

tasar ecosystems, the activity of reduviid bugs is especially prominent during the later stages of the rearing season, usually from August to November, with peak predatory activity occurring during September and October when tasar silkworm populations are abundant and highly vulnerable (Sahay *et al.*, 1994). Environmental factors such as temperature and relative humidity strongly influence the activity, survival, and predatory efficiency of *S. collaris*. Moderate temperature and high humidity favour active movement, prey searching, and feeding behaviour, whereas excessive heat and low humidity may reduce activity due to physiological stress and desiccation. The assassin bug is primarily a diurnal predator and exhibits maximum activity during cooler morning and evening hours when environmental conditions are favourable for efficient hunting. The predatory behaviour of *S. collaris* is highly specialized and ecologically significant in tasar silkworm rearing systems. The insect actively hunts silkworm larvae on host plants using stealth, rapid movement, and tactile as well as visual cues for prey detection. Upon locating a suitable host, the predator firmly grasps the silkworm using its forelegs and inserts its sharp rostrum through the integument. Toxic saliva containing digestive enzymes and neurotoxic compounds is then injected into the prey, resulting in rapid paralysis and tissue liquefaction. The predator subsequently sucks the body fluids of the immobilized larva, leaving behind an empty integument. Such predation can cause severe damage to tasar silkworm populations, particularly in outdoor rearing conditions where larvae remain continuously exposed to natural enemies. In heavily infested areas, larval mortality caused by reduviid bugs may exceed 15%, resulting in substantial reduction in cocoon yield and silk productivity (Sahay *et al.*, 1994). Early instar silkworm larvae are especially susceptible to predation because of their smaller body size, soft integument, and reduced mobility, making them easy targets for assassin bugs. Continuous predation not only reduces larval population density but also weakens surviving larvae, adversely affecting cocoon quality and economic returns to sericulture farmers. Consequently, *S. collaris* is regarded as one of the most economically important predators in tasar culture, and understanding its biology, ecology, and behavioural dynamics is essential for developing effective integrated pest management strategies in sustainable sericulture systems.

Mazumdar et al (2024) reported that *Sycanus collaris* was the most active and dominant predator throughout the observation period on tasar silkworm (especially in Madhupur and Dumka region of Jharkhand). The evaluation mentioned that *S. collaris* were highest during the early morning hours between 6:00–8:00 am (1.544068), followed by a gradual decline during 8:00–10:00 am (1.39794), 10:00 am–12:00 pm (1.255273), and 1:00–3:00 pm (1.146128), with a slight increase again during 3:00–5:00 pm (1.20412). This pattern clearly demonstrates that the predator exhibits greater activity under comparatively cooler and more humid environmental conditions prevailing during morning and late afternoon hours. The results strongly suggest that temperature and relative humidity play a crucial role in regulating the behaviour, movement, hunting efficiency, and ecological dominance of *S. collaris* in tasar ecosystems. Similar observations have been reported by Ambrose (2003) and Sahay *et al.* (1994), who noted that reduviid predators show maximum activity during moderate temperature and high humidity conditions because such environments favour mobility, prey detection, and physiological performance. *Sycanus collaris* belongs to the family Reduviidae under the order Hemiptera and is commonly known as an assassin bug. It is an important generalist predator widely distributed in tropical agricultural and forest ecosystems. The insect is highly predaceous during both nymphal and adult stages and attacks a wide range of soft-bodied insects, including caterpillars and silkworm larvae. The predator possesses elongated legs, a narrow head, piercing-sucking mouthparts, and strong raptorial forelegs adapted for capturing prey. It injects toxic saliva through its rostrum, paralyzing the prey and subsequently sucking out body fluids. In tasar culture, *S. collaris* is considered one of the most destructive predators because of

its aggressive feeding behaviour and high predation efficiency on exposed silkworm larvae reared under outdoor conditions (Thangavelu, 1992). The high activity recorded during the early morning hours may therefore be associated with favourable environmental conditions that enhance the predator's searching and feeding behaviour. Temperature is one of the most important abiotic factors influencing insect physiology, metabolism, and behaviour. In poikilothermic organisms such as insects, body temperature and physiological activity are directly affected by ambient environmental temperature. The higher activity of *S. collaris* during the early morning hours indicates that moderate temperatures prevailing at that time provide optimum conditions for locomotion, prey capture, and energy conservation. During early morning periods, environmental temperatures are relatively lower and humidity is comparatively higher due to overnight condensation and reduced evaporation. Such conditions reduce water loss from the insect body and maintain favourable physiological balance, thereby promoting active foraging behaviour. In addition, cooler temperatures may also reduce thermal stress and prevent excessive metabolic exhaustion, allowing the predator to remain active for longer durations. As the day progresses and temperature increases, the activity of *S. collaris* gradually declines, suggesting that excessive heat adversely affects predator movement and feeding efficiency. High temperature may increase respiratory water loss, accelerate metabolism, and induce physiological stress, thereby reducing predatory activity during midday and early afternoon hours (Chapman, 2013).

Relative humidity also exerts considerable influence on the activity and survival of reduviid predators. High humidity during morning hours creates favourable microclimatic conditions for insect movement, prey location, and successful predation. Moist environmental conditions prevent desiccation and help maintain water balance within the insect body. In contrast, low humidity during midday and afternoon periods may increase dehydration stress, forcing the predator to reduce movement and seek shaded or sheltered locations. The gradual reduction in activity from morning to afternoon observed in the present study may therefore be attributed to declining humidity coupled with increasing temperature. Similar findings were reported by George and Ambrose (1999), who observed that reduviid bugs exhibited greater feeding and reproductive activity under moderate temperature and humid environmental conditions. The slight increase in activity recorded during late afternoon hours (3:00–5:00 pm) may be associated with the gradual reduction in temperature and partial restoration of atmospheric humidity during evening periods. This recovery in favourable microclimatic conditions may stimulate renewed foraging behaviour before sunset.

The observed activity pattern of *S. collaris* may also be closely associated with the behaviour and availability of host insects. Tasar silkworm larvae are generally more exposed and less active during cooler periods of the day, making them more vulnerable to predator attack. Early morning hours may therefore provide ideal conditions for efficient prey capture because silkworm larvae remain relatively sluggish and easier to subdue. The assassin bug relies heavily on tactile and visual cues for prey detection, and favourable light intensity during morning hours further enhances hunting efficiency. The predator generally attacks by stealthily approaching the prey, grasping it firmly with the forelegs, and injecting paralyzing saliva through the rostrum. Since tasar silkworms are reared on host trees under open environmental conditions, they remain continuously exposed to predation by *S. collaris*. Heavy infestation can therefore result in severe larval mortality, reduced cocoon formation, and significant economic losses to sericulture farmers (Sahay *et al.*, 1994). Comparative analysis with other predators recorded in the study further highlights the ecological adaptability of *S. collaris*. While *Polistes* spp. exhibited maximum activity during late morning hours, *Eocanthecona furcellata*, *Hierodula* spp., and small dipterans showed comparatively lower and more restricted activity patterns. Unlike these predators, *S. collaris* maintained relatively high

activity throughout the day, indicating its greater tolerance to fluctuating environmental conditions and its superior predatory adaptability. This broad activity range may contribute significantly to its ecological success and predatory dominance in tasar rearing fields. The ability of reduviid bugs to remain active under varying environmental conditions has also been associated with their efficient water conservation mechanisms and behavioural adaptability (Ambrose, 2003). The ecological implications of the present findings are highly significant for tasar sericulture. Since the highest activity of *S. collaris* occurs during early morning hours, management practices aimed at reducing predation losses should be concentrated during these periods. Protective netting, regular field inspection, manual removal of predators, and disturbance of resting sites may be more effective when implemented during peak activity periods. Understanding the relationship between environmental factors and predator behaviour can also assist in predicting seasonal outbreaks and developing integrated pest management strategies. Furthermore, climate change and increasing temperature variability may alter predator-prey dynamics by affecting the survival, distribution, and feeding behaviour of *S. collaris*. Therefore, long-term ecological monitoring of predator populations in relation to climatic variables is essential for sustainable tasar silkworm production and effective conservation of forest-based sericultural ecosystems.

4.4.4. *Hierodula* spp. (Praying mantis)

Praying mantises are highly specialized predatory insects recognized for their distinctive raptorial forelegs, elongated body, triangular mobile head, and characteristic ambush hunting behaviour, making them efficient predators in both agricultural and forest ecosystems. In tasar sericulture, species such as *Hierodula bipapilla* are considered important natural enemies of tasar silkworms, often causing considerable larval mortality and subsequent reduction in cocoon yield and silk productivity (Selvakumar *et al.*, 2025). Praying mantises undergo incomplete metamorphosis or hemimetabolous development, in which the transformation from immature stages to adults occurs gradually without the formation of a pupal stage. Their life cycle consists of three major stages: egg, nymph, and adult. Following mating, the female produces a specialized egg case known as an ootheca, a hardened frothy structure secreted from accessory reproductive glands that protects the developing eggs from environmental stress, predators, and desiccation. The ootheca, generally measuring about 3–4 cm in length and containing approximately 24 egg chambers or several dozen eggs depending on the species, is carefully attached to suitable substrates such as twigs, branches, stems, bark, or foliage. Within the ootheca, embryonic development occurs gradually, and in many species the structure serves as an overwintering stage that enables embryos to survive adverse environmental conditions including low temperature and reduced food availability. With the onset of favourable environmental conditions, especially during spring or humid seasons, the eggs hatch and release young nymphs that resemble miniature wingless adults. The nymphal stage generally consists of four to six instars, during which the developing mantids actively feed, grow, and undergo successive molts before reaching maturity. Throughout these stages, the nymphs exhibit highly predaceous behaviour and attack a wide range of small insects and arthropods. Upon completion of the final nymphal instar, the insect undergoes a terminal molt and emerges as a fully developed winged adult possessing functional reproductive organs and characteristic raptorial forelegs armed with sharp spines for grasping prey. Adult praying mantises are slender and elongated insects with well-developed wings capable of short-distance flight, although they are primarily sedentary ambush predators that depend on camouflage and stealth for successful hunting. Their lifespan varies according to species, environmental conditions, and prey availability, but most individuals survive for several months, while some species may persist for nearly a year under favourable ecological conditions. Both nymphs and adults are highly efficient predators that remain motionless

for long periods while waiting for prey to approach within striking distance. Once prey is detected, the mantis rapidly extends its specialized forelegs, firmly grasps the victim, and delivers a powerful bite using strong mandibulate mouthparts. In tasar ecosystems, praying mantises pose a serious threat particularly to early instar tasar silkworm larvae (I–III instars), which are highly vulnerable due to their smaller body size, soft integument, and limited mobility. Heavy infestation by mantids can therefore lead to significant larval mortality, poor larval growth, reduced cocoon formation, and considerable decline in silk production. Effective management of praying mantises in tasar rearing systems primarily involves mechanical, physical, and cultural control methods. Regular surveillance and manual handpicking of mantids and their oothecae from rearing fields can substantially reduce predator populations before serious infestation occurs. During chawki rearing, the use of fine-mesh nylon nets with approximately 2 mm mesh size provides effective protection against predation by preventing mantids from accessing young silkworm larvae. Maintenance of proper sanitation and hygienic conditions within rearing areas also helps minimize favourable habitats for mantid shelter and reproduction. In addition, sticky traps prepared using adhesive-coated bamboo poles or other supporting materials can be employed for trapping adult mantids and reducing their abundance in rearing fields. Collectively, these integrated management practices play an important role in minimizing predatory damage caused by praying mantises and ensuring improved survival and productivity of tasar silkworms in outdoor sericultural ecosystems.

The host seeking activity of pest and predator of tasar silkworm, studied by Mazumdar et al (2024) is the only single report where the activities of the praying mantis was assessed and reported from Indian subcontinent. *Hierodula* spp., commonly known as praying mantids, are important predatory insects frequently encountered in forest and agricultural ecosystems and constitute one of the natural enemies of tasar silkworms in outdoor sericulture systems. Belonging to the order Mantodea and family Mantidae, these insects are highly specialized ambush predators characterized by their elongated body, triangular and highly mobile head, large compound eyes, flexible prothorax, and powerful raptorial forelegs adapted for grasping prey. Their cryptic coloration, usually green or brown, enables them to camouflage effectively among foliage and vegetation, thereby enhancing their predatory success. Mantids exhibit hemimetabolous development, undergoing gradual metamorphosis through egg, nymphal, and adult stages without a pupal phase. Female mantids lay eggs in characteristic frothy egg masses known as oothecae, which harden upon exposure to air and provide protection to the developing embryos against environmental stress and predation. The incubation period varies depending on temperature and humidity, after which numerous nymphs emerge simultaneously. The nymphs resemble miniature adults but lack fully developed wings and reproductive organs. Throughout successive molts, the nymphs progressively increase in size and predatory efficiency before finally transforming into sexually mature adults (Prete *et al.*, 1999). Both nymphs and adults are voracious predators capable of attacking a wide range of insects, including caterpillars, moths, flies, beetles, grasshoppers, and silkworm larvae. In tasar ecosystems, *Hierodula* spp. act as opportunistic predators and can cause considerable damage to silkworm populations when their abundance increases during favourable environmental conditions. The present observations on diurnal activity patterns indicated that the abundance of *Hierodula* spp. was comparatively lower than that of *Sycanus collaris* and *Polistes* spp., with activity values recorded as 0.30103 during 6:00–8:00 am, increasing slightly to 0.477121 during 8:00–10:00 am, declining again to 0.30103 during 10:00 am–12:00 pm, disappearing completely during 1:00–3:00 pm, and reappearing at a low level (0.30103) during 3:00–5:00 pm. These fluctuations clearly indicate that the activity of *Hierodula* spp. is strongly influenced by environmental parameters, particularly temperature, humidity, and light intensity. The relatively higher activity observed during morning hours suggests that moderate temperature and comparatively high relative humidity provide favourable conditions

for movement, prey searching, and ambush hunting behaviour. Mantids are generally sit-and-wait predators that rely heavily on camouflage, visual perception, and rapid foreleg strikes for prey capture. Cooler morning conditions may therefore enhance their ability to remain concealed while minimizing physiological stress and water loss. Similar observations were reported by Hurd (1999) and Ehrmann (2002), who noted that mantid activity is significantly influenced by microclimatic conditions and prey availability. During midday and early afternoon hours, rising temperature and declining humidity may reduce activity due to increased risk of desiccation and thermal stress. Mantids possess relatively soft cuticular surfaces compared to some other predatory insects and are therefore more susceptible to water loss under hot and dry conditions. Consequently, they may retreat into shaded vegetation or remain motionless during periods of excessive heat, explaining the complete absence of activity observed during 1:00–3:00 pm in the present study. The slight resurgence of activity during late afternoon hours may be associated with decreasing temperature and partial recovery of atmospheric humidity, which create more favourable conditions for hunting and locomotion. Temperature is one of the most important ecological factors influencing the physiology, metabolism, development, and behavioural ecology of mantids. As ectothermic organisms, mantids depend largely on ambient environmental temperature for maintaining muscular activity, feeding behaviour, and reproductive functions. Moderate temperature conditions enhance mobility, visual orientation, and predatory efficiency, whereas extremely high temperatures may disrupt metabolic balance and reduce feeding activity. Relative humidity also plays a vital role in maintaining body water balance, successful molting, and egg viability. High humidity favours normal development and activity, while low humidity can increase desiccation stress and mortality, particularly during nymphal stages (Prete *et al.*, 1999). In forest ecosystems associated with tasar sericulture, seasonal changes in temperature and humidity therefore directly influence mantid abundance and predatory intensity. Spatially, Hierodula spp. are widely distributed throughout tropical and subtropical regions where dense vegetation and abundant prey populations provide suitable habitats for survival and reproduction. In India, these predators are commonly encountered in forested tasar-growing regions such as Jharkhand, West Bengal, Odisha, and Chhattisgarh. Their abundance generally increases during warm and humid months when insect prey populations are high. In tasar rearing fields, Hierodula spp. attack exposed silkworm larvae resting or feeding on host plants. The mantid captures prey using rapid extension of its raptorial forelegs armed with strong spines that firmly grasp the victim and prevent escape. Unlike reduviid bugs or predatory wasps, mantids do not inject venom but instead consume prey directly using strong chewing mouthparts. Larger mantids are capable of consuming entire silkworm larvae, thereby causing direct economic loss to tasar farmers. Early and middle instar silkworms are particularly vulnerable because of their smaller size and limited defensive capability. However, despite their predatory nature, the comparatively lower abundance and intermittent activity pattern of *Hierodula* spp. observed in the present study suggest that they may exert less overall predatory pressure on tasar silkworm populations than dominant predators such as *Sycanus collaris* and *Polistes* spp. Nevertheless, under favourable ecological conditions and high predator density, mantids can contribute significantly to cumulative larval mortality in forest-based sericulture systems. The ecological significance of *Hierodula* spp. extends beyond their role as predators of tasar silkworms because they also help regulate populations of various phytophagous insects within forest ecosystems. Their dual ecological role highlights the complexity of predator-prey interactions in outdoor sericulture environments where beneficial and harmful effects may coexist simultaneously. Understanding the behavioural ecology, activity rhythm, and environmental responses of mantids is therefore essential for developing balanced and ecologically sustainable pest management strategies in tasar culture. Since the activity of *Hierodula* spp. appears highest during moderate morning conditions, field monitoring and protective measures

may be more effective during these periods. Furthermore, changing climatic conditions associated with global warming may alter the abundance, distribution, and predatory behaviour of mantids through modifications in temperature and humidity regimes, thereby influencing predator-prey dynamics within tasar ecosystems. Long-term ecological investigations are therefore necessary to understand the adaptive responses of mantids to environmental variability and their subsequent impact on tasar silkworm survival and silk productivity.

4.5. CONCLUSION

The present study highlights the significant influence of predatory insects on tasar silkworm rearing and emphasizes the ecological importance of understanding their biology, behaviour, and activity patterns in relation to environmental conditions. Among the various predators recorded, *Sycanus collaris*, *Polistes* spp., *Eocanthecona furcellata*, *Hierodula* spp., and small dipterans were identified as important natural enemies associated with tasar ecosystems. The observations demonstrated clear temporal variations in predator abundance and activity, indicating that temperature, humidity, light intensity, and host availability strongly regulate predator behaviour and predation efficiency. *Sycanus collaris* emerged as the most dominant predator, exhibiting maximum activity during cooler and humid morning hours, while *Polistes* spp. showed peak activity during late morning periods when moderate temperature and favourable humidity supported active flight and foraging behaviour. In contrast, *Hierodula* spp. and *Eocanthecona furcellata* displayed comparatively lower abundance and restricted activity patterns, indicating differential ecological adaptability among predator species.

4.6. ACKNOWLEDGEMENT

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4.7. REFERENCES

Guo, K., Sun, O. J., & Kang, L. (2011). The responses of insects to global warming. In Recent Advances in Entomological Research: From Molecular Biology to Pest Management (pp. 201-212). Berlin, Heidelberg: Springer Berlin Heidelberg.

Jaramillo, C., & Cárdenas, A. (2013). Global warming and neotropical rainforests: a historical perspective. Annual Review of Earth and Planetary Sciences, 41, 741-766.

Jolly, M. S., Sinha, S. S., & Razdan, J. L. (1971). Influence of temperature and photoperiod on termination of pupal diapause in the Tasar silkworm, Antheraea mylitta. Journal of Insect Physiology, 17(4), 753-760.

Mazumdar, S. M., Banerjee, N., Alam, K., Harsha, R., & Selvakumar, T. (2024). An Overview of Climatic and Genetic Influences on the Emergence of Antheraea spp. Biotechnology for Silkworm Crop Enhancement: Tools and Applications, 147-165.

Mazumdar, S.M., Bharati, V.P., Nadaf, H.A., Mittal, V., Selvaraj C., Reddy, B.T., Bawaskar, D.M., Visakha, GV, Selvakumar, T. (2024) Activities of pest and predator associated with tropical tasar silkworm *Antheraea mylitta*: a study in littipara region (Jharkhand). Plant Archives 24: 8-13.

Menéndez, R. (2007). How are insects responding to global warming?. Tijdschrift voor entomologie, 150(2), 355.

Peng, Z., Zhang, X., Meng, F., Zhao, Y., & Xian, J. (2025). Influence of temperature on development, life table parameters, and predation of the predatory stink bug, Eocanthecona furcellata (Wolff) (Heteroptera: Pentatomidae). Phytoparasitica, 53(5), 92.

Ubukata, H. (2000). The impact of global warming in insects. A Threat to Life: The Impact of Climate Change on Japan's Biodiversity. IUCN/Tsukiji-Shokan, Gland, Switzerland, 61-70.

CHATPER 5: AGROCLIMATIC ZONE WISE SELECTION OF PRUNING AND BRUSHING SCHEDULE IN TASAR CULTURE: AN EFFECTIVE TECHNOLOGY UNDER THE CHANGING CLIMATE

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5.1. INTRODUCTION

Tasar culture represents a vital forest-based economic venture, serving as a primary livelihood for approximately 3.5 lakh rural and tribal families across India. Deeply rooted in the country's ecological fabric, this practice involves the rearing of tasar silkworm larvae on various forestry host plants. For forest-dependent communities, two to three rearing cycles per year provide a critical financial cushion, making tasar culture the backbone of tribal socio-economic development. However, the success of this traditional industry is inherently tied to regional ecological factors, including edaphic, topographic, and biotic conditions, all of which are increasingly threatened by the onset of the industrial era's most pressing challenge: climate change.

The escalating concentration of greenhouse gases has triggered significant climatic variability, disrupting the delicate balance of the ecosystems where tasar silkworms thrive. These shifts manifest in unpredictable weather patterns that directly or indirectly influence the productivity of both the silkworms and their primary food plants. Depending on the agro-climatic zone, these changes can lead to decreased yield, altered pest dynamics, or total crop failure. Given that the majority of practitioners belong to marginalized communities, there is a significant barrier to adopting expensive, high-tech interventions to shield their crops from environmental stressors.

In this context, adaptation is not merely a strategy but a necessity for survival. To minimize the harmful effects of climate change without imposing a financial burden on poor farmers, emphasis must shift toward low-cost, eco-friendly, and culturally accessible technologies. One of the most effective strategies involves the precise regional and seasonal adjustment of silkworm brushing dates and host plant pruning schedules. By synchronizing these activities with shifting local weather patterns, farmers can ensure that the biological needs of the silkworm align with the peak nutritional value of the foliage.

Selection of optimal pruning and brushing schedules in different agroclimatic zones acts as a natural safeguard. This methodology not only enhances the quality of cocoon production but also mitigates the impact pests that are often exacerbated by climate fluctuations. Because this approach relies on behavioral and timing adjustments rather than expensive chemical or mechanical inputs, it remains entirely cost-free and sustainable. Implementing these synchronized schedules offers a robust pathway for enhancing farmer income and ensuring the resilience of tasar culture in an era of environmental uncertainty.

5.2. AGROCLIMATIC ZONE WISE PEST INFESTATION ON FOOD PLANTS

Pest infestation and leaf yield varied significantly across different agroclimatic zones and between seasons. Pest infestation levels across major tasar-growing states, with gall insects and defoliators emerging as the most significant threats. In Jharkhand, gall infestation peaks at 17% in the South Eastern Plateau, while Chhattisgarh's plains face the highest overall pressure, with stem borers

reaching 9% and bark eaters 12%. Odisha also records substantial gall and defoliator activity, particularly in the North Western Plateau. These fluctuations across agro-climatic zones underscore the necessity of region-specific management, as environmental variables directly influence the prevalence of wood-boring and leaf-eating pests in tasar food plants.

Table: 1: Agroclimatic zone wise pest infestation in major tasar growing state

Name of the states	Agro-climatic Zone	Pest infestation			
		Stem Borer (%)	Bark eater (%)	Gall (%)	Defoliators (%)
Jharkhand	Western Plateau Zone	1-3	4-8	10-14	4-15
	Central and North Eastern Plateau Zone	2-4	5-10	10-16	5-12
	South Eastern Plateau Zone	1-3	3-9	12-17	7-16
Chhattisgarh	C.G. Plains (15 Distt)	6-9	10-12	14-18	8-15
	Plateau (7 Distt)	2-4	3-8	8-10	6-12
	Northern Hills (5 Distt)	3-4	4-8	10-16	5-10
Odisha	North Western Plateau	4-5	6-8	12-16	10-15
	North Central Plateau	2-3	4-6	5-10	10-15
	Eastern Ghat High Land	2-4	3-5	10-12	8-10

5.2.1. Effect of pruning date on pest infestation and leaf yield production

Selection of pruning date is a highly effective, zero-cost strategy for mitigating pest infestation and maximizing leaf yield in tasar food plants across diverse agro-climatic zones. The results indicate that pest infestation and cocoon yield varied significantly across different agroclimatic zones and between seasons. These findings also differ from the previously recommended pruning dates for tasar food plants. This variation may be attributed to the impact of climate change, particularly the increasing temperature trends observed in different agroclimatic zones. With the help of adjustment of brushing schedule farmers not only avoid the harmful effect of climate change but also increase the production without additional input.

In first crop, adjusting the pruning schedule significantly influenced the incidence of gall insects and defoliators. In the Western Plateau Zone of Jharkhand, shifting to 01st March (T3) dramatically reduced gall infestation to 10.51% compared to the higher rates seen in 01st February (T1) and 15th February (T2). Similarly, in Chhattisgarh's Plateau and Northern Hills, the 01st March (T3 schedule consistently yielded the lowest pest pressure, reducing defoliator rates from a high of 40% down to 20%. These findings suggest that strategic pruning disrupts the life cycle of pests by ensuring that the emergence of vulnerable new foliage does not coincide with peak pest activity. The impact on productivity was equally pronounced. In Odisha's North Western Plateau, the pruning on 1st April (T5) treatment resulted in a peak leaf yield of 9.6 kg/plant, compared to only 8.0 kg/plant under 1st February (T1). In Chhattisgarh, the 01st March (T3) date emerged as the optimal intervention for all districts, consistently producing the highest biomass (up to 6.9 kg/plant). Similar trend was also observed in second crop.

Table:2.: Agroclimatic zone pest infestation in tasar food plants

State/ Agroclimatic zone	First crop				Second crop		
	Pruning date for first & Second cop	Gall (%)	Defoli ators (%)	Leaf yield kg/ plant	Gall (%)	Defoli ators (%)	Leaf yield kg/ plant
Jharkhand State							
Western Plateau Zone	T1	22.28	12	7.5	14.50	10	8.5
	T2	25.21	15	7.0	13.40	8	8.7
	T3	10.51	8	8.3	10.51	12	8.6
	T4	11.71	5	8.0	10.71	10	8.0
	T5	12.35	8	8.10	8.35	15	9.3
Central and North Eastern Plateau Zone	T1	12.60	15.5	5.6	10.0	12.5	6.0
	T2	16.30	20.4	5.2	9.2	16.20	5.27
	T3	10.60	10.30	7.3	8.8	8.30	6.2
	T4	6.50	8.5	6.5	8.6	6.5	7.5
	T5	8.0	9.0	6.0	10.0	12.5	6.0
South Eastern Plateau Zone	T1	72	10	5.0	76.63	1	6.0
	T2	21	6	7.4	47.51	10	7.0
	T3	33	10	6.0	31.42	8	7.8
	T4	44	10	5.7	23.2	5	6.7
	T5	36	8	6.2	26.29	6	6.8
Chhattisgarh State							
C.G. Plains (15 Distt)	T1	12	20	4.8	15	20	6.0
	T2	08	10	6.6	10	10	7.8
	T3	11	20	5.6	15	20	6.4
	T4	11	14	5.4	16	16	6.2
	T5	13	16	4.9	18	18	6.0
Plateau (7 Distt)	T1	28	40	5.2	23	15	5.9
	T2	12	15	4.9	22	10	5.7
	T3	11	10	6.4	18	08	7.4
	T4	16	14	6.0	15	08	6.5
	T5	15	18	5.7	15	5	5.9
Northern Hills (5 Distt)	T1	28	40	5.0	23	25	5.9
	T2	22	35	4.4	22	20	5.7
	T3	21	20	6.9	18	18	7.4
	T4	27	24	6.3	15	18	6.5
	T5	29	30	5.9	15	10	5.9
Odisha State :							

State/ Agroclimatic zone	First crop				Second crop		
	Pruning date for first & Second cop	Gall (%)	Defoli ators (%)	Leaf yield kg/ plant	Gall (%)	Defoli ators (%)	Leaf yield kg/ plant
North Western Plateau	T1	15	14	8.0	12	15	8.4
	T2	13	15	8.4	10	17	8.2
	T3	10	10	9.6	7	13	10.2
	T4	14	21	9.0	14	20	9.3
	T5	17	23	8.7	17	21	8.9
North Central Plateau	T1	20	25	7.9	15	25	7.9
	T2	10	14	9.4	10	10	9.9
	T3	16	20	7.7	8	14	9.0
	T4	15	18	8.5	15	18	8.8
	T5	15	16	7.9	15	16	8.6

Note: 1. Selection of suitable pruning date for first crop:T_1= 1st Feb, T_2= 15th Feb, T_3= 1st March,T_4= 15th March,T_5= 1st April ;Suitable pruning date for second crop : T_1= 1st March, T2= 15th March,T3= 1st April, T4= 15th April,T6= 1st May

5.2.2. Recommendation of pruning date in major tasar growing state

Based on the pest infestation and yield /plant in different pruning date recommendation of pruning date are given table number 3.3 for higher crop yield and low pest infestation.

Table.3: Recommendation of pruning date in major tasar growing state.

Agro-climatic Zone	Districts cum under Agro-climatic zone	Recommendation
Jharkhand State		
Western Plateau Zone	Bokaro, Latehar, Lohardanga ,Gumla, Hazaribagh, Palamau, Ranchi, Simdega, Chatara, Garhwa	1 March (for I crop) 30 April (for II crop)
Central and North Eastern Plateau Zone	Jamtara, Koderma,Pakur, Dhanbad, Dumka, Sahebganj	1 March (I crop) 15 April (II crop)
South Eastern Plateau Zone	East Singbhum, Saraikela/Kharsawan, West Singhbhum	15 February (I crop) 1 April (II crop)
Chhattisgarh State		
C.G. Plains (15 Distt)	Raipur, Gariyaband, Balodabazar, Mahasamund, Dhamtari, Durg, Balod, Bemetara, Rajnandgaon, Kabirdham, Bilaspur, Mungeli, Korba, Janjgeer, Raigarh & a part of Kanker Districts (Narharpur & Kanker Block)	15 February (I crop) 15 March (II crop)
Plateau (7 Distt)	Jagdalpur, Narayanpur, Beejapur, Kondagaon, Dantewada, Sukma and the remaining part of Kanker Districts	1 March (I crop) 1 April (II crop)
Northern Hills (5 Distt)	Sarguja, Surajpur, Balrampur, Koria, Jashpur & Dharamjaigarh Tehsil of Raigarh Districts	15 Feb (I crop) 15 March (II crop)
Odisha State		
North Western Plateau	Sundargarh, parts of Deogarh, Sambalpur & Jharsuguda	1 March (I crop) 1 April (II crop)

Agro-climatic Zone	Districts cum under Agro-climatic zone	Recommendation
North Central Plateau	Mayurbhanj, major parts of Keonjhar, (except Anandapur & Ghasipura block)	15 Feb (I crop) 15 March (II crop)

5.3. AGROCLIMATIC ZONE WISE PEST INFESTATION ON TASAR SILKWORM IN MAJOR TASAR GROWING STATE

Emergence and outbreak of pest infestation in tasar silkworm are depends on three components viz., Endo-parasitoid (Uzi Fly and Yellow Fly), Pedators (Stink bug, Reduvid Bug, wasp, praying Mentis) and environmental condition. A survey was conducted in different agroclimatic zone for assessment of pest infestation in silkwom and infestation are given in table number 3.4.

Table: 4: Agroclimatic zone wise pest infestation in major tasar growing state

Name of the states	Agro-climatic Zone	Pest infestation					
		Uzifly (%)	Yellow fly (%)	Stink Bug (%)	Reduvid bug (%)	Wasp (%)	Praying Mentis (%)
Jharkhand	Western Plateau Zone	0-5	0-4	5-8	4-6	0-5	0-4
	Central and North Eastern Plateau Zone	0-7	0-8	6-8	5-7	5-15	3-6
	South Eastern Plateau Zone	0-5	0-5	5-8	5-10	0-4	0-6
Chhattisgarh	C.G. Plains (15 Distt)	0-6	5-10	5-10	5-10	0-6	0-4
	Plateau (7 Distt)	0-4	5-8	5-10	5-9	0-5	0-6
	Northern Hills (5 Distt)	0-6	5-10	5-10	4-8	0-5	0-8
Odisha	North Western Plateau	0-8	0-10	6-10	5-13	5-14	4-9
	North Central Plateau	0-6	0-9	5-9	5-9	5-12	3-8
	Eastern Ghat High Land	0-4	5-10	5-12	4-14	0-15	0-10

5.3.1. Effect of brushing date on pest infestation and cocoons production

The results indicate that pest infestation and cocoon yield varied significantly across different agroclimatic zones and between seasons. These findings also differ from the previously recommended pruning dates for tasar food plants. This variation may be attributed to the impact of climate change, particularly the increasing temperature trends observed in different agroclimatic zones. With the help of adjustment of brushing schedule farmers not only avoid the harmful effect of climate change but also increase the production without additional input.

Table 5: Pest infestation in first cop in tasar in different agroclimatic zone

State/ Agroclimatic zone	Brusing date for first cop	Stink bug	Reduvid bug	Wasp	Praying Mentis	Cocoon /dfl
Jharkhand State						
Western Plateau Zone	T1	05	04	0	0	62
	T2	04	04	0	0	55
	T3	03	02	0	0	75
	T4	05	05	0	0	61
	T5	04	03	0	0	58
Central and North Eastern Plateau Zone	T1	06	03	0	0	58
	T2	04	05	2	1	50
	T3	06	04	2	4	54
	T4	06	04	4	2	60
	T5	02	04	2	0	65
South Eastern Plateau Zone	T1	5	05	0	2	51
	T2	06	01	2	0	53
	T3	03	02	0	3	55
	T4	02	02	0	2	63
	T5	05	05	3	0	53
Chhattisgarh State						
C.G. Plains (15 Distt)	T1	03	04	0	2	62
	T2	05	04	2	0	55
	T3	05	06	0	0	55
	T4	02	03	0	0	61
	T5	05	04	1	2	58
Plateau (7 Distt)	T1	04	03	0	2	60
	T2	04	05	2	0	51
	T3	05	06	0	0	53
	T4	03	04	0	0	65
	T5	04	05	1	2	52
Northern Hills (5 Distt)	T1	03	04	0	2	45
	T2	05	04	2	0	50
	T3	05	06	0	0	53
	T4	02	03	0	0	60
	T5	05	04	1	2	51
Odisha State						
North Western Plateau	T1	02	03	01	0	55
	T2	03	03	02	0	49
	T3	03	05	01	0	47
	T4	04	04	01	02	45
	T5	01	02	0	0	61

State/ Agroclimatic zone	Brusing date for first cop	Stink bug	Reduvid bug	Wasp	Praying Mentis	Cocoon /dfl
North Central Plateau	T1	04	05	02	2	50
	T2	05	03	02	0	46
	T3	04	04	01	0	48
	T4	04	04	02	02	49
	T5	03	02	0	0	58

Note. Suitable brushing date for first crop ; T_1= 25th June, T_2= 30th June,T_3= 5th July,T_4= 10th July,T_5= 15th July,

Table 6: Pest infestation in second cop in tasar in different agroclimatic zone

State/ Agroclimatic zone	Brusing date for Second cop	Stink bug	Reduvid bug	Wasp	Praying Mentis	Cocoon /dfl
Jharkhand State						
Western Plateau Zone	T1	03	04	0	0	62
	T2	03	04	0	0	55
	T3	05	04	03	0	64
	T4	03	02	0	0	80
	T5	05	05	0	0	61
Central and North Eastern Plateau Zone	T1	06	03	0	0	58
	T2	03	04	1	1	54
	T3	05	03	1	4	58
	T4	02	01	1	0	75
	T5	03	03	2	2	64
South Eastern Plateau Zone	T1	05	05	0	2	55
	T2	06	01	2	0	58
	T3	03	02	0	3	66
	T4	05	05	3	0	53
	T5	02	02	0	2	69
Chhattisgarh State ,						
C.G. Plains (15 Distt)	T1	03	04	0	0	58
	T2	03	04	0	0	51
	T3	05	04	03	0	60
	T4	05	05	0	0	57
	T5	03	02	0	0	76
Plateau (7 Distt)	T1	06	03	0	0	55
	T2	03	04	1	1	51
	T3	05	03	1	4	54
	T4	03	03	2	2	60
	T5	02	01	1	0	70

State/ Agroclimatic zone	Brusing date for Second cop	Stink bug	Reduvid bug	Wasp	Praying Mentis	Cocoon /dfl
Northern Hills (5 Distt)	T1	05	05	0	2	57
	T2	06	01	2	0	59
	T3	03	02	0	3	60
	T4	05	05	3	0	56
	T5	02	02	0	2	72
Odisha State :						
North Western Plateau	T1	05	04	0	0	53
	T2	04	03	1	1	47
	T3	02	01	1	0	67
	T4	03	03	2	2	58
	T5	05	03	1	4	50
North Central Plateau	T1	04	04	1	2	50
	T2	05	02	2	0	53
	T3	03	02	0	3	54
	T4	05	05	3	0	56
	T5	02	02	0	2	65

Note.T_1= 5th September,T_2= 10th September, T_3= 15th September T_4=20th September,T_5= 25th September

5.3.2. Recommendation of Brushing date in different agroclimatic zone:

Strategic adjustment of **brushing dates**—the time when silkworm larvae are placed onto host plants—is essential for synchronizing the silkworm life cycle with optimal environmental conditions and leaf quality. Based on regional climate data and pest pressure assessments, the following schedules are recommended for the first and second crops across major tasar-growing states.

Table 7. Recommendation of bruising date in first and second crop in different agroclimatic zone

Agro-climatic Zone	Districts cum under Agro-climatic zone	Recommendation	
		(I crop)	(II crop)
Jharkhand State			
Western Plateau Zone	Bokaro, Latehar, Lohardanga ,Gumla, Hazaribagh, Palamau, Ranchi, Simdega, Chatara, Garhwa	5 July	20 September
Central and North Eastern Plateau Zone	Jamtara, Koderma,Pakur, Dhanbad, Dumka, Sahebganj	15 July	20 September
South Eastern Plateau Zone	East Singbhum, Saraikela/Kharsawan, West Singhbhum	10 July	15 September
Chhattisgarh State			
C.G. Plains (15 Distt)	Raipur, Gariyaband, Balodabazar, Mahasamund, Dhamtari, Durg, Balod, Bemetara, Rajnandgaon, Kabirdham, Bilaspur, Mungeli, Korba, Janjgeer, Raigarh & a part of Kanker Districts (Narharpur & Kanker Block)	5 July	25 September

Agro-climatic Zone	Districts cum under Agro-climatic zone	Recommendation	
		(I crop)	(II crop)
Plateau (7 Distt)	Jagdalpur, Narayanpur, Beejapur, Kondagaon, Dantewada, Sukma and the remaining part of Kanker Districts	10 July	25 September
Northern Hills (5 Distt)	Sarguja, Surajpur, Balrampur, Koria, Jashpur & Dharamjaigarh Tehsil of Raigarh Districts	10 July	25 September
Odisha State			
North Western Plateau	Sundargarh, parts of Deogarh, Sambalpur & Jharsuguda	15 July	15 September
North Central Plateau	Mayurbhanj, major parts of Keonjhar, (except Anandapur & Ghasipura block)	10 July	25 September

The results confirm that fixed, traditional pruning dates are no longer sufficient under current climatic variability. By adopting region-specific schedules—specifically the T3 window in most zones—tasar farmers can effectively "bypass" the harmful effects of climate change. This adjustment ensures higher quality foliage and improved crop protection without the need for additional chemical inputs, safeguarding the livelihoods of the tribal and rural populations dependent on this forest-based venture. The recommendations indicate that brushing schedules vary across agro-climatic zones due to differences in rainfall, temperature, and topography. Most regions recommend the first crop during early to mid-July and the second crop between mid to late September, ensuring better crop establishment, efficient resource use, and improved productivity.

5.4. REFERENCES

Deshmukh, D. T., and H. S. Lunge 2013: A Study of Temperature and Rainfall Trends In Buldana District of Vidarbha, India, *International Journal of Scientific & Technology Research* Volume 2, ISSUE 2, ISSN 2277-8616

Ghonmode, S. V. 2020: Effect of high temperature on silk production and its impact on livelihood of sericulture farmers in Maharashtra, *Vidyawarta* Issue-33, Vol-05, ISSN: 2319 9318

Hussain, Mubashar., Shakil Ahmad Khan, Muhammad Naeem and Ata-Ul-Mohsin 2011: Effect of Relative Humidity on Factors of Seed Cocoon Production in some Inbred Silk Worm (Bombyx mori) Lines, INTERNATIONAL JOURNAL OF AGRICULTURE & BIOLOGY, ISSN Print: 1560–8530; ISSN Online: 1814–9596, 10–284/SAE/2011/13–1–57–60 http://www.fspublishers.org

Karar, H., Jalal Arif,Asifa Hameed,Amjad Ali,Mussarat Hussain,Fiaz Hussain Shah5 and Saghir Ahmad2013. Effect of Cardinal Directions and Weather Factors on Population Dynamics of Mango Mealybug, *Drosicha mangiferae* (Green) (Margarodidae: Homoptera) on Chaunsa Cultivar of Mango*Pakistan J. Zool., vol. 45(6), pp. 1541-1547, 2013.*

Kumaresan, Jaishankar and S.M.H. Qadri 2010. Impact of urbanization on Sericulture development in Karnataka , Journal of Rural Development, Vol. 29, No. (2) pp. 113 - 123, NIRD, Hyderabad

Mishra, A.B.; Upadhyay, V.B. 1992. Nutritional efficiency of bivoltine, Bombyx mori Linn. larvae at higher regimes of relative humidity. J.*Adv. Zool.* 13 (1 & 2):16-18.

Oripov Otabek Oripovich 2016: The effect of climatic condition in Uzbekistan on biological indicators of Chinese silkworm breed and hybrids, EPRA *International Journal of Research and Development* (IJRD) 5 (11) 469-474.

Rahmathulla V. K. 2012: Management of Climatic Factors for Successful Silkworm (Bombyx mori L.) Crop and Higher Silk Production: A Review, Hindawi Publishing Corporation Psyche Volume 2012, Article ID 121234, 12 pages, doi:10.1155/2012/121234

Sah, Akhilesh and Md. Naiyar Ali 2017: Impact of Climate Change in Palamau Region of Jharkhand, India, International Journal of Current Microbiology and Applied Sciences ISSN: 2319-7706 Volume 6 Number 11 (2017) pp. 53-60 Journal homepage: http://www.ijcmas.com

Sharma k. B. and Sarfaraz Ali 2013. Impact of environmental factors on the indoor rearing performances of tropical tasar silkworm, *Antheraea mylitta D*. (Saturniidae: Lepidoptera)*An International Quarterly Journal of Environmental Sciences* Special issue, Vol. IV: 255-260: www.theecoscan.in

Sharma, Arti, Palvi Sharma, Jyoti Thakur, S. Murali, Sardar Singh and Nirmal Singh 2018: Impact of Room Temperature on Chawki Stage and Its Effect on Later Stages of Double Hybrid, *Bombyx mori* L., Its Growth, Development and Cocoon Productivity, *Int.J.Curr.Microbiol.App.Sci* *7*(6): 1521-1526

Singh, J., A. Kumar, S. Mukherjee, G.P. Singh, S. Ray, K.S. Rawat and A.K. Sinha 2017: Assessment of Brushing Date and Direction on Tasar Silkworm, *Antheraea mylitta* D Production and Protection, *International Journal of Current Microbiology and Applied Sciences ISSN: 2319-7706* 6 (10) 4853-4859.

Singh, J., K.S. Rawat, A. Kumar, S. Mukherjee, G.P. Singh, S. Ray, T. Pandiaraj and A.K. Sinha 2018: Weather Based Forewarning of Predators in Tasar Silkworm (*Antheraea mylitta* D) at Kathikund, Dumka (Jharkhand - India) *International Journal of Current Microbiology and Applied Sciences ISSN:* 7(2): 633-638.

Upadhyay, V.B.; Mishra, A.B. 1991. Nutritional ability of bivoltine silkworm Bombyx mori Linn. larvae at higher temperature regimes. *J. Adv. Zool*., 12 (1) : 56-59.

Wadood A. and Pragyan Kumari 2009: Impact of Climate Change On Jharkhand Agriculture: Mitigation And Adoption, ISPRS Archives XXXVIII-8/W3 Workshop Proceedings: Impact of Climate Change on Agriculture, 206-209.

CHATPER 6: IMPACT OF CLIMATE CHANGE ON TASAR SILKWORM DISEASES AND THEIR MANAGEMENT

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6.1. INTRODUCTION

India is the only country producing all four major commercial silks, namely mulberry, tasar, muga, and eri silk. Tropical tasar silk is produced by the wild silkworm *Antheraea mylitta* Drury, which is widely distributed across different ecological regions of India. Tasar sericulture plays an important socio-economic role among tribal and rural communities inhabiting forest and semi-forest regions (Hansda et al 2008). The major tasar-producing states include Jharkhand, Chhattisgarh, Odisha, Maharashtra, and West Bengal. The silkworm is primarily reared outdoors on host plants such as *Terminalia arjuna*, *Terminalia tomentosa*, and *Shorea robusta*. Unlike mulberry sericulture, which is generally conducted under controlled indoor conditions, tasar culture is directly exposed to natural environmental fluctuations (Mahapatra HC 2009). Consequently, climatic variability has emerged as one of the major constraints affecting tasar cocoon productivity and silkworm health. Rising temperature, erratic rainfall, prolonged droughts, increased humidity, and frequent extreme weather events have substantially altered disease incidence and crop stability. Climate change influences pathogen multiplication, host susceptibility, environmental persistence of pathogens, and host plant nutritional quality, thereby intensifying disease outbreaks and economic losses. Among the diseases affecting tasar silkworms, virosis, pebrine, bacteriosis, and muscardine are economically important. These diseases collectively account for nearly 40% crop loss in tasar sericulture and this crop loss may increase further. Virosis contributes approximately 25–30% crop loss, followed by pebrine (20–25%), bacteriosis (10–15%), and muscardine (2–5%) (Sahay *et al.*, 2000). Environmental stress, ineffective disinfection, poor sanitation, overcrowding, and adverse climatic conditions are major factors responsible for disease outbreaks.

6.2. CLIMATE CHANGE AND TASAR ECOSYSTEM

Climate change refers to long-term alterations in temperature, precipitation patterns, atmospheric carbon dioxide concentration, and weather dynamics resulting primarily from anthropogenic greenhouse gas emissions and associated environmental disturbances. In tasar-growing ecosystems, climate variability is increasingly manifested through rising temperatures, shortened winter periods, erratic monsoon patterns, fluctuating humidity, prolonged droughts, intense rainfall events, and an increased frequency of heat waves (Susikaran *et al.*, 2024; Gedam *et al.*, 2023). As poikilothermic organisms, tasar silkworms rely heavily on ambient environmental conditions for the regulation of metabolism, growth, development, feeding, moulting, reproduction, and immunity (Jena *et al.*, 2013). Consequently, changes in temperature and humidity directly affect larval performance and cocoon productivity. Elevated temperature increases metabolic demands and energy expenditure, resulting in physiological stress, reduced feeding efficiency, impaired digestion, and weakened immune responses.

Temperature and humidity also play critical roles in determining disease incidence and severity. Elevated temperature coupled with high relative humidity creates favorable conditions for the survival, multiplication, and transmission of bacterial, viral, fungal, and microsporidian pathogens.

Prolonged periods of high humidity increase microbial contamination of host plant foliage and rearing environments, thereby predisposing silkworms to diseases such as virosis, bacteriosis, muscardine, and pebrine. Heavy rainfall further enhances disease spread by increasing leaf wetness and facilitating pathogen sporulation and dispersal. Conversely, prolonged drought adversely affects host plant growth and leaf nutritional quality, resulting in nutritionally stressed larvae with reduced immunity and greater susceptibility to infection.

Climate variability is increasingly recognized by farmers as a major constraint to tasar production. A field survey conducted among tribal tasar rearers in the Vidarbha region of Maharashtra revealed that more than 75% of respondents perceived substantial climatic changes during the past decade (Gedam *et al.*, 2023). The rearers has associated rising temperatures, erratic rainfall, and seasonal irregularities with declining cocoon yield, increased disease incidence, and frequent crop failures. Fluctuations in temperature and humidity during the fourth and fifth instars were considered particularly damaging because these stages represent the most active feeding and silk-producing phases of larval development. Climatic stress during these critical stages often results in reduced larval survival, poor cocoon formation, and enhanced vulnerability to opportunistic pathogens.

In addition to its direct effects on silkworms, climate change significantly influences the physiology and nutritional quality of tasar host plants. Variations in temperature and moisture availability affect leaf protein content, moisture balance, tannin concentration, photosynthetic efficiency, secondary metabolites, and leaf toughness. Such changes alter food quality and directly influence larval feeding behavior, food conversion efficiency, growth, immunity, and silk biosynthesis. Climate-induced stress in major host plants such as *Terminalia arjuna*, *Terminalia tomentosa*, and *Shorea robusta* may further affect leaf availability and nutritional suitability during critical rearing periods. Hazarika *et al.* (2025) demonstrated the significant influence of host plant quality on silkworm growth, nutritional indices, development, and silk production. Nutritional imbalance resulting from environmental stress reduces food utilization efficiency, weakens immune competence, and increases susceptibility to pathogens. Poor-quality foliage may additionally disrupt gut microbial homeostasis and nutrient assimilation, thereby exacerbating physiological stress and disease vulnerability.

Extreme weather events associated with climate change, including heat waves, prolonged droughts, unseasonal rainfall, storms, and flooding, pose additional challenges to tasar sericulture. These events can disrupt host plant phenology, reduce leaf availability, alter pathogen dynamics, and increase physiological stress in silkworms. Heat waves frequently lead to elevated larval mortality and reduced cocoon quality, whereas prolonged wet periods favor pathogen persistence and disease outbreaks. Such climatic extremes often result in severe crop instability and economic losses for tasar-dependent communities.

Overall, climate change might affect tasar sericulture through complex and interconnected pathways involving silkworm physiology, host plant quality, pathogen ecology, and environmental stress. The combined effects of thermal stress, oxidative damage, nutritional imbalance, altered host–pathogen interactions, and enhanced pathogen proliferation contribute to increased disease incidence, reduced cocoon productivity, and economic losses. These challenges underscore the urgent need for climate-resilient tasar production systems incorporating improved host plant management, disease surveillance, stress-tolerant silkworm breeds, climate-smart rearing technologies, and integrated disease management strategies.

6.3. INFLUENCE OF CLIMATE CHANGE ON DISEASE EPIDEMIOLOGY

Climate change influences the epidemiology of tasar silkworm diseases through both direct and indirect mechanisms. Variations in temperature, humidity, rainfall, and other climatic factors affect pathogen survival, multiplication, transmission, and environmental persistence while simultaneously altering host susceptibility and immune competence. Among these factors, temperature and relative humidity are considered the most important drivers of disease outbreaks in tropical tasar ecosystems. Recent studies have demonstrated strong correlations between climatic variables and the incidence of bacterial, viral, fungal, and microsporidian diseases in commercial sericulture systems (Rabha *et al.*, 2025).

6.3.1. Effect of Temperature

Temperature is one of the critical environmental factors regulating silkworm health, disease development, and pathogen proliferation. Elevated temperature increases metabolic activity and energy expenditure, resulting in physiological stress that adversely affects growth, feeding efficiency, digestion, nutrient assimilation, endocrine regulation, and silk protein biosynthesis (Bai *et al.*, 2025). Prolonged thermal stress suppresses both cellular and humoral immune responses, thereby reducing the ability of larvae to resist pathogenic infections. In addition, elevated temperature promotes the generation of reactive oxygen species (ROS), leading to oxidative damage of cellular components including proteins, lipids, nucleic acids, and biological membranes. Jena *et al.* (2013) reported that thermal stress significantly alters oxidative stress and antioxidant defense systems in *Antheraea mylitta*, affecting growth and development.

The combined effects of elevated temperature and high relative humidity create highly favorable conditions for pathogen establishment and disease development. Climatic stress can damage the integrity of the midgut epithelium, alter digestive physiology, and disrupt gut microbial homeostasis, thereby facilitating invasion of opportunistic pathogens into the haemocoel (Shi *et al.*, 2024; Patra & Kar, 2021; Guo *et al.*, 2025). Such physiological disturbances reduce nutrient utilization efficiency and increase susceptibility to bacterial, viral, fungal, and microsporidian infections. Furthermore, elevated temperature accelerates pathogen replication, shortens incubation periods, and may increase pathogen virulence, thereby intensifying disease outbreaks under field conditions (Rabha *et al.*, 2025).

6.3.2 Influence of Humidity and Rainfall

Humidity is a major determinant of viral, fungal and bacterial disease outbreaks in tasar sericulture. High relative humidity and prolonged wet conditions favor fungal sporulation, bacterial proliferation, and environmental persistence of pathogens. Heavy rainfall increases moisture accumulation on host plants and rearing sites, thereby facilitating pathogen spread and contamination of foliage. Temporal analysis of commercial sericulture crops in West Bengal from 2018–2024 revealed that temperature and relative humidity were the principal climatic drivers influencing disease outbreaks. Viral and bacterial diseases were more prevalent during hot and humid conditions, whereas fungal diseases were severe during cool and moist crops (Rabha *et al.*, 2025). Rainfall also influences disease epidemiology indirectly by affecting host plant quality. Excessive moisture may result in succulent leaves with poor nutrient balance, whereas drought conditions produce hard and nutritionally deficient foliage. Both situations adversely affect silkworm health and immunity.

6.4. MAJOR TASAR SILKWORM DISEASES UNDER CLIMATE CHANGE

6.4.1. Pebrine

Pebrine is a serious microsporidian disease caused by the microsporidian pathogen *Nosema mylitta*. The disease occurs throughout the year and affects all developmental stages of tasar silkworms. Pebrine is particularly dangerous because of its transovarial and horizontal modes of transmission (Hassan et al 2020). The disease is characterized by black pepper-like spots on larvae, irregular growth, delayed moulting, sluggishness, poor feeding, unequal larval size, reduced cocoon shell weight, and wing deformities in moths. Infected larvae show reduced food utilization efficiency, impaired digestion, decreased silk gland development, and lower reproductive potential (Singh et al 2021). Rath *et al.* (2003) reported significant reductions in larval weight, food conversion efficiency, fecundity, and fertility in pebrine-infected silkworms. Warm and humid conditions favor horizontal transmission and increase latent infection in disease-free layings (DFLs) (Rahamatullah et al 2012). Environmental stress and poor sanitation further aggravate disease outbreaks under outdoor rearing conditions. Recent advancements in pebrine diagnosis include Pebrine Visualization Solution (PVS) during mother moth examination (Singh et al 2018), molecular diagnostics using PCR, serological assays, and staining techniques such as Chromotrope-2R and Naphthalene Blue Black (Singh et al 2019). These technologies improve rapid and accurate detection of *Nosema* spores under field conditions. The relation between pebrine incidence and climatic factors is not clearly understood. However, serious attempts in this regard are being made by CTRTI, Ranchi.

6.4.2. Virosis

Virosis caused by *Antheraea mylitta* Cytoplasmic Polyhedrosis Virus (AmCPV) is one of the most destructive diseases affecting tropical tasar silkworms. The disease is more severe during rainy seasons under conditions of high humidity, overcrowding, poor sanitation, and nutritional stress. Infected larvae exhibit slow growth, cessation of feeding, hanging posture ("tree-top symptom"), dark fluid oozing from the mouth, tissue liquefaction, and foul odor after death. Infected larvae when transform to pupae and moths also show deformities and poor cocoon quality (Singh et al 2021). High temperature associated with elevated humidity has been shown to favor viral multiplication and disease progression, resulting in severe epizootics during commercial tasar crops (Sruthy *et al.*, 2024). Wind and rain facilitate dissemination of viral particles from contaminated feces and dead larvae. Poor nutritional quality of host plants further increases disease susceptibility weakening the immunity of silkworms. Physiologically stressed larvae exhibit reduced immune competence, allowing rapid viral replication within the midgut and other tissues. Infected larvae typically show cessation of feeding, sluggishness, tissue degeneration, and eventual liquefaction, often resulting in extensive mortality and significant crop losses. Recently, tiger band disease caused by granulovirus (*Antheraea proylei* granulovirus Imphal) has emerged as a serious threat in oak tasar culture. Tiger band disease causes a staggering 70–80% mortality rate in infected silkworms, climate-induced spikes in the disease directly threaten the livelihoods of farmers (Kajje et al 2022). Climatic instability may facilitate emergence of novel viral strains with higher pathogenicity.

Virosis outbreaks have been reported from all major tasar-producing regions of India, including Jharkhand, Chhattisgarh, Odisha, Maharashtra, and West Bengal, where seasonal fluctuations in temperature and humidity create favorable conditions for disease development. In particular, rainy-season crops are highly vulnerable because prolonged humidity, frequent rainfall, and elevated temperature enhance the survival and dissemination of viral occlusion bodies. Studies indicate that virosis alone may account for approximately 25–30% crop loss in tropical tasar culture, making it

one of the most economically damaging diseases in tasar sericulture (Sahay *et al.*, 2000; Sruthy *et al.*, 2024).

Environmental dissemination of viral particles is facilitated through contaminated foliage, larval excreta, diseased cadavers, rain splash, and wind currents. Under humid conditions, viral occlusion bodies remain viable on host plant surfaces for extended periods, thereby increasing the likelihood of transmission to healthy larvae. In addition, climate-induced deterioration of host plant quality may result in nutritional stress, further weakening larval immunity and enhancing susceptibility to infection. Consequently, the interaction between climatic stress, pathogen biology, and host physiological responses plays a pivotal role in determining the severity and frequency of virosis outbreaks in tropical tasar ecosystems.

6.4.3. Bacteriosis

Bacteriosis is one of the major bacterial diseases affecting tropical tasar silkworm *Antheraea mylitta* and is commonly associated with opportunistic pathogens such as *Serratia marcescens*, *Proteus vulgaris*, and *Pseudomonas mendocina* (Singh *et al.*, 2021). The disease is particularly severe during the monsoon and post-monsoon periods (June–September), when high temperature and elevated relative humidity create favorable conditions for bacterial growth and transmission. Infected larvae exhibit characteristic symptoms including chain-type excreta, rectal protrusion, sealing of anal lips, flaccid body, loss of appetite, reduced feeding activity, sluggish movement, and body discoloration. As the disease progresses, the larvae become weak and lethargic, eventually leading to mortality. Bacterial pathogens generally invade through the alimentary canal and proliferate rapidly within the gut before spreading into the haemocoel, resulting in septicemia and tissue degeneration.

Climate change is likely to aggravate bacteriosis incidence by creating environmental conditions favorable for bacterial multiplication and survival. Elevated temperature, high humidity, irregular rainfall, and deterioration of host plant quality induce physiological and nutritional stress in silkworms, thereby weakening immune responses and increasing susceptibility to infection. Under such conditions, bacterial pathogens multiply rapidly and crop losses become more frequent and severe, particularly in outdoor tasar rearing systems. Therefore, maintenance of proper field sanitation, use of healthy host plant foliage, timely removal of diseased larvae, and adoption of climate-resilient integrated disease management strategies are essential for minimizing losses due to bacteriosis under changing climatic conditions (Singh *et al.*, 2021).

6.4.4 Muscardine

Muscardine is an important fungal disease of tropical tasar silkworm *Antheraea mylitta*, primarily caused by *Penicillium citrinum* and *Paecilomyces varioti* (Singh *et al.*, 2021). The disease is most prevalent during humid weather conditions, particularly from September to November, when environmental conditions favor fungal growth and transmission. Infected larvae exhibit reduced feeding, sluggish movement, and progressive weakness before death. The dead larvae become hard, brittle, and mummified, often covered with white fungal growth that produces abundant spores. High relative humidity, prolonged leaf wetness, overcrowding, poor aeration, and continuous rainfall create ideal conditions for fungal spore germination, infection, and disease spread.

Climate change may be expected to increase the incidence and severity of muscardine in tasar-growing regions by creating favorable conditions for fungal pathogens through increased humidity, erratic rainfall, and prolonged wet periods. Climatic stress also weakens silkworm immunity, making larvae more susceptible to fungal infection. Reports from major tasar-producing states indicate that muscardine disease incidence are frequently associated with prolonged rainy spells

and poor field sanitation. Effective management requires maintaining proper aeration, avoiding overcrowding, timely removal of infected larvae, and adopting climate-resilient disease forecasting and integrated disease management approaches (Rabha *et al.*, 2025; Singh *et al.*, 2021).

6.5. FUTURE STRATEGIES FOR CLIMATE-RESILIENT TASAR DISEASE MANAGEMENT

The increasing impact of climate change on tasar sericulture necessitates development of advanced, sustainable, and climate-resilient disease management strategies. Conventional disease control approaches alone may not be sufficient under rapidly changing environmental conditions. Future strategies should therefore integrate modern biotechnology, climate-smart rearing practices, digital forecasting systems, ecological approaches, and genetic improvement programs to enhance resilience of tasar silkworms and host plants against climatic stress and emerging diseases.

6.5.1. Development of Climate-Resilient Silkworm Breeds

One of the most important long-term strategies is the development of robust thermo-tolerant and disease-resistant tasar silkworm breeds capable of surviving under fluctuating climatic conditions (CTRTI Annual reports). Selection of genetically stable ecoraces with enhanced adaptability to environmental stress may reduce mortality during extreme climatic conditions. Molecular breeding, marker-assisted selection, genomic selection, and transcriptomic analysis can accelerate identification of genes associated with thermal tolerance, immune regulation, stress proteins, and pathogen resistance. Recent advances in functional genomics and RNA sequencing technologies may further help identify climate-responsive genes involved in heat shock response, antioxidant defense, and immune signaling pathways. Development of transgenic or genome-edited silkworm lines using CRISPR-Cas technologies may become an important future approach for improving disease resistance and environmental adaptability.

6.5.2. Climate-Resilient Host Plant Management

Since tasar silkworm performance is directly dependent on host plant quality, development of climate-resilient host plant systems is essential for sustainable disease management. Climate change significantly alters leaf nutritional quality, tannin concentration, moisture balance, and secondary metabolites, thereby affecting larval immunity and disease susceptibility. Future host plant strategies should include development of drought-tolerant host plant varieties, scientific irrigation management, precision nutrient management, agroforestry-based tasar plantations, moisture conservation practices, and restoration of degraded forest ecosystems. Application of biofertilizers, mycorrhizal fungi, and organic soil amendments may improve plant health and stress tolerance. Identification of host plant genotypes with superior nutritional composition and climate resilience may significantly enhance silkworm immunity and reduce disease incidence. Climate-smart plantation models integrating *Terminalia arjuna*, *Terminalia tomentosa*, and mixed forest species may improve ecosystem stability and buffer the adverse effects of climate variability.

6.5.3. Precision Disease Surveillance and Early Warning Systems

Climate-driven disease outbreaks require real-time monitoring and predictive surveillance systems. Future disease management programs should integrate artificial intelligence (AI), machine learning, remote sensing, Internet of Things (IoT)-based sensors, and climate forecasting models. Development of climate-based disease prediction systems using meteorological parameters such as temperature, humidity, rainfall, dew point, and wind speed can help forecast disease outbreaks before severe crop damage occurs. AI-driven predictive models can identify disease risk periods and support timely prophylactic interventions in tasar growing climatic areas. IoT-based environmental sensors installed in tasar fields may continuously monitor microclimatic parameters and provide

automated alerts regarding favorable conditions for pathogen development. Remote sensing technologies and satellite-based vegetation analysis may also assist in monitoring host plant stress and identifying vulnerable rearing zones.

6.5.4. Advanced Molecular Diagnostics

Rapid and accurate pathogen detection is critical for preventing disease spread under changing climatic conditions. Conventional microscopic methods are often time-consuming and less sensitive during latent infections. Future diagnostic approaches should focus on portable PCR systems, real-time quantitative PCR (qPCR), loop-mediated isothermal amplification (LAMP) (Esvaran et al 2018), biosensors, nanotechnology-based diagnostics, and CRISPR-based pathogen detection systems. These technologies can improve sensitivity, speed, and field applicability for detection of *Nosema*, viral pathogens, and bacterial infections. Development of multiplex diagnostic platforms capable of simultaneously detecting multiple pathogens may significantly strengthen disease surveillance systems.

6.5.5. Microbiome Engineering and Probiotic Approaches

Recent research indicates that gut microbiota plays a critical role in silkworm digestion, immunity, detoxification, and pathogen resistance. Climate stress disrupts gut microbial homeostasis, thereby increasing disease susceptibility. Future strategies may include probiotic supplementation, microbiome engineering, microbial consortia development, and gut microbial restoration technologies. Beneficial microbes capable of enhancing immunity, suppressing pathogens, and improving nutrient assimilation may become important tools for climate-resilient sericulture (Roy et al 2009). Application of microbial antagonists and symbiotic bacteria may also reduce pathogen colonization and improve larval survival under environmental stress conditions.

6.5.6. Molecular Immune Enhancement

RNA interference (RNAi)-based technologies represent a promising future strategy for silkworm disease management. RNAi can specifically silence pathogen-associated genes responsible for virulence, replication, and infection. Future applications may include antiviral RNAi therapeutics, gene silencing against bacterial virulence factors, immune pathway activation, and dsRNA-mediated suppression of pathogen replication. Similarly, molecular approaches targeting heat shock proteins, antioxidant pathways, and immune signaling genes may improve stress tolerance and disease resistance.

6.5.7. Eco-Friendly and Biological Disease Management

Excessive dependence on chemical disinfectants may negatively affect environmental sustainability and silkworm health. Therefore, future disease management should prioritize eco-friendly biological approaches. Important future strategies include plant-derived antimicrobials, entomopathogen antagonists, herbal formulations, microbial biocontrol agents, nanoparticles synthesized from botanical extracts, and biodegradable disinfectants. Medicinal plant extracts with antiviral, antibacterial, and antifungal properties may provide sustainable alternatives to synthetic chemicals. Few botanical formulations such as Jeevan Sudha developed against AmCPV have shown promising results under field conditions (Singh *et al.*, 2010).

6.5.8. Climate-Smart Rearing Technologies

Future tasar sericulture will increasingly require climate-buffering technologies to reduce exposure of silkworms to environmental stress. Potential technologies include semi-indoor rearing systems, microclimate-modified nylon net enclosures, UV-protective covers, portable humidification

systems, and automated environmental regulation devices. Climate-smart rearing shelters may reduce mortality during heat waves, heavy rainfall, and abrupt temperature fluctuations. Use of drone-based environmental monitoring and pathogen surveillance may also emerge as a future precision sericulture technology.

6.5.9. Integrated Climate-Resilient Disease Management (ICRDM)

Future disease management strategies should move beyond conventional integrated disease management (IDM) and adopt Integrated Climate-Resilient Disease Management (ICRDM) approaches combining environmental regulation, host plant management, disease surveillance, climate forecasting, biological control, resistant breeds, and molecular diagnostics. ICRDM should be ecosystem-based, adaptive, and location-specific to accommodate regional climatic variability and disease patterns.

6.5.10. Policy Support and Capacity Building

Sustainable climate-resilient tasar sericulture also requires strong institutional and policy support. Future priorities should include climate insurance schemes for tasar rearers, climate advisory services, digital disease information systems, tribal capacity-building programs, and region-specific climate adaptation packages. Training programs should educate farmers regarding climate risk assessment, disease symptom recognition, sanitation practices, adaptive rearing technologies, and emergency response during climatic extremes. Strengthening collaboration among research institutes, forest departments, meteorological agencies, and rural development organizations will be essential for developing effective climate adaptation frameworks.

6.6. FUTURE RESEARCH PRIORITIES

Future research should focus on climate-resilient silkworm genomics, transcriptomic response under combined heat and pathogen stress, epigenetic adaptation mechanisms, silkworm gut microbiome engineering, AI-based disease forecasting systems, nanotechnology-assisted diagnostics, and sustainable eco-friendly prophylactic technologies. Understanding interactions among climatic stress, host plant chemistry, silkworm immunity, pathogen evolution, and environmental microbiota will be critical for developing sustainable disease management strategies under future climate scenarios.

6.7. CONCLUSION

Climate change has emerged as a major threat to sustainable tasar sericulture by profoundly influencing silkworm health, pathogen epidemiology, host plant quality, and cocoon productivity. Rising temperature, irregular rainfall, fluctuating humidity, and extreme climatic events enhance the severity and spread of diseases such as pebrine, virosis, bacteriosis, and muscardine. Since tropical tasar silkworms are reared under outdoor environmental conditions, their vulnerability to climate-induced stress is considerably higher than indoor sericulture systems. Future sustainability of tasar culture will therefore depend on adoption of climate-resilient disease management strategies integrating advanced molecular diagnostics, climate-smart rearing technologies, resistant silkworm breeds, ecological host plant management, AI-based forecasting systems, microbiome engineering, and integrated climate-resilient disease management approaches. Strengthening research, policy support, and farmer capacity-building programs will be essential for ensuring sustainable tasar silk production under future climate change scenarios.

6.8. REFERENCES

Esvaran, V. G., Mohanasundaram, A., Mahadeva, S., Gupta, T., & Ponnuvel, K. M. (2018). Development and comparison of PCR tools targeting β-tubulin gene for detection of *Nosema* infection in silkworms. *Journal of Parasitic Diseases*. https://doi.org/10.1007/s12639-018-1053-4

Gedam, P. C., Bawaskar, D. M., Chowdary, N. B., Venugopal, A., & Ingale, A. D. (2023). Perception of tasar silkworm rearers about the climate change impact on the tasar silk production of Maharashtra. *Asian Journal of Agricultural Extension, Economics & Sociology, 41*(7), 153–164. https://doi.org/10.9734/AJAEES/2023/v41i71958

Guo, Y., Zou, Y., Chen, Y., Liu, J., Ye, Y., Huang, X., & Wu, Z. (2025). Changes in gut microbiota, midgut structure, and gene expression of *Spodoptera frugiperda* infected by *Serratia marcescens*. *Insects, 16*(9), 933. https://doi.org/10.3390/insects16090933

Hansda, G., Reddy, R., Sinha, M. K., Ojha, N. G., & Vijayaprakash, N. B. (2008). Ex situ stabilization and utility prospects of Jata ecorace of tropical tasar silkworm *Antheraea mylitta* Drury. *International Journal of Industrial Entomology, 17*(2), 169–172.

Hassan, W., Nath, B. S., Ponnuvel, K. M., Mishra, R. K., & Pradeep, A. N. R. (2020). Evolutionary diversity in the intracellular microsporidian parasite *Nosema* sp. infecting wild silkworm revealed by IGS nucleotide sequence diversity. *Journal of Molecular Evolution, 88*(4), 345–360. https://doi.org/10.1007/s00239-020-09936-2

Hazarika, E., Chowdhury, K., & Bora, D. (2025). Influence of host plants on growth, development, nutritional indices and silk production of muga silkworm *Antheraea assamensis* Helfer. *Indian Journal of Entomology*, 1–5. https://doi.org/10.55446/IJE.2025.1796

Jena, K., Kar, P. K., Kausar, Z., & Babu, C. S. (2013). Effects of temperature on modulation of oxidative stress and antioxidant defenses in testes of tropical tasar silkworm *Antheraea mylitta*. *Journal of Thermal Biology, 38*(4), 199–204. https://doi.org/10.1016/j.jtherbio.2013.02.003

Khajje, D., Devi, S. S., Subrahmanyam, G., Kobayashi, J., Sivaprasad, V., Terenius, O., & Ponnuvel, K. M. (2022). Investigation on pathological aspects, mode of transmission, and tissue tropism of *Antheraea proylei* nucleopolyhedrovirus infecting oak tasar silkworm. *Journal of Insect Science, 22*(5), 9. https://doi.org/10.1093/jisesa/ieac057

Mahapatra, H. C. (2009). Tropical tasar biodiversity and forestry. In *Proceedings of the National Workshop on Seri-Biodiversity Conservation* (pp. 163–167). Central Silk Board Gene Resource Centre, Hosur, India.

Patra, A. K., & Kar, I. (2021). Heat stress on microbiota composition, barrier integrity, and nutrient transport in gut, production performance, and its amelioration in farm animals. *Journal of Animal Science and Technology, 63*(2), 211–247. https://doi.org/10.5187/jast.2021.e48

Rabha, M., Ethungbeni, T. N., Rahul, K., *et al.* (2025). Temporal analysis of climatic factors influencing silkworm disease incidences in commercial sericulture crops of West Bengal, India (2018–2024). *Journal of Basic and Applied Zoology, 86*, 65.

Rahmathulla, V. K., Kumar, C. M. K., Angadi, B. S., & Sivaprasad, V. (2012). Influence of weather factors on incidence and intensity of microsporidiosis in silkworm (*Bombyx mori* L.). *Journal of Entomology, 9*, 266–273.

Rath, S. S., Prasad, B. C., & Sinha, B. R. R. P. (2003). Food utilization efficiency in fifth instar larvae of *Antheraea mylitta* infected with *Nosema* sp. and its effect on reproductive potential and silk production. *Journal of Invertebrate Pathology, 83*, 1–9.

Roy, D. K., Sahay, A., Singh, G. P., Ojha, N. G., & Vijayaprakash, N. B. (2009). Development and transfer of microbial technology for protection of tasar cocoon crop at field level. *Sericologia, 49*(3), 321–329.

Sahay, D. N., Roy, D. K., & Sahay, A. (2000). Diseases of tropical tasar silkworm *Antheraea mylitta* D.: Symptoms and control measures. In *Lessons on Tropical Tasar*. Central Tasar Research and Training Institute, Ranchi.

Shi, Y.-X., Bian, D.-D., Chen, F.-X., Jin, Y., Jiang, Q., Liu, Q.-N., Tang, B.-P., & Dai, L.-S. (2024). Effect of lead exposure on silkworm midgut: Insights into oxidative gene expression, digestive function, and microbial community structure. *Process Safety and Environmental Protection, 190*(Part A), 481–494. https://doi.org/10.1016/j.psep.2024.07.048

Singh, G. P., Baig, M. M., & Bajpayi, C. M. (2021). Recent trends in tasar silkworm *Antheraea mylitta* Drury disease management. In *Methods in Microbiology* (Vol. 49, pp. 175–200). Elsevier. https://doi.org/10.1016/bs.mim.2021.05.001

Singh, G. P., Baig, M. M., Singh, J., Pandey, J. P., Jena, K., & Sahay, A. (2019). Chromotrope-2R and naphthalene blue black stains for easy detection of *Nosema mylittensis* spores infecting tropical tasar silkworm. *Journal of Entomology and Zoology Studies, 7*(3), 1388–1390.

Singh, G. P., Baig, M. M., Singh, J., Pandey, J. P., Sinha, A. K., & Jena, K. B. (2018). Use of certain chemicals for easy and quick detection of *Nosema mylittensis* spores infecting tropical tasar silkworm, *Antheraea mylitta* Drury (Saturniidae: Lepidoptera). *Journal of Entomology and Zoology Studies, 6*(5), 2328–2331.

Singh, G. P., Sahay, A., Kulshrestha, V., Kumar, K. P., Ojha, N. G., Pallavi, S., & Prasad, B. C. (2010). Screening of medicinal plants against the infection of *Antheraea mylitta* cytoplasmic polyhedrosis virus (AmCPV). *International Journal of Industrial Entomology, 19*(1), 13–17.

Sruthy, K. S., Pandey, J. P., Singh, J., & Chowdary, N. B. (2024). Research on virosis management in tropical tasar silkworms: A time travel. *Plant Archives, 24*(Special Issue VS), 134–137. https://doi.org/10.51470/PLANTARCHIVES.2024.v24.specialissue.021

Susikaran, S., Bharathi, B. K. M., Loveson, A., Vasanth, V., Krishnan, S. N., & Kiruthika, C. (2024). Silkworm growth and silk yield under changing climatic conditions: Challenges and adaptations. *International Journal of Insects, 1*(2), 1–5.

CHAPTER 7: CLIMATE CHANGE AND FARMER PERCEPTION IN TROPICAL TASAR SERICULTURE: CHALLENGES, IMPACTS AND ADAPTATION STRATEGIES

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7.1. INTRODUCTION

Tasar sericulture is the art and science of rearing the Tasar silkworm i.e. *Antheraea mylitta* Drury, for the production of vanya silk. It is an important cottage-based, agro-forestry enterprise extensively practice across the Tasar-silk producing states such as Jharkhand, Bihar, Orissa, Chhattisgarh, West Bengal, Andhra Pradesh, Maharashtra, Telangana and Uttar Pradesh (Nadaf *et al.*, 2022). The sector provides livelihood support to lakhs of rural and tribal families and plays a significant role in employment generation, ecological conservation, prevention of rural migration, and preservation of socio-cultural heritage (Suryanarayana & Srivastava, 2005).

Unlike mulberry sericulture, which is largely practiced under controlled indoor conditions, tropical tasar sericulture is an outdoor, forest-based activity highly dependent on natural environmental conditions (Bhatia and Yousuf, 2013). Tasar silkworms are primarily reared on forest host plants such as *Terminalia arjuna*, *Terminalia tomentosa* and *Shorea robusta* (Rai *et al.*, 2023). Climate—encompassing temperature, humidity, rainfall, and photoperiod—plays a pivotal role in every stage of the silkworm's life cycle, from egg incubation and larval rearing to pupation, moth emergence, and seed production (Beck, 1980). Optimal climatic conditions ensure healthy larval growth, high cocoon yield, and quality silk, while deviations lead to stress, diseases, mortality, and economic losses. Climate change has amplified these vulnerabilities, making understanding climate's role essential for sustainable production.

Climate change refers to the long-term alteration of temperature, precipitation patterns, and other meteorological factors on Earth's surface, primarily driven by human activities such as the burning of fossil fuels and deforestation (Hulmi, 2005). The current state of climate change is marked by unprecedented global warming, evidenced by rising average temperatures, melting glaciers, and shifting weather patterns (Gahlawat and Lakra, 2020).

Understanding the influence of climate change on tasar sericulture and documenting farmers' perceptions regarding these changes are essential for developing climate-resilient sericultural practices and sustainable livelihood strategies.

7.2. CLIMATE CHANGE TRENDS RELEVANT TO SERICULTURE IN INDIA

India has witnessed an approximate rise of 0.5°C in average temperature during the last century, with projections of 1.5–4°C further increase by 2100 depending on emission scenarios (Ravindra *et al.*,2024). Key changes due climate change include:

- More erratic and intense monsoons.
- Increased heat waves and shortened winters.
- Prolonged dry spells interspersed with heavy rainfall.
- Rising atmospheric CO_2 levels affecting plant physiology.

These alterations disrupt the delicate microclimates required for sericulture. The host plants of Tasar sericulture i.e. *Terminalia arjuna*, *Terminalia tomentosa and Shorea robusta* are sensitive to temperature and water stress (Gadad *et al.*, 2026). Similarly, tasar silkworms thrive only within a relatively narrow range of environmental conditions.

7.2.1. Key Climatic Parameters for Tasar sericulture and Their Influence on production

7.2.1.1 Temperature

Since tasar rearing is conducted outdoors, silkworms are directly exposed to fluctuating environmental conditions. There are several abiotic factors such as temperature, relative humidity, rainfall, degree days etc. those affect the growth and development of silkworms. Temperature is the most critical abiotic factor influencing Tasar silkworm physiology, as the species is poikilothermic (cold-blooded). The impact of temperature on silkworm physiology is elaborated as below;

- **Optimal ranges**: Larval development thrives at 25–30°C with relative humidity of 65–85%. Ideal rearing temperatures are often cited as 24–30°C depending on instar stage.
- **Effects of high temperature**: Summer diapausing pupae endure 35–42°C, but prolonged extremes cause pupal mortality, unseasonal emergence, male sterility, crinkled wings, reduced fecundity (down to 120–150 eggs/moth), and poor hatching. Late instar larvae under high heat become restless, leading to mortality above 35°C combined with low humidity.
- **Low temperature**: Low temperature during the rearing delays the silkworm development increase the duration of rearing thereby affects voltinism (number of generations per year).
- **Phenological impacts**: Temperature and photoperiod regulate voltinism. Bivoltine races may behave as tri-voltine in hotter low-altitude areas, leading to instability.

The continual rising average temperatures due to climate change disrupt these balances, causing phenological asynchrony between silkworm life cycles and host plant leaf availability.

7.2.1.2 Humidity and Rainfall

- **Optimal humidity**: The optimal range of relative humidity is 65–85% during larval stages and it supports proper growth and spinning. However, any fluctuations could increase disease susceptibility and there cause to lose the entire crop. Moreover, it will have adverse impact on Tasar silkworm seed production since the humidity is a crucial factor for seed production.
- **Rainfall patterns**: Outdoor nature of Tasar rearing is certainly get impacted by the rainfall since Tasar rearing is rainfed. Adequate monsoon rains promote lush, nutritious host plant foliage. Erratic or unseasonal rains trigger false moth emergence, poor pairing, and larval wash-off. Prolonged dry spells reduce leaf quality (low nutritive value), affecting larval growth and cocoon parameters like shell weight and silk content.
- **Impacts**: Direct exposure to the heavy rains during rearing increase mortality of silkworms from drowning or fungal diseases. The rainfall right after the brushing can cause the severe loss of the larvae eventually lead to the loss of the crop. Intermittent rainfall coupled with the scorching sun cause the increase in the humidity and increases the chances of bacterial and viral disease infection. Drought stresses host plants, altering soil moisture and microflora, indirectly impacting silkworm nutrition.

7.2.1.3 Photoperiod and Seasonal Variations

Photoperiod, in association with temperature, regulates diapause, voltinism, and seasonal synchronization in tasar silkworms (Kumar *et al.*, 2013). Shifts in seasonal timing due to climate variability alter brushing schedules and grainage (seed production) operations.

Climate change—manifested through rising temperatures, altered rainfall patterns, increased frequency of extreme events, and shifts in humidity—poses significant challenges to this traditional sericulture practice. Farmers' perceptions of these changes are crucial because they influence adaptation behaviours, technology adoption, and the overall sustainability of the Tasar sericulture sector. Understanding these perceptions helps bridge the gap between scientific knowledge and on-ground realities, informing policy and extension strategies.

This chapter draws primarily on empirical studies, notably one conducted in Maharashtra, while contextualizing findings with broader trends in Tasar-growing regions.

7.3. UNDERSTANDING FARMER PERCEPTION IN CLIMATE CHANGE STUDIES

Farmer perception refers to the way farmers observe, interpret, and respond to climatic and environmental changes over time. In climate-sensitive sectors such as tasar sericulture, farmers perception becomes particularly significant because farmers make management decisions based on practical observations rather than meteorological records.

Perception includes:

- Recognition of increasing temperatures
- Awareness of shifting seasonal patterns
- Experience of rainfall irregularity
- Observation of pest and disease changes
- Economic interpretation of crop loss
- Assessment of livelihood insecurity

In tasar farming communities, climate perception is often cumulative and experiential, developed through repeated interactions with the environment across generations.

7.3.1 Methodology of Key Perception Studies

A notable study by Gedam *et al.* (2023) surveyed 160 tasar silkworm rearers across four districts in Maharashtra: Bhandara, Gondia, Gadchiroli, and Chandrapur. Data were collected via Rapid Rural Appraisal (RRA) and Focus Group Discussions (FGD). Researchers employed two key indices: the Climate Change Perception Index (CCPI) and the Climate Change Impact Perception Index (CCIPI), supplemented by Weighted Average Indices (WAI) for ranking impacts. Descriptive statistics and correlation analyses were used.

Similar qualitative and quantitative approaches in other states highlight consistent themes, though regional variations exist due to differences in topography, host plant availability, and socio-economic conditions.

7.3.2. Farmers' General Perception of Climate Change

A substantial majority of Tasar rearers acknowledge climate change. In the Maharashtra study, over 75 per cent tasar farmers perceived ongoing shifts in climate change with a CCPI of 2.81 indicating moderate to high awareness (Gedam *et al.*, 2023). Key observed changes include:

Increased temperatures and heat waves: Over 88 per cent reported more frequent and intense heat waves.

Altered rainfall patterns: About 80 per cent noted a decrease in total rainy days, alongside erratic or unseasonal rains.

Other indicators: Shifts in seasonal timing, prolonged dry spells, and increased unpredictability.

These perceptions align with broader meteorological trends in India, such as an approximate 0.5°C rise in average temperatures over the past century, which affects rainfed, forest-dependent activities like Tasar rearing.

Farmers often link these changes to personal experiences: failed crops, timing mismatches in brushing and moth emergence issues.

7.3.3. Perceived Impacts on Tasar Silkworm Rearing and Production

Tasar rearing's outdoor nature amplifies vulnerability. Farmers perceive multiple direct and indirect effects:

7.3.4. Decline in Cocoon Yield and Production

Ranked highest (WAI 2.81), with most farmers reporting reduced output over the past decade. Climate change is seen as a major contributor by around 81%.

7.3.5. Increased Crop Losses

Higher frequency of total or partial losses due to sudden weather shifts (WAI 2.76).

7.3.6. Increased Disease Incidence

Warmer temperatures and humidity fluctuations correlate strongly with diseases like grasserie (correlation ~0.74) and flacherie (~0.80). Outbreaks of viral, bacterial, and fungal diseases rise (Aradhana *et al.*, 2020).

7.3.7. Increased predators and parasitoid incidence

Blepharipa zebina, *Xanthopimpla pedator*, Predatory wasps.

7.3.8. Larval and Pupal Mortality

Increased mortality in final instar larvae and issues with pupal development.

7.3.9. Hatching and Seed Problems

Poor hatching rates in disease-free laying (DFLs), erratic moth emergence (15-30 per cent in some cases), male sterility, reduced fecundity, and crinkled wings.

7.3.10. Host Plant Quality

Reduced nutritive value of leaves due to drought or erratic rains, affecting larval growth.

7.3.11. Economic and Social Ripple Effects

Decreased income (high ranking), rising labour costs for protective measures, and declining interest in the activity among younger generations. Quality of cocoons has also deteriorated.

Broader literature notes additional challenges: phenological asynchrony (mismatch between silkworm life cycle and host plant availability), voltinism instability, and habitat fragmentation.

7.4. REGIONAL VARIATIONS AND SOCIO-ECONOMIC CONTEXT

In core Tasar states like Jharkhand and Chhattisgarh, impacts may be compounded by deforestation and reliance on wild populations. Maharashtra's study highlights tribal rearers' vulnerability, with many depending on Tasar as a supplementary income. Women play a major role in the value chain, making livelihood disruptions particularly significant.

Socio-economic factors influencing perception include education, exposure to extension services, age, and landholding size. Farmers with better access to information tend to have sharper perceptions and are more likely to experiment with adaptations.

7.5. ADAPTATION STRATEGIES AND COPING MECHANISMS

Farmers report informal adaptations such as:

- Adjusting brushing schedules.
- Using protective coverings for young larvae.
- Selecting hardier local eco-races.
- Diversifying income sources.

However, systematic adoption of climate-resilient practices (e.g., thermo-tolerant breeds, improved host plant management, integrated pest management) remains limited due to awareness gaps, resource constraints, and lack of tailored extension. Research emphasizes the need for climate-smart tasar varieties, better seed technology, and agroforestry integration.

Policy and Research Implications

Farmers' perceptions underscore the urgency for:

- **Climate-resilient breeding**: Developing thermo-tolerant, disease-resistant *A. mylitta* lines and robust host plants.
- **Extension and Capacity Building**: Targeted training on weather-based advisories and adaptive practices.
- **Conservation Efforts**: Protecting tasar host plant habitats and germplasm.
- **Support Systems**: Crop insurance, subsidies for protective infrastructure, and market linkages to buffer income losses.
- **Integrated Approaches**: Combining tasar with other agroforestry or livelihood options for resilience.

Future studies should expand to more states, incorporate longitudinal data, and explore gender-disaggregated perceptions.

7.6. CONCLUSION

Tropical tasar sericulture is highly vulnerable to climate variability because of its outdoor, forest-dependent nature. Farmers across India, particularly in Maharashtra, clearly perceive climate change as a major threat affecting cocoon production, silkworm health, host plant quality, and household livelihoods. Rising temperatures, erratic rainfall, prolonged droughts, and increased pest and disease incidence are significantly disrupting traditional tasar rearing systems. Nevertheless, farmers' experiential knowledge and adaptive responses provide valuable insights for designing climate-resilient sericultural strategies. Sustainable development of tasar sericulture will require integrated efforts involving scientific research, climate-resilient breeding, participatory extension, ecological conservation, and policy support. Strengthening adaptive capacity among tribal and rural rearers is essential not only for sustaining tasar silk production but also for preserving the socio-cultural and ecological significance of this traditional livelihood system.

7.7. REFERENCES

Aradhana Sharma, Suraksha Chanotra, Rucku Gupta and Rakesh Kumar. 2020. Influence of Climate Change on Cocoon Crop Loss under Subtropical Conditions. Int.J.Curr.Microbiol.App.Sci. 9(05): 167-171.

Beck, SD. Insect Photoperiodism, Academic press, New York, II Edition. 1980.

Bhatia, N.K. and Yousuf, M., 2013. Forest insect industry in collaborative forest management: an overview. *International Journal of Industrial Entomology*, *27*(1), pp.166-179.

Gadad, H., Shreyansh, Bhagat, A., Prabhu, I.G., Mittal, V. and Chowdary, N.B., 2026. Non-mulberry Plants' Responses to Abiotic and Biotic Challenges Associated with Climate Change: Crosstalk and Trade-Offs. In *Sustainable Sericulture in India: Climate Change Impacts and Mitigation Strategies* (pp. 371-425). Cham: Springer Nature Switzerland.

Gahlawat, I.N. and Lakra, P., 2020. Global Climate change and its effects. *Integrated Journal of Social Sciences*, *7*(1), pp.14-23.

Gedam, P.C., Bawaskar, D.M., Chowdary, N.B., Venugopal, A. and Ingale, A.D., 2023. Perception of tasar silkworm rearers about the climate change impact on the tasar silk production of maharashtra. *Asian Journal of Agricultural Extension, Economics & Sociology*, *41*(7), pp.153-164.

Hulmi P E. Adapting to climate change: is there scope for ecological management in the face of a global threat. Journal of Applied Entomology. 2005; 42:784-794

Kumar, D., Subrahmanyam, B., Sharan, S.K., Mishra, P.K., Singh, B.M. and Suryanarayana, N., 2013. Endogenous 20-hydroxyecdysone levels in the haemolymph of non-diapause-destined and diapause-destined generations of tasar silkworm, Antheraea mylitta (Lepidoptera: Saturniidae) and associated developmental changes. *EJE*, *105*(4), pp.591-598.

Nadaf, H.A., Vishaka, G.V., Sathyanarayana, K., Chandrashekharaiah, M., Rathore, M.S., Balaji Chowdary, N., Reddy, B.T. and Selvaraj, C., 2022. INTEGRATED FARMING SYSTEM–A KEY TO SUSTAINABLE LIVELIHOOD IN TASAR SERICULTURE. *Journal of Experimental Zoology India*, *25*(2).

Rai, M.M., Rathod, M., Wazalwar, S. and Raina, S.K., 2023. Tropical Tasar Insect. In *Commercial Insects* (pp. 49-81). CRC Press.

Ravindra, K., Bhardwaj, S., Ram, C., Goyal, A., Singh, V., Venkataraman, C., Bhan, S.C., Sokhi, R.S. and Mor, S., 2024. Temperature projections and heatwave attribution scenarios over India: A systematic review. *Heliyon*, *10*(4).

Suryanarayana, N. and Srivastava, A.K. (2005). Monograph on tropical tasar silkworm. Central Tasar Research and Training Institute, Ranchi, India. pp.134.

CHAPTER 8: SOIL MICROBIAL COMMUNITIES UNDER CHANGING CLIMATE: IMPLICATIONS TO TASAR SERICULTURE

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8.1. INTRODUCTION:

Soil is often understood as a physico-chemical medium of plant growth which provides a substratum for anchoring of the plants and base retaining air, water and nutrients required for plant growth. However, soil in reality is a living ecosystem harbouring of thousands of species of microflora (soil microorganisms), microfauna and mesofauna. The soil ecosystem in itself holds numerous microhabitats along with the microhabitats present in the soil-plant-root ecosystem. Soil microorganisms constitute a major and most crucial component of the soil ecosystem. A teaspoonful of soil is supposed to contain 1 billion microbial cells and around 10,000 species of microorganisms (UK Centre for Ecology & Hydrology). Soils around the world hold microbial biomass of about ≈20 Gt C contributed by ≈12 Gt of fungal biomass C and ≈8Gt of bacterial and archaeal biomass C (Bar-On *et al.*, 2018). Soils contribute to around 59% of the total global biodiversity and the soil bacteria contribute 43% of global bacterial diversity and soil fungi contribute 90% of the global fungal diversity (Anthony *et al.*, 2023). These estimates clearly indicate that the Soil microbial communities are the lifeline for plant productivity and allied activities of crop production. All the bio-geo-chemical cycling of plant nutrients in soil are carried out by the soil microorganisms ensuring the nutrient supply to the plants. Bacteria are involved in crucial processes like nitrogen fixation, nitrification, phosphate solubilization, sulphur oxidation, mineralization and solubilization of micronutrients and fixation and demobilization of pollutants and heavy metals, etc. Fungi are majorly involved in C turnover, decomposition of organic matter and their mineralization and phosphate solubilization. The structure and function of microbial communities are known to be greatly affected by the crop management practices and anthropogenic activities. Given the huge contribution of soil microorganisms to global biomass and biodiversity, the impact of climate change on the soil microbial community structure and function also could be considerable interest indirectly affecting the plant production practices.

Tasar sericulture being a wild sericulture, is carried out in forest areas or the block plantations of tasar host plants and the soil ecosystem has a direct impact majorly through plant leaf quality and quantity as well as the abundances of pests and pathogens. The microbial community structure and function thus determine the soil nutrient cycling and availability and thus the nutritional quality of the food of the tasar silkworms. Hence, along with the direct impacts of climate change on physiology of tasar host plants and silkworms themselves, the impact of climate change on soil microbial community structure and function is of immense importance to tasar sericulture.

8.2. CAUSES AND EFFECTS OF CLIMATE CHANGE (NASA: CLIMATE CHANGE):

The one-word representation of the causes of climate change is the “green house gases”. Majority of the causes leading to the climate change are man made and the effectors of climate change are the green house gas emissions.

8.2.1. Causes of climate change:

The following are the major causes of climate change:

8.2.2. Rise in atmospheric CO_2 levels:

Many natural and anthropogenic activities cause rise in atmospheric CO2 levels, with the anthropogenic activities like burning of fossil fuels and reduction in forest cover being the major contributors. Past 60 years have seen a hazardous increase of 100 ppm of atmospheric CO_2 concentration due to industrialization (National Oceanic and Atmospheric Administration, USA) and CO2 is found to have 80% share in causing climate change due to its high ability to absorb, retain and scatter heat globally.

8.2.3. Methane emissions:

Methane emissions are caused by both anthropogenic activities like industries, landfills, production and transportation of fossil fuels, natural gas in particular, etc., as well as activities supporting human life like livestock and paddy cultivation. Methane is ~25-80 times more potent than CO_2 but considerably short lived in the atmosphere than CO_2.

8.2.4 Nitrous Oxide

Nitrous Oxide, a potent greenhouse gas, is now increasingly becoming important due to constant rise in its atmospheric levels as it is ~100 times potent than CO2. It is majorly produced by farming practices, and is also released during fertilizer production (). Release of nitrous oxide also is released from agricultural systems due to use of chemical fertilizers for crop production. Nitrous oxide emission has increased by 18% in the last century.

Other minor greenhouse gases released during various industrial processes also contribute to the climate change at a smaller scale.

8.2.5. Effects of Climate Change:

The major effects of climate change include rise in temperatures and humidity, frequent destructive storms, rainfall, floods, drought and other natural calamities, erratic seasons, etc.

8.3. IMPACT OF CLIMATE CHANGE ON SOIL MICROBIAL COMMUNITY

Both the causes and effects of climate change affect all the living organisms on earth including the microbial communities native to soil and those associated with the soil-plant root system.

8.3.1. Impact of increased CO_2 levels on soil microbiota

Elevated levels of CO_2 cause both direct and indirect impacts on soil microbiota. Higher atmospheric CO_2 levels cause higher photosynthetic activity in plants resulting a higher exudation of labile carbon compounds into the soil (Ainsworth and Long, 2005). This labile Carbon in turn alters the soil microbial community structure favouring the microbes which can actively utilize these labile carbon sources, i.e., population of zymogenous microorganisms increase thereby changing the proportions of various bacterial taxa present in the soil. Higher microbial activity in terms of FDA hydrolysis and active microbial biomass (Kassem *et al.*, 2008) were recorded in soils exposed to higher CO2 levels. Elevated CO2 levels also change the pH of the soil solution present in the pore spaces of soils created by micro and macro-aggregates. Since pH is a major driving factor of microbial diversity (Zhou *et al.*, 2024), shifts in the soil microbial community compositions readily occur changing the rates of nutrient cycling in the root zone as well as the root free soil. The species richness decreases with lowering pH (Zhou *et al.*, 2024) and important taxa like Actinobacteria which are crucial for phosphate mobilization and other nutrient cycling are replaced with the taxa like Acidobacteria. Higher atmospheric CO2 levels are also found to alter the balance between

bacteria and fungi, supporting the proportion and biomass of fungi over bacteria (Carney *et al.*, 2007).

8.3.2. Impact of Increased Temperature on soil microorganisms:

Increased temperatures significantly alter soil ecosystems, primarily by accelerating microbial metabolic rates and shifting community structures. While moderate warming can boost decomposition and nutrient cycling, extended temperature spikes reduce overall microbial biodiversity, often releasing more carbon dioxide into the atmosphere and exacerbating climate change. Sun *et al.*, (2025) showed that the diversity of bacteria and fungi in soils as indicated by Shannon diversity index reduced by 16 and 19.7% respectively. Warming increases the microbial activity in soils which is reflected in the soil respiration dynamics. Such increases in microbial activity eventually leads to faster depletion of organic and inorganic nutrients required for microbial growth. The activity as well as diversity of both bacteria and fungi thus follow a declining trend on long term warming of soils.

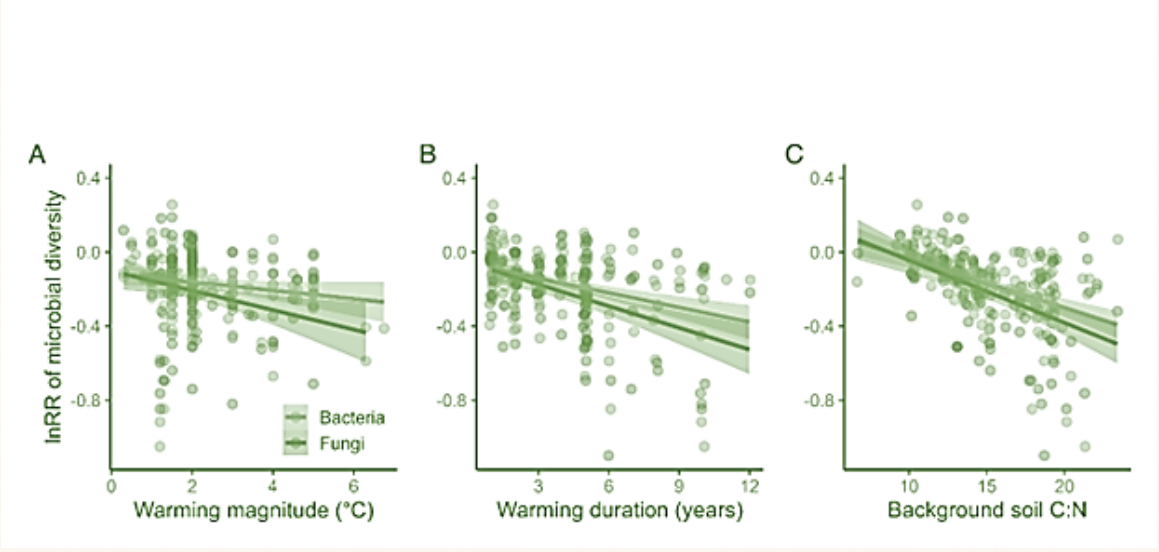


Figure 1: Effects of warming on soil microbial diversity in relation to warming magnitude, warming duration, and background soil C:N ratios. Sun *et al.*, (2025)

8.3.3. Effect of climate change on Carbon turnover in soil:

Climate change accelerates soil carbon turnover by primarily increasing microbial decomposition rates. As temperatures rise, soil microorganisms become more active, causing organic matter to break down faster. This process releases stored carbon into the atmosphere as CO2, creating a positive feedback loop that exacerbates global warming. The rate at which carbon cycles through the soil is fundamentally dictated by shifting weather patterns, plant productivity, and soil biology. Again, the soil microbial community shifts play a major role in determining C turnover rates.

Elevated levels of CO2 as well as temperatures, as indicated above, increase microbial activity favouring the rapid breakdown of complex carbon compounds present in soil. Worsening the condition, alternating drought and precipitation causes accelerated loss of soil organic carbon stock. Drought condition along with either elevated CO2 (Kassem *et al.*, 2008) or temperature exerts stress on the soil microbial community increasing the microbial activity without net increase in microbial biomass. On precipitation, wetting causes release of labile C generated by the microbial activity as well as carbon from the weakened microbial biomass. Thus, climate change accelerates depletion of soil organic carbon stocks aggravating the effects of climate change.

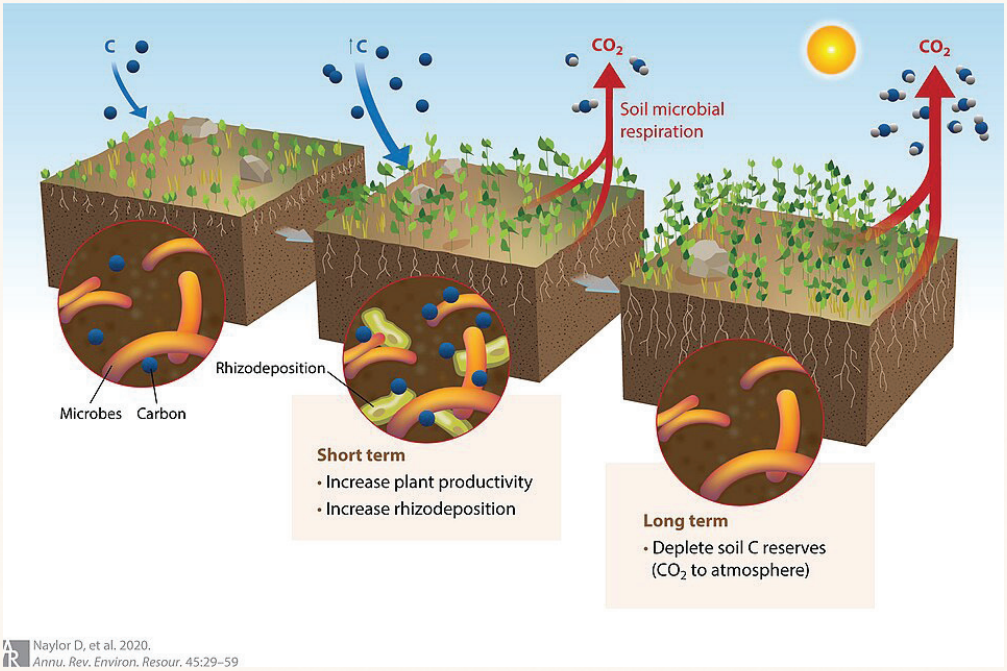


Figure 2: Predicted effects of elevated carbon dioxide on soil carbon reserves

8.4. IMPLICATIONS TO TASAR SERICULTURE:

Major Tasar sericulture areas are predominantly acidic and low fertile soils with moderate to low nutrient availability (especially Phosphorus) and organic carbon content. The inherent microbial activity in terms of dehydrogenase activity was observed to be very low ranging from 0-20 ug TPF/g soil/ day. The average microbial abundance as well as diversity is thus very low. The microbial activity is further reduced due to the sanitization and disinfection activities carried out during tasar sericulture. However, due to the soil acidity a wide diversity of symbiotic and lignolytic fungi have been observed. In the current and future scenario of climate change, further reductions in total microbial activity and bacterial diversity may be observed. Thus, remedial practices which can bring climate resilience to soils of tasar sericulture plantations or forests need to be taken up with emphasis on addition of more organic carbon to soils and improve microbial diversity and functional redundancy of soils. The plant-microbiome symbiosis needs to be maintained by applying suitable composts, particularly the composted leaf litter facilitating proliferation of native microbial species as well as the symbiotic partners of the roots.

8.5. REFERENCES:

Ainsworth, E. A., & Long, S. P. (2005). What have we learned from 15 years of free-air CO2 enrichment (FACE)? A meta-analytic review of the responses of photosynthesis, canopy properties and plant production to rising CO2. *New phytologist*, *165*(2), 351-372.

Anthony, M. A., Bender, S. F., & Van Der Heijden, M. G. (2023). Enumerating soil biodiversity. *Proceedings of the National Academy of Sciences*, *120*(33), e2304663120.

Bar-On, Y. M., Phillips, R., & Milo, R. (2018). The biomass distribution on Earth. *Proceedings of the National Academy of Sciences*, *115*(25), 6506-6511.

Carney, K. M., Hungate, B. A., Drake, B. G., & Megonigal, J. P. (2007). Altered soil microbial community at elevated CO2 leads to loss of soil carbon. *Proceedings of the National Academy of Sciences*, *104*(12), 4990-4995.

https://science.nasa.gov/climate-change/causes

https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

Kassem, I. I., Joshi, P., Sigler, V., Heckathorn, S., & Wang, Q. (2008). Effect of elevated CO2 and drought on soil microbial communities associated with Andropogon gerardii. *Journal of integrative plant biology*, *50*(11), 1406-1415.

WHY: do soil microbes matter? https://www.ceh.ac.uk/our-science/case-studies/case-study-why-do-soil-microbes-matter

Zhou, X., Tahvanainen, T., Malard, L., Chen, L., Pérez-Pérez, J., & Berninger, F. (2024). Global analysis of soil bacterial genera and diversity in response to pH. Soil Biology and Biochemistry, 198, 109552.

CHAPTER 9: CLIMATE RESILIENCE AND ADAPTIVE POTENTIAL OF TASAR SILKWORM ECORACES IN SERICULTURE

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9.1. INTRODUCTION

Climate change has emerged as one of the greatest global environmental challenges affecting agriculture, biodiversity, forestry, and insect-based production systems. Increasing concentrations of greenhouse gases have resulted in rising global temperatures, altered precipitation regimes, and frequent extreme weather events that threaten ecosystem stability and rural livelihoods. The Intergovernmental Panel on Climate Change (IPCC) has emphasized that global warming beyond 1.5°C may severely affect biodiversity, ecosystem services, and agricultural sustainability (IPCC, 2023).

Among climate-sensitive rural enterprises, sericulture occupies a unique position because of its ecological, economic, and social significance. Sericulture integrates forestry, agriculture, insect biology, and textile production while supporting millions of rural and tribal households. Unlike many industrial systems, sericulture contributes positively to environmental sustainability through perennial vegetation cover, carbon sequestration, and biodiversity conservation.

India is the only country in the world producing all major commercial silks, including mulberry, tasar, muga, and eri silk. Among non-mulberry silks, tasar sericulture is particularly important due to its association with forest ecosystems and tribal livelihoods. Tropical tasar silk is produced mainly by the silkworm *Antheraea mylitta* Drury, which is reared outdoors on host plants such as *Terminalia arjuna*, *Terminalia tomentosa*, and *Shorea robusta*. Tasar culture is widely practiced in Jharkhand, Chhattisgarh, Odisha, West Bengal, Maharashtra, Telangana, and Madhya Pradesh.

Tasar sericulture is traditionally practiced by tribal communities inhabiting forested regions of central and eastern India. The system not only generates employment and supplementary income but also promotes sustainable utilization of forest resources. Unlike intensive agricultural systems, tasar sericulture depends heavily on ecological balance, climatic suitability, and natural vegetation. Consequently, climatic fluctuations directly influence silkworm survival, cocoon yield, disease incidence, and host plant quality.

The tropical tasar silkworm exhibits extraordinary intraspecific diversity represented by more than forty identified ecoraces distributed across different ecological zones. These ecoraces differ in morphology, voltinism, cocoon characteristics, geographical distribution, and adaptation to local environmental conditions. Genetic variability among tasar ecoraces provides an important foundation for climate resilience and adaptation (Prabhu *et al.*, 2026; Sandhya *et al.*, 2026).

Recent studies have shown that climate change significantly affects tasar silkworm physiology and rearing ecology. Elevated temperatures and humidity have been associated with increased prevalence of diseases such as grasserie and flacherie. Irregular rainfall patterns, prolonged droughts, and changing photoperiods also influence diapause behavior, larval development, cocoon formation, and emergence patterns.

At the same time, certain tasar ecoraces possess adaptive mechanisms enabling them to tolerate environmental stressors. Traits such as thermotolerance, diapause flexibility, metabolic adaptation,

stress-responsive gene regulation, and host plant plasticity contribute to ecological resilience (Prabhu *et al.*, 2026). Modern molecular approaches including SNP & SSR markers, RAPD-SCAR systems, genome sequencing, transcriptomics, and multi-omics technologies are now facilitating identification of climate-resilient germplasm and stress-responsive genes (Alam *et al.*, 2024).

In this context, understanding the climate resilience and adaptive potential of tasar silkworm ecoraces has become increasingly important for sustainable sericulture development. Conservation and scientific utilization of indigenous ecoraces can support climate adaptation strategies, enhance silk productivity, and strengthen livelihood resilience among forest-dependent communities (Prabhu *et al.*, 2026; Sandhya *et al.*, 2026).

This chapter aims to examine the diversity and ecological distribution of tasar silkworm ecoraces and to analyze the impacts of climate change on tasar sericulture. It further explores the physiological, ecological, and genetic mechanisms underlying climate resilience in different ecoraces, with special emphasis on adaptive traits and environmental tolerance. In addition, the chapter discusses recent advances in genomics, molecular biology, and breeding approaches that contribute to the development of climate-resilient silkworm strains. Finally, it highlights the importance of biodiversity conservation, indigenous knowledge systems, and climate-smart sericultural practices for ensuring the sustainability and long-term resilience of tasar sericulture under changing climatic conditions.

9.2. BIOLOGY AND DIVERSITY OF TASAR SILKWORM ECORACES

9.2.1 Taxonomy, Distribution and Biological Characteristics of Tasar Silkworm

The tropical tasar silkworm, *Antheraea mylitta* Drury, belongs to the order Lepidoptera and family Saturniidae, a group comprising several economically important wild silk-producing moths. Unlike the fully domesticated mulberry silkworm (*Bombyx mori*), *A. mylitta* is considered a semi-domesticated or wild silkworm species that is primarily reared under outdoor forest conditions. The species is indigenous to India and forms the backbone of tropical tasar silk production, particularly in the tribal and forest-dominated regions of central and eastern India (Alam *et al.*, 2024). Tasar silk produced by *A. mylitta* is characterized by its coppery-brown color, coarse texture, durability, high tensile strength, and natural sheen, making it highly valued in the textile and handicraft industries (Jolly et al., 1974).

India occupies a unique position in global sericulture because it is the only country producing all major commercial silks, including mulberry, tasar, eri, and muga silk. Among these, tropical tasar silk has substantial ecological and socio-economic importance because it is intimately associated with forest ecosystems and the livelihoods of indigenous tribal communities. Tropical tasar culture is predominantly practiced in Jharkhand, Chhattisgarh, Odisha, Maharashtra, Madhya Pradesh, West Bengal, Telangana, and parts of Uttar Pradesh. The silkworm is generally reared on naturally growing or cultivated host plants such as *Terminalia arjuna* (Arjun), *Terminalia tomentosa* (Asan), and *Shorea robusta* (Sal), which provide suitable foliage for larval development.

The life cycle of *A. mylitta* consists of four distinct stages: egg, larva, pupa, and adult moth. The larval stage is economically most important because it directly influences cocoon formation and silk production. Larvae undergo five instars before spinning cocoons. The duration of each developmental stage varies considerably depending upon environmental conditions such as temperature, humidity, rainfall, photoperiod, and host plant quality. Since the silkworm is ectothermic, its metabolism, feeding efficiency, growth rate, reproduction, and survival are strongly influenced by climatic conditions.

Voltinism in *A. mylitta* differs among geographical populations and ecological regions. Univoltine, bivoltine, and trivoltine forms have been reported depending upon climatic suitability and local adaptation. In many tropical regions, bivoltine and trivoltine races are more common because favourable environmental conditions permit multiple generations annually. Seasonal synchronization between larval emergence and host plant leaf availability represents an important ecological adaptation ensuring survival under natural conditions.

The species also exhibits remarkable ecological plasticity. Different populations have adapted to diverse climatic conditions ranging from humid tropical forests to relatively dry deciduous ecosystems. Such adaptation has resulted in the evolution of distinct ecoraces possessing characteristic morphological, physiological, behavioural, and genetic traits. These ecoraces represent valuable reservoirs of adaptive genetic variability that can be utilized for breeding climate-resilient silkworm strains.

9.2.2 Concept and Significance of Ecoraces in Tasar Silkworm

The term "ecorace" refers to geographically isolated populations of a species that have evolved distinct adaptive characteristics in response to local environmental conditions. In the case of *Antheraea mylitta*, ecoraces are differentiated on the basis of ecological distribution, host plant preference, voltinism, cocoon characteristics, larval morphology, behaviour, and climatic adaptation. India possesses one of the richest repositories of tropical tasar ecoraces in the world, making the species an important model for ecological adaptation and evolutionary diversification.

More than forty ecoraces of *A. mylitta* have been identified from different forest ecosystems across India. These ecoraces are distributed in varying agro-climatic regions characterized by differences in temperature, humidity, rainfall patterns, altitude, vegetation, and photoperiod. Geographic isolation, natural selection, and ecological pressures have contributed to the evolution of specialized adaptive traits among these populations.

The significance of tasar ecoraces extends beyond biodiversity conservation. Ecoraces serve as important genetic resources for improving productivity, stress tolerance, disease resistance, and climate resilience in tasar sericulture (Prabhu *et al.*, 2026). Because each ecorace has evolved under unique environmental conditions, they collectively provide a broad genetic base that enhances the adaptive capacity of the species under changing climatic scenarios (Jolly *et al.*, 1974).

Certain ecoraces demonstrate greater tolerance to high temperatures, irregular rainfall, or drought conditions, whereas others exhibit better adaptation to humid forest environments. Some races possess superior cocoon quality and shell weight, while others display enhanced resistance to pathogens and predators. Such variability is highly valuable for breeding programs aimed at developing climate-resilient and high-yielding silkworm strains.

The Central Tasar Research and Training Institute (CTRTI), Ranchi, has undertaken conservation and breeding programs focusing on important ecoraces such as Daba, Modal, Raily, and Laria. These efforts aim to conserve indigenous genetic diversity while simultaneously enhancing productivity and adaptive potential through selective breeding.

9.2.3 Major Tasar Ecoraces and Their Adaptive Characteristics

Several economically and ecologically important ecoraces of *A. mylitta* are distributed across different regions of India. Each ecorace exhibits characteristic adaptive features associated with local ecological conditions. Table 1 list the major tasar ecoraces and their key features.

Daba Ecorace

The Daba ecorace is one of the most commercially exploited and extensively cultivated tropical tasar races. It is widely distributed in Jharkhand and neighbouring regions and is considered highly adaptable to diverse climatic conditions. Daba exhibits bivoltine and trivoltine forms and is known for its relatively stable cocoon production, superior shell weight, and broad environmental tolerance. Due to its economic importance, several improved Daba lines such as Double Laying Silk Daba (DLSD), Plus Laying Silk Daba (PLSD), and Average Laying Silk Daba (ALSD) have been developed through selective breeding programs.

Sukinda Ecorace

The Sukinda ecorace is mainly distributed in Odisha and is adapted to humid forest ecosystems dominated by *Shorea robusta*. This race exhibits moderate cocoon productivity and better adaptation to high humidity conditions. However, comparatively lower genetic diversity has been reported in Sukinda populations.

Modal Ecorace

Modal is predominantly found in Odisha and neighbouring forest regions. It is generally univoltine and exhibits strong ecological adaptation to deciduous forest ecosystems. Modal populations possess relatively stable seasonal synchronization with host plant phenology and environmental conditions.

Raily Ecorace

The Raily ecorace is distributed mainly in Chhattisgarh and adjoining regions. It is ecologically important because of its adaptation to semi-arid and drought-prone environments. The race is regarded as a potentially valuable genetic resource for climate-resilient breeding programs.

Bhandara Ecorace

The Bhandara ecorace from Maharashtra has shown high levels of genetic polymorphism in molecular studies. This indicates substantial adaptive variability and evolutionary divergence. Such genetic richness may contribute to enhanced resilience under changing environmental conditions.

Andhra Local Ecorace

The Andhra Local race is distributed in the warmer climatic regions of Telangana and exhibits adaptation to elevated temperature conditions. It is generally trivoltine and demonstrates relatively rapid larval development under tropical environments.

Sarihan and Laria Ecoraces

Sarihan and Laria races are important from the conservation perspective because they represent localized genetic resources adapted to specific ecological niches. Recent conservation initiatives in Jharkhand have emphasized in-situ preservation of Sarihan populations through community-based approaches and forest conservation strategies.

Table 1. Major Tasar Silkworm Ecoraces and Their Adaptive Features

Ecorace	Geographic Distribution	Voltinism	Major Host Plants	Important Adaptive Traits
Daba	Jharkhand	Bi/Trivoltine	Arjun, Asan	Broad climatic adaptability
Sukinda	Odisha	Bivoltine	Sal	Humidity tolerance

Ecorace	Geographic Distribution	Voltinism	Major Host Plants	Important Adaptive Traits
Modal	Odisha	Univoltine	Asan	Seasonal synchronization
Raily	Chhattisgarh	Bivoltine	Arjun	Drought adaptation
Bhandara	Maharashtra	Bivoltine	Arjun	High genetic polymorphism
Andhra Local	Telangana	Trivoltine	Arjun	Heat tolerance
Sarihan	Jharkhand	Univoltine	Sal	Ecological specialization
Laria	Jharkhand	Bivoltine	Asan	Forest ecosystem adaptation

9.2.4 Ecological Adaptation and Environmental Plasticity

One of the most remarkable biological features of tasar silkworm ecoraces is their ecological plasticity. Different populations have evolved adaptive responses that allow survival under variable environmental conditions. Such ecological adaptation is influenced by natural selection, host plant interactions, climatic pressures, and geographical isolation.

Environmental factors such as temperature, humidity, rainfall, and photoperiod strongly affect silkworm physiology and development. Climatic adaptation among ecoraces is reflected in larval feeding behaviour, growth rate, cocoon spinning, diapause regulation, and adult emergence patterns. For example, ecoraces inhabiting warmer regions tend to exhibit enhanced thermotolerance and faster developmental rates, whereas races distributed in humid forest ecosystems may show improved tolerance to moisture-related stresses.

Diapause is another important adaptive mechanism observed in tasar silkworms. It enables the species to survive unfavourable environmental conditions such as drought, low temperature, or scarcity of host plant foliage. Climatic factors including temperature and photoperiod regulate diapause induction and termination. Environmental synchronization of diapause ensures successful completion of the life cycle under fluctuating climatic conditions.

Host plant adaptation also plays a crucial role in ecological resilience. Different ecoraces exhibit varying degrees of preference and feeding efficiency on specific host plants. Variability in nutritional quality, leaf chemistry, and moisture content of host plants influences larval performance, cocoon quality, and survival rates (Prabhu *et al.*, 2026). Therefore, adaptation to local host plant species contributes significantly to the ecological success of different tasar populations.

9.2.5 Genetic Diversity and Molecular Characterization of Tasar Ecoraces

Genetic diversity forms the foundation of adaptive evolution and climate resilience in biological systems. In *Antheraea mylitta*, substantial genetic variability exists both within and among ecoraces, enabling the species to survive under diverse ecological conditions. Molecular characterization of tasar populations has therefore become essential for conservation, breeding, and climate adaptation studies (Nagaraju J. 2002; Alam *et al.*, 2024; Prabhu *et al.*, 2026).

Early molecular investigations using RAPD and ISSR markers demonstrated significant polymorphism among tasar ecoraces. Vijayan *et al.* (2005) reported considerable inter- and intra-population genetic variability, indicating evolutionary divergence among geographically isolated populations. Subsequent studies employing SSR markers provided more detailed insights into population structure and phylogenetic relationships. Renuka and Shamitha (2016) analyzed genetic

diversity among several tropical tasar ecoraces using microsatellite markers and observed substantial polymorphism across populations. Among the studied populations, Bhandara exhibited the highest polymorphism level, while Andhra Local and Sukinda populations showed comparatively lower variability. Cluster analysis grouped populations into distinct phylogenetic clades, demonstrating ecological and evolutionary differentiation.

Molecular marker systems such as RAPD-SCAR have also been utilized to identify economically important traits including shell weight and thermotolerance. Recent studies reported the development of molecular markers linked to heat tolerance and productivity traits in Daba lines, highlighting their importance in climate-resilient breeding programs.

Advances in genomics have further transformed research on tasar silkworm adaptation. Draft genome assemblies and whole-genome sequencing of *A. mylitta* have enabled identification of genes associated with stress response, metabolism, immunity, diapause regulation, and environmental adaptation. Comparative genomic analyses have revealed closer evolutionary relationships between *A. mylitta* and other wild silkmoths such as *Antheraea yamamai*. Mitochondrial DNA markers, particularly cytochrome *b* gene analysis, have proven useful in DNA barcoding and identification of region-specific ecoraces (Ray *et al.*, 2024). Such molecular tools provide valuable information for biodiversity conservation, phylogenetic analysis, and germplasm management.

Recent studies integrating genomics, transcriptomics, proteomics, and metabolomics have opened new possibilities for understanding adaptive mechanisms in tasar silkworms. Multi-omics approaches facilitate identification of stress-responsive pathways, adaptive gene networks, and molecular signatures associated with climate resilience (Prabhu *et al.*, 2026). These technologies are expected to play a major role in developing climate-smart sericulture systems in the future.

9.2.6 Importance of Conserving Tasar Ecoracial Diversity

Conservation of tasar ecoraces is essential for maintaining ecological stability, evolutionary potential, and long-term sustainability of sericulture. Rapid environmental changes, deforestation, habitat fragmentation, climate variability, and anthropogenic disturbances pose serious threats to indigenous tasar germplasm (Waldvogel *et al.*, 2020; Prabhu *et al.*, 2025).

Loss of ecoracial diversity may reduce the adaptive capacity of the species and increase vulnerability to climatic stress, diseases, and ecological disturbances. Therefore, both in situ and ex situ conservation strategies are necessary for preserving valuable genetic resources. Forest conservation, establishment of germplasm banks, molecular characterization, and community-based conservation initiatives represent important approaches for safeguarding indigenous tasar populations.

Recent conservation programs in regions such as Jharkhand and the Similipal Biosphere Reserve have emphasized habitat protection, biodiversity monitoring, and sustainable forest management (Alam *et al.*, 2024). Such initiatives not only preserve ecological diversity but also support the livelihoods of tribal communities dependent on tasar culture.

The integration of molecular genetics, genomics-assisted conservation, and traditional ecological knowledge can significantly strengthen future conservation programs. Climate-resilient tasar sericulture ultimately depends upon preserving the rich diversity of ecoraces that constitute the adaptive and evolutionary foundation of the species (Waldvogel *et al.*, 2020).

9.3. CLIMATE CHANGE AND TASAR SERICULTURE

Climate change has emerged as one of the most critical environmental challenges affecting agricultural and forest-based production systems worldwide. Rising global temperatures, altered

rainfall patterns, prolonged droughts, increased frequency of extreme weather events, and ecological disturbances have significantly influenced biodiversity, ecosystem functioning, and rural livelihoods (Kitching *et al.*, 2018). Insect-based industries such as sericulture are particularly vulnerable because insects are highly sensitive to environmental fluctuations. The tropical tasar silkworm, *Antheraea mylitta* Drury, being an ectothermic organism reared predominantly under outdoor conditions, is profoundly influenced by climatic variability and ecological instability (Sandhya *et al.*, 2026).

Tasar sericulture is largely dependent on forest ecosystems and perennial host plants such as *Terminalia arjuna*, *Terminalia tomentosa*, and *Shorea robusta*. Unlike controlled indoor silkworm rearing systems, tasar culture is practiced under natural environmental conditions where silkworms are directly exposed to changing weather patterns. Consequently, fluctuations in temperature, humidity, rainfall, wind velocity, and photoperiod substantially affect silkworm growth, cocoon productivity, disease incidence, and survival rates. Climate-induced disturbances in host plant phenology and forest ecology further intensify production risks.

The Intergovernmental Panel on Climate Change (IPCC) has emphasized that global surface temperatures have already risen by approximately 1.1°C above pre-industrial levels, and continued greenhouse gas emissions are likely to intensify climatic extremes in the coming decades (IPCC, 2023). Such environmental changes pose serious threats to the sustainability of non-mulberry sericulture systems, particularly in ecologically fragile and tribal-dominated forest regions.

9.3.1. Influence of Climatic Factors on Tasar Silkworm Biology

Environmental parameters play a decisive role in regulating the physiological and developmental processes of tasar silkworms. Temperature, humidity, rainfall, and photoperiod collectively influence feeding behavior, larval growth, cocoon spinning, pupal development, diapause, adult emergence, and reproductive performance (Sandhya *et al.*, 2026). Table 2 shows the major climatic factors that affect tasar silkworm productivity and Table 3 list the impact of climate change on tasar silk production ecosystem.

9.3.1.1 Temperature

Temperature is one of the most important abiotic factors affecting tasar silkworm biology. Since *A. mylitta* is an ectothermic insect, its body temperature and metabolic activities are regulated by surrounding environmental conditions. Moderate temperatures support optimum larval growth and cocoon formation, whereas excessive heat or sudden temperature fluctuations may cause physiological stress, reduced feeding efficiency, metabolic imbalance, and mortality. Elevated temperatures have been associated with shortened larval duration, reduced cocoon weight, poor shell ratio, and increased susceptibility to diseases. Heat stress also affects endocrine regulation and enzymatic activities involved in silk protein synthesis. Sharma *et al.* (2020) reported strong positive correlations between elevated temperatures and the occurrence of silkworm diseases such as grasserie and flacherie under subtropical conditions.

Excessively high temperatures may also disrupt synchronization between silkworm life cycles and host plant phenology. Such mismatches adversely affect larval nutrition and cocoon productivity. Conversely, moderate warming in some temperate regions may temporarily extend growing seasons and support increased biomass production of host plants. However, the overall impact of climate warming on tasar sericulture is predominantly negative in tropical and semi-arid ecosystems.

9.3.1.2. Relative Humidity

Relative humidity significantly influences larval physiology, feeding activity, cocoon spinning, and disease incidence. Tasar silkworms require optimum humidity levels for successful growth and development. High humidity conditions often favour proliferation of pathogenic microorganisms including bacteria, fungi, and viruses, thereby increasing disease outbreaks. Studies have shown that excessive humidity combined with elevated temperatures creates highly favourable conditions for grasserie, virosis, and fungal infections in silkworm populations. Low humidity, on the other hand, may lead to desiccation stress, reduced larval feeding, poor cocoon formation, and increased mortality. Humidity also affects host plant physiology by influencing leaf moisture content, nutritional quality, and secondary metabolite composition. Therefore, climatic changes altering atmospheric moisture levels indirectly affect tasar productivity through host plant interactions (Bhatia *et al.*, 2014).

9.3.1.3. Rainfall and Drought

Rainfall patterns play a vital role in maintaining host plant growth and forest ecosystem stability essential for tasar culture. Erratic rainfall distribution, delayed monsoons, excessive precipitation, and prolonged droughts have become increasingly common under changing climatic scenarios. Such disturbances significantly affect silkworm rearing cycles and cocoon production. Adequate rainfall promotes vegetative growth and leaf production in host plants, thereby ensuring sufficient nutritional resources for larvae. However, excessive rainfall may physically damage larvae and cocoons, wash away eggs, and increase disease incidence due to persistent moisture conditions. Waterlogging and prolonged wet conditions also negatively affect host plant health and leaf quality.

Drought conditions pose even greater challenges to tasar sericulture. Reduced soil moisture adversely affects host plant growth, leaf succulence, and nutrient composition, resulting in poor larval nutrition and reduced cocoon yield. Drought stress also weakens forest ecosystems and increases vulnerability to pests and diseases. Gedam *et al.* (2023) reported that nearly 75% of tasar farmers in Maharashtra perceived climate change as a major factor responsible for declining silkworm productivity. Farmers identified erratic rainfall, prolonged droughts, and rising temperatures as key constraints affecting cocoon production and silkworm survival.

Table 2. Major Climatic Factors and Their Effects on Tasar Sericulture

Climatic Factor	Effect on Silkworm	Effect on Host Plant	Overall Impact on Sericulture
Rising Temperature	Heat stress, reduced larval survival, poor cocoon quality, increased disease incidence	Leaf scorching, reduced moisture content	Decline in cocoon yield and silk productivity
Irregular Rainfall	Disturbed larval development, mortality during rearing	Altered leaf flushing and growth	Crop instability and seasonal uncertainty
High Humidity	Increased fungal and viral diseases	Increased pathogen load on foliage	Higher crop loss due to disease outbreaks
Low Humidity / Drought	Desiccation stress, reduced feeding activity	Poor leaf quality and biomass reduction	Reduced cocoon formation
Extreme Weather Events	Physical damage to larvae and cocoons	Forest degradation and host plant loss	Severe economic losses
Altered Photoperiod	Disturbed diapause and emergence patterns	Indirect effects on plant phenology	Asynchrony between host plant and silkworm

9.3.2. Climate Change and Host Plant Dynamics

The success of tasar sericulture is closely linked to the health and productivity of host plants. Climatic disturbances directly influence host plant distribution, growth, physiology, nutritional quality, and resistance to pests and diseases. Since tasar silkworms depend entirely on host plant foliage during larval development, any adverse effects on host plants ultimately affect cocoon production and silkworm survival. The primary tasar host plants—*Terminalia arjuna*, *T. tomentosa*, and *Shorea robusta*—are predominantly C3 plants whose physiological processes are highly sensitive to climatic variables. Rising atmospheric CO_2 concentrations may enhance photosynthetic efficiency and biomass production under certain conditions. Studies have indicated that elevated CO_2 levels can improve photosynthetic activity and reduce transpiration losses in C3 plants. However, such potential benefits may be offset by increased temperature stress, irregular rainfall, and drought conditions (Long *et al.*, 2006; Sonmez *et al.*, 2023).

Climate-induced changes in host plant phenology may alter the timing of leaf flushing, maturation, and senescence, thereby disrupting synchronization with silkworm developmental stages. Poor synchronization often results in inadequate food availability during critical larval stages, negatively affecting growth and cocoon formation. Deforestation, habitat degradation, and forest fragmentation associated with climate change further reduce availability of host plant resources. Forest fires, invasive species, and ecological disturbances may also threaten the sustainability of host plant ecosystems. Therefore, conservation and climate-resilient management of host plant resources are essential for sustaining tasar sericulture under changing environmental conditions.

9.3.3. Effect of Climate Change on Disease and Pest Incidence

Climate variability significantly influences the epidemiology of silkworm diseases and pest outbreaks. Temperature and humidity fluctuations affect pathogen survival, multiplication, transmission, and host susceptibility. Under favourable environmental conditions, pathogens spread rapidly, leading to severe crop losses. Major diseases affecting tasar silkworms include: **Grasserie, Flacherie, Muscardine, Pebrine, and Virosis**. Among these, grasserie and flacherie are strongly associated with elevated temperature and humidity conditions. Climate stress weakens silkworm immunity and physiological resistance, thereby increasing vulnerability to infections.

In addition to diseases, predators and parasitoids also pose major threats under changing environmental conditions. Uzi fly infestation, predatory insects, ants, birds, and wasps often cause substantial mortality in outdoor tasar rearing systems. Climate-induced ecological imbalances may alter predator-prey relationships and increase pest prevalence. Host plant stress caused by drought or temperature extremes may further reduce silkworm resistance by compromising nutritional quality. Therefore, climate change creates a complex network of interactions involving host plants, silkworms, pathogens, and forest ecosystems (Bhatia *et al.*, 2014).

Table 3. Climate Change Impacts on Different Components of Tasar Ecosystem

Component	Climate-Induced Changes	Consequences
Silkworm Physiology	Metabolic stress, altered growth	Reduced productivity
Host Plant Ecology	Reduced foliage quality and biomass	Nutritional deficiency
Forest Ecosystem	Habitat degradation and fragmentation	Decline in biodiversity
Disease Dynamics	Enhanced pathogen proliferation	Increased crop mortality
Tribal Livelihoods	Reduced cocoon yield and income	Socio-economic vulnerability
Biodiversity	Loss of adaptive ecoraces	Reduced resilience potential

9.3.4. Climate Change and Diapause Regulation

Diapause is a critical adaptive mechanism enabling tasar silkworms to survive unfavourable environmental conditions. Climatic factors such as temperature, rainfall, and photoperiod regulate diapause induction, maintenance, and termination in *A. mylitta*. Studies have shown that warm temperatures and long photoperiods generally favour production of diapausing eggs, whereas cooler conditions promote non-diapausing forms. Environmental changes affecting seasonal cues may therefore disrupt normal diapause cycles and emergence patterns (Tsurumaki *et al.*, 1999 & Takeda *et al.*, 2014). Mazumdar *et al.* (2023) observed substantial variation in adult emergence rates of *A. mylitta* across different months, with optimal emergence occurring during June, July, September, and October when rainfall and humidity conditions were favourable. In contrast, low rainfall and reduced humidity during off-season months significantly reduced emergence rates.

Climate change-induced alterations in seasonal patterns may therefore affect voltinism, reproductive cycles, synchronization with host plants, and overall silkworm population dynamics. Understanding diapause regulation mechanisms is thus essential for developing climate-resilient sericultural strategies.

9.3.5. Socio-Economic Implications of Climate Change on Tasar Sericulture

Tasar sericulture is deeply integrated with the livelihoods, culture, and traditional knowledge systems of tribal communities inhabiting forest regions. Climate-induced declines in cocoon production directly affect household income, employment, food security, and socio-economic stability among vulnerable rural populations. Erratic climatic conditions often result in: crop failure, reduced cocoon yield, increased disease incidence, poor silk quality, and financial losses.

Marginal farmers and tribal rearers are particularly vulnerable because of limited access to irrigation, modern technologies, disease management facilities, and climate adaptation resources. Climate uncertainty also discourages youth participation in traditional sericulture practices, threatening continuity of indigenous knowledge systems. At the same time, tasar sericulture itself contributes positively to climate mitigation through forest conservation, perennial vegetation cover, carbon sequestration, and biodiversity enhancement (Giacomin *et al.*, 2017). Thus, promoting climate-resilient tasar culture can simultaneously support ecological sustainability and rural livelihood resilience.

9.3.6. Need for Climate-Resilient Tasar Sericulture

The increasing vulnerability of tasar sericulture to climatic disturbances necessitates the development of adaptive and climate-smart strategies. Sustainable tasar production under changing climatic conditions requires integration of ecological conservation, resilient germplasm, improved host plant management, disease control, and technological innovations.

Climate resilience in tasar sericulture can be strengthened through:

- conservation of adaptive ecoraces,
- development of thermotolerant silkworm strains,
- genomics-assisted breeding,
- climate-resilient host plant cultivation,
- microclimate management,
- community-based forest conservation,
- and climate forecasting systems.

Recent advances in genomics, transcriptomics, molecular markers, and systems biology provide promising opportunities for understanding stress adaptation and developing resilient silkworm breeds. Integrating scientific innovations with indigenous ecological knowledge may play a crucial role in safeguarding the future sustainability of tasar sericulture.

9.4. CLIMATE RESILIENCE MECHANISMS IN TASAR SILKWORM ECORACES

The remarkable ecological adaptability of *Antheraea mylitta* ecoraces reflects their evolutionary responses to diverse environmental conditions prevailing across different forest ecosystems of India. Climate resilience in tasar silkworms is a multifaceted phenomenon involving physiological, biochemical, behavioural, ecological, and genetic mechanisms that collectively enable survival under fluctuating environmental conditions. Since tasar silkworms are reared outdoors and directly exposed to climatic variability, adaptive resilience becomes essential for sustaining growth, reproduction, cocoon formation, and population continuity (Prabhu *et al.*, 2026; Sandhya *et al.*, 2026).

Different tasar ecoraces have evolved distinct adaptive traits in response to local climatic pressures such as high temperature, drought, irregular rainfall, humidity fluctuations, and seasonal variations. These adaptive mechanisms not only support survival under environmental stress but also contribute to maintaining cocoon productivity and ecological stability. Understanding such resilience mechanisms is increasingly important in the context of global climate change and the development of climate-smart sericulture systems.

Recent advances in molecular biology, genomics, transcriptomics, proteomics, and physiological studies have significantly improved our understanding of stress adaptation in tasar silkworms. Climate resilience mechanisms operate at multiple biological levels, including metabolic regulation, diapause control, immune response, stress-responsive gene expression, host plant interactions, and ecological synchronization.

9.4.1 Physiological Mechanisms of Climate Resilience

Physiological adaptation constitutes one of the primary mechanisms enabling tasar silkworms to survive under stressful environmental conditions. Climatic stressors such as heat, drought, and humidity fluctuations directly affect metabolic activities, enzyme functions, hormonal balance, respiration, water regulation, and nutrient assimilation in silkworm larvae. Table 4 list the physiological mechanisms contributing to climate resilience in tasar ecoraces

9.4.1.1. Thermotolerance and Heat Stress Regulation

Temperature regulation is critical for maintaining physiological stability in ectothermic organisms like silkworms. Certain tasar ecoraces possess enhanced thermotolerance that allows them to survive under elevated temperature conditions. Heat-tolerant races exhibit improved metabolic flexibility, cellular protection mechanisms, and stress-responsive biochemical pathways. Under heat stress, silkworms activate physiological defense systems including: synthesis of heat shock proteins (HSPs), antioxidant enzyme activation, membrane stabilization, and metabolic adjustments (Prabhu *et al.*, 2026).

Heat shock proteins act as molecular chaperones that protect cellular proteins from denaturation and oxidative damage during thermal stress. Antioxidant defense mechanisms involving catalase, superoxide dismutase, and peroxidases help neutralize reactive oxygen species generated under stress conditions. Sahoo *et al.* (2015) observed variations in oxidative stress and antioxidant protection between diapause and non-diapause groups of *A. mylitta*, indicating physiological

adaptation associated with environmental stress tolerance. Ecoraces adapted to warmer regions such as Andhra Local and certain Daba strains may possess enhanced thermotolerance due to long-term exposure to high ambient temperatures. Such adaptive physiological traits are highly valuable for breeding climate-resilient silkworm lines.

9.4.1.2. Water Balance and Desiccation Resistance

Water regulation is another crucial aspect of climate resilience in tasar silkworms. Drought conditions and low humidity can cause severe desiccation stress leading to reduced feeding activity, impaired metabolism, and larval mortality. Adapted ecoraces maintain water balance through: reduced transpiration, efficient cuticular protection, metabolic water conservation, and behavioral adjustments. Larvae exposed to dry conditions often exhibit reduced activity and altered feeding patterns to minimize water loss. Some ecoraces may also exhibit enhanced tolerance to dehydration through physiological regulation of osmotic balance and cellular hydration. Such desiccation resistance becomes particularly important in drought-prone tasar-growing regions where climate change has intensified water scarcity and forest degradation.

9.4.1.3. Metabolic Plasticity

Metabolic plasticity refers to the ability of organisms to alter metabolic pathways in response to environmental stress. Tasar silkworms exhibit remarkable metabolic adjustments under fluctuating climatic conditions. Environmental stress may induce: altered carbohydrate metabolism, lipid mobilization, protein turnover, and energy redistribution. These metabolic responses support survival during unfavourable conditions and help maintain developmental stability. Climatic adaptation often involves optimization of energy utilization efficiency, particularly during diapause and nutrient stress.

Recent multi-omics approaches have identified metabolic pathways associated with stress adaptation in non-mulberry silkworms. Such findings provide important insights into the molecular basis of climate resilience.

Table 4. Physiological Mechanisms Contributing to Climate Resilience in Tasar Ecoraces

Physiological Mechanism	Function Under Stress	Adaptive Significance
Heat Shock Protein Synthesis	Protection of cellular proteins	Thermotolerance
Antioxidant Enzyme Activation	Reduction of oxidative damage	Stress survival
Metabolic Plasticity	Energy optimization	Developmental stability
Water Conservation Mechanisms	Prevention of desiccation	Drought adaptation
Hormonal Regulation	Developmental synchronization	Environmental adaptation
Diapause Regulation	Survival during unfavourable periods	Seasonal resilience

9.4.2. Behavioural and Ecological Adaptations

Behavioural adaptation plays an important role in enabling tasar silkworms to cope with changing environmental conditions. Since *A. mylitta* is reared under natural forest conditions, behavioural flexibility contributes significantly to ecological resilience.

9.4.2.1. Feeding Behaviour and Host Plant Selection

Different ecoraces exhibit variability in feeding efficiency, host plant preference, and feeding rhythms under varying climatic conditions. During periods of heat stress or reduced humidity, larvae may alter feeding schedules to cooler periods of the day to minimize physiological stress.

Host plant selection also represents an important adaptive strategy. Certain ecoraces exhibit better feeding efficiency and survival on specific host plants such as *Terminalia arjuna*, *T. tomentosa*, or *Shorea robusta*. Variability in host plant utilization contributes to ecological specialization and local adaptation. Nutritional quality of host plants strongly influences larval growth, immunity, cocoon quality, and stress tolerance. Therefore, adaptation to local host plant resources forms an integral component of climate resilience.

9.4.2.2. Seasonal Synchronization and Phenological Adaptation

Synchronization between silkworm life cycles and environmental conditions is essential for successful survival and reproduction. Tasar ecoraces have evolved seasonal adaptations that ensure larval emergence coincides with availability of tender host plant foliage.

Climate-induced disturbances in rainfall and temperature patterns may disrupt such synchronization. However, resilient ecoraces exhibit greater flexibility in adjusting developmental timing and emergence patterns according to environmental conditions. Mazumdar *et al.* (2023) reported significant seasonal variation in adult emergence rates of *A. mylitta* associated with rainfall, humidity, and temperature conditions. Such phenological plasticity represents an important adaptive mechanism under climate variability.

9.4.2.3. Diapause as a Survival Strategy

Diapause is among the most important ecological adaptations observed in tasar silkworms. It enables survival during unfavourable climatic conditions such as drought, low temperature, or scarcity of host plants. Environmental cues regulating diapause include: temperature, photoperiod, humidity, and seasonal changes. Takeda *et al.* (2014) highlighted the role of molecular regulators including cyclin kinase inhibitors and paralytic peptides in diapause regulation. Climate-resilient ecoraces often exhibit flexible diapause behavior that enhances survival under unstable environmental conditions (Tsurumaki *et al.*, 1999).

9.4.3. Genetic and Molecular Basis of Climate

Genetic diversity forms the evolutionary foundation of climate adaptation in tasar silkworms. Different ecoraces possess distinct genetic architectures that influence stress tolerance, metabolism, immunity, development, and ecological adaptation. Table 5 in brief describes the genetic and molecular mechanism of resilience in tasar ecoraces.

Molecular studies using RAPD, ISSR, SSR, SCAR, and mitochondrial markers have demonstrated substantial genetic differentiation among tasar ecoraces. Vijayan *et al.* (2005) and Renuka and Shamitha (2016) reported considerable polymorphism and phylogenetic divergence among populations from different ecological regions.

Climate resilience is strongly associated with expression of stress-responsive genes regulating: heat tolerance, antioxidant defense, immunity, metabolic adaptation, and diapause regulation (Prabhu *et al.*, 2026). Recent genomic investigations have enabled identification of candidate genes involved in environmental adaptation. Transcriptomic studies have revealed differential expression of stress-associated pathways under temperature and humidity stress conditions. Prabhu *et al.* (2023) applied RAPD-SCAR markers to identify thermotolerant tasar lines, demonstrating the utility of molecular tools in climate-resilient breeding.

9.4.4. Genomics and Whole Genome Sequencing

Whole genome sequencing has significantly advanced understanding of adaptive evolution in *A. mylitta*. Hybrid sequencing approaches integrating PacBio and Illumina technologies generated the first comprehensive genome assembly of a non-mulberry silkworm species. Genome sequencing facilitates identification of adaptive genes, analysis of structural variation, mapping of quantitative trait loci, and molecular breeding for stress tolerance (Waldvogel *et al.*, 2020). Comparative genomic analyses revealed greater similarity between *A. mylitta* and *Antheraea yamamai* than with *Bombyx mori*, reflecting evolutionary adaptation among wild silkmoths.

9.4.4.1. Role of Molecular Markers in Climate-Resilient Breeding

Molecular markers provide powerful tools for identifying adaptive genetic variation among tasar populations. SNP, SSR, ISSR, RAPD-SCAR, and mitochondrial markers are increasingly utilized for genetic diversity analysis, germplasm characterization, conservation planning, and marker-assisted selection. Ray *et al.* (2024) demonstrated the usefulness of cytochrome *b* gene analysis for DNA barcoding and identification of regional ecoraces. Such tools facilitate precise identification and conservation of adaptive germplasm resources.

Table 5. Molecular and Genetic Mechanisms of Climate Resilience in Tasar Silkworms

Mechanism	Role in Adaptation	Application
Heat Shock Protein Genes	Cellular protection under heat stress	Thermotolerance breeding
Antioxidant Pathways	Oxidative stress reduction	Stress survival
SNP, SSR and ISSR Markers	Genetic diversity analysis	Conservation and breeding
RAPD-SCAR Markers	Trait-linked identification	Marker-assisted selection
Genome Sequencing	Identification of adaptive genes	Genomics-assisted breeding
Transcriptomics	Gene expression analysis	Understanding stress responses

9.4.5. Role of Host Plant Interactions in Climate Resilience

Host plants form an integral component of tasar silkworm adaptation and resilience. Nutritional quality, moisture content, phytochemical composition, and ecological stability of host plants directly influence silkworm physiology and productivity.

Different ecoraces exhibit varying degrees of adaptation to specific host plants. Such specialization enhances ecological fitness under local environmental conditions. Climatic stress affecting host plants indirectly influences: larval nutrition, cocoon quality, disease resistance, and developmental stability. Molecular studies on host plants such as *Terminalia arjuna* have revealed significant genetic diversity associated with environmental adaptation. Sarwat *et al.* (2011) utilized AFLP and SAMPL markers to characterize genetic diversity in *T. arjuna*, emphasizing its importance in sustainable tasar sericulture. Climate-resilient host plant management therefore constitutes a critical component of sustainable tasar production systems.

9.4.6. Integrated Climate Resilience in Tasar Sericulture

Climate resilience in tasar sericulture is ultimately the result of integrated interactions among: silkworm genetics, physiological adaptation, ecological synchronization, host plant dynamics, and environmental management. The adaptive diversity present among tasar ecoraces represents a valuable biological resource for sustaining sericulture under changing climatic conditions.

Conservation and scientific utilization of this diversity are essential for ensuring long-term ecological stability and livelihood security (Sandhya *et al.*, 2026).

Modern approaches integrating genomics-assisted breeding, conservation biology, agroforestry, climate-smart rearing, and indigenous knowledge systems can substantially strengthen the adaptive capacity of tasar sericulture systems (Batley & Edwards, 2016). Future research focusing on multi-omics integration, stress physiology, conservation genomics, and precision sericulture will play a major role in developing resilient silkworm strains capable of withstanding future climatic challenges.

9.5. ROLE OF BIODIVERSITY AND INDIGENOUS KNOWLEDGE IN CLIMATE-RESILIENT TASAR SERICULTURE

Biodiversity and indigenous knowledge constitute two of the most important pillars supporting the sustainability and climate resilience of tasar sericulture. The tropical tasar ecosystem is deeply interconnected with forest biodiversity, ecological stability, and traditional tribal practices that have evolved over centuries through continuous interaction with natural environments (Bhatia *et al.*, 2014). Unlike intensive monoculture-based agricultural systems, tasar sericulture depends upon a biologically diverse forest ecosystem involving silkworms, host plants, associated flora and fauna, microbial communities, and indigenous management practices (Sandhya *et al.*, 2026). This ecological complexity enhances resilience against climatic disturbances and contributes significantly to sustainable silk production. Table 6 list the role biodiversity plays in climate resilient tasar sericulture.

The rich diversity of tasar silkworm ecoraces distributed across different ecological regions of India represents an invaluable genetic reservoir for climate adaptation (Sandhya *et al.*, 2026). Simultaneously, indigenous tribal communities possess extensive traditional ecological knowledge regarding silkworm behavior, seasonal cycles, host plant management, forest conservation, and disease management. Such knowledge systems often function as natural climate adaptation strategies and play a critical role in maintaining ecological balance under changing environmental conditions.

In recent years, increasing recognition has been given to the integration of biodiversity conservation and indigenous knowledge into climate-resilient agricultural systems. In tasar sericulture, conservation of genetic diversity and preservation of traditional ecological wisdom are essential not only for sustaining silk productivity but also for strengthening livelihood resilience among forest-dependent communities.

9.5.1. Importance of Biodiversity in Tasar Sericulture

Biodiversity forms the ecological foundation of tasar sericulture. The sustainability of tasar production depends upon interactions among diverse biological components including: silkworm ecoraces, host plant species, forest vegetation, microorganisms, pollinators, predators, and associated ecosystem organisms (Bhatia *et al.*, 2014). This biological diversity enhances ecosystem stability, improves adaptive capacity, and reduces vulnerability to climatic stress.

9.5.1.1. Diversity of Tasar Ecoraces as Adaptive Genetic Resources

The presence of multiple ecoraces of *Antheraea mylitta* across India provides substantial genetic variability necessary for climate adaptation. Different ecoraces possess unique adaptive traits associated with thermotolerance, humidity tolerance, drought resistance, diapause behavior, disease resistance, and ecological synchronization. Such adaptive diversity increases the resilience potential

of the species under changing climatic conditions. Loss of ecoracial diversity may significantly reduce the capacity of tasar populations to respond to environmental stress (Prabhu *et al.*, 2026).

Molecular studies have demonstrated considerable genetic differentiation among tasar ecoraces using RAPD, ISSR, SSR, and mitochondrial markers. These findings highlight the evolutionary significance of biodiversity conservation in maintaining climate resilience. Conservation programs initiated by the Central Tasar Research and Training Institute (CTRTI), Ranchi, have emphasized preservation of important ecoraces such as Modal, Raily, and Sarihan due to their ecological and adaptive significance (Prabhu *et al.*, 2025; Prabhu *et al.*, 2026).

9.5.1.2. Host Plant Biodiversity and Ecosystem Stability

Host plant diversity is another critical component of tasar ecosystem resilience. Major host plants such as *Terminalia arjuna*, *T. tomentosa*, and *Shorea robusta* not only provide nutrition for silkworm larvae but also contribute to ecological sustainability through carbon sequestration, soil conservation, water retention, and biodiversity support.

Agroforestry-based tasar systems involving mixed vegetation are generally more resilient to climatic disturbances than monoculture systems. Diverse forest ecosystems provide ecological buffering against drought, temperature extremes, pest outbreaks, and habitat degradation. Host plant biodiversity also improves nutritional diversity available to silkworms, thereby supporting physiological adaptation and disease resistance. Climatic variability affecting one host plant species may be compensated by alternative host resources within biodiverse ecosystems. Sarwat *et al.* (2011) demonstrated substantial genetic diversity in *Terminalia arjuna*, emphasizing its importance for sustainable tasar sericulture and climate adaptation.

Table 6. Role of Biodiversity in Climate-Resilient Tasar Sericulture

Biodiversity Component	Ecological Function	Contribution to Climate Resilience
Tasar Ecoraces	Genetic variability	Stress adaptation and survival
Host Plant Diversity	Nutritional support	Ecological buffering
Forest Vegetation	Habitat stabilization	Microclimate regulation
Soil Microorganisms	Nutrient cycling	Improved ecosystem health
Pollinators and Natural Enemies	Ecological balance	Pest regulation
Forest Biodiversity	Ecosystem resilience	Reduced climatic vulnerability

9.5.2. Indigenous Knowledge Systems in Tasar Sericulture

Indigenous tribal communities inhabiting tasar-growing regions possess rich traditional ecological knowledge developed through long-term observation and interaction with forest ecosystems. This indigenous knowledge includes practical understanding of: seasonal climatic patterns, host plant phenology, silkworm behavior, pest and disease occurrence, cocoon harvesting, and forest resource management. Table 7 list the indigenous practices supporting climate resilience in tasar sericulture**.**

Traditional practices often represent highly sustainable and ecologically adaptive management systems that have enabled tribal communities to cope with environmental variability over generations. Traditional tasar rearers possess detailed knowledge regarding:

- selection of suitable host plants,
- timing of brushing,
- seasonal crop scheduling,

- larval protection,
- and cocoon harvesting techniques.

Rearing calendars are generally synchronized with local climatic conditions and host plant phenology. Such synchronization helps optimize larval survival and cocoon productivity under natural environmental conditions. Many tribal rearers adjust rearing schedules according to rainfall patterns, humidity levels, and temperature fluctuations based on indigenous climatic indicators. These adaptive practices reduce exposure of silkworms to unfavourable environmental conditions and disease outbreaks. Traditional methods such as selective pruning of host plants, maintenance of forest vegetation, and rotational utilization of rearing sites also contribute to ecological sustainability.

9.5.2.1. Indigenous Climate Forecasting and Ecological Indicators

Local communities often utilize environmental indicators to predict seasonal climatic changes and plan sericultural activities accordingly. Such indicators may include: flowering patterns, bird migration, insect behaviour, wind direction, cloud formation, and forest phenology. These indigenous forecasting systems assist rearers in anticipating droughts, rainfall variability, and seasonal transitions. Such ecological knowledge becomes increasingly valuable under uncertain climatic conditions where modern forecasting systems may not always reach remote forest communities.

9.5.2.2. Traditional Disease and Pest Management

Indigenous rearers also possess traditional knowledge related to disease prevention and pest management. Common practices include: maintaining proper spacing between larvae, removal of diseased individuals, smoke treatment, use of botanical extracts, and habitat sanitation. Many traditional practices indirectly strengthen climate resilience by reducing environmental stress and improving silkworm health under fluctuating conditions.

9.5.3. Community-Based Conservation and Sustainable Forest Management

Community participation plays a central role in conserving tasar biodiversity and sustaining forest ecosystems. Since tasar sericulture is closely associated with tribal livelihoods, local communities often act as custodians of forest biodiversity and indigenous germplasm resources. Community-based conservation approaches include: protection of host plant forests, conservation of wild silkworm populations, participatory plantation programs, and sustainable cocoon harvesting practices.

Recent conservation initiatives in Jharkhand and Odisha have emphasized in situ conservation of important ecoraces through community participation and forest ecosystem management. Conservation structures such as pagoda systems and conservation nets have been used to preserve indigenous tasar populations and maintain ecological balance. The Similipal Biosphere Reserve represents an important example where biodiversity conservation and sustainable forest management contribute to preservation of tasar habitats. Remote sensing and GIS studies have demonstrated expansion of *Shorea robusta* forest cover in certain protected areas, supporting habitat conservation for tasar silkworms.

9.5.4. Biodiversity Conservation Under Climate Change

Climate change poses significant threats to forest biodiversity and indigenous genetic resources. Rising temperatures, habitat fragmentation, deforestation, forest fires, and ecological disturbances

may lead to: loss of adaptive ecoraces, decline in host plant diversity, disruption of ecological interactions, and erosion of traditional knowledge systems.

Conservation of biodiversity under climate change therefore requires integrated approaches combining molecular characterization, genomics-assisted conservation, habitat restoration, community participation, and policy support. Modern molecular tools including SNP, SSR markers, genome sequencing, and GIS mapping are increasingly utilized for identifying and conserving genetically important tasar populations. Such approaches facilitate targeted conservation of climate-resilient germplasm. At the same time, preserving indigenous knowledge systems is equally important because traditional ecological wisdom provides practical adaptation strategies developed through long-term environmental experience.

Table 7. Indigenous Practices Supporting Climate Resilience in Tasar Sericulture

Indigenous Practice	Ecological Significance	Climate Resilience Benefit
Seasonal crop scheduling	Synchronization with climate	Reduced environmental stress
Mixed forest conservation	Biodiversity maintenance	Ecosystem stability
Host plant management	Sustainable foliage production	Improved larval nutrition
Indigenous weather prediction	Climatic adaptation	Better crop planning
Botanical pest control	Eco-friendly disease management	Reduced crop loss
Rotational rearing practices	Reduced habitat pressure	Sustainable productivity

9.5.5. Integration of Traditional Knowledge and Modern Science

The future sustainability of tasar sericulture depends upon successful integration of indigenous knowledge systems with modern scientific innovations. While molecular biology, genomics, and climate modelling provide advanced technological solutions, traditional ecological knowledge offers locally adapted and field-tested management practices. Integration of both approaches can strengthen climate adaptation, biodiversity conservation, ecosystem management, and livelihood resilience (Kitching *et al.*, 2018).

Climate-smart tasar sericulture should therefore incorporate: genomics-assisted breeding, agroforestry, participatory conservation, indigenous forecasting systems, and community-led forest management. Participatory research involving tribal communities can help document traditional practices and integrate them with scientific interventions. Such collaborative approaches are essential for developing socially inclusive and ecologically sustainable sericulture systems.

9.5.6. Future Perspectives

In the context of climate change, biodiversity conservation and indigenous knowledge will become increasingly important for sustaining tasar sericulture. Future strategies should focus on: conservation genomics, community-based biodiversity management, restoration of degraded host plant forests, documentation of traditional ecological knowledge, and integration of climate forecasting with indigenous adaptation practices.

Strengthening collaborations among researchers, policymakers, forest departments, and tribal communities can substantially improve the resilience and sustainability of tasar production systems. Ultimately, the combined strength of biological diversity and indigenous ecological wisdom provides a powerful foundation for developing climate-resilient tasar sericulture capable of withstanding future environmental challenges.

9.6. STRATEGIES FOR CLIMATE-RESILIENT TASAR SERICULTURE

The increasing vulnerability of tasar sericulture to climate change necessitates the development of integrated and adaptive management strategies capable of sustaining productivity, ecological stability, and livelihood security under changing environmental conditions. Rising temperatures, erratic rainfall, prolonged droughts, increased disease incidence, and degradation of forest ecosystems have intensified production risks in tropical tasar culture. Since tasar sericulture is primarily practiced under outdoor forest-based conditions, building climate resilience requires a multidimensional approach integrating genetic improvement, ecological conservation, climate-smart rearing technologies, sustainable host plant management, and institutional support systems (Prabhu *et al.*, 2026).

Climate-resilient tasar sericulture aims to enhance the adaptive capacity of silkworms, host plants, ecosystems, and farming communities while minimizing climate-induced risks and maintaining long-term sustainability. Recent advances in genomics, molecular breeding, agroforestry, environmental monitoring, and conservation biology have opened new opportunities for strengthening resilience in non-mulberry sericulture systems. Table 8 list the conservation strategies for Climate-Resilient tasar ecoraces. The following sections discuss major strategies that can contribute to the development of climate-resilient tasar sericulture.

9.6.1. Conservation and Utilization of Climate-Resilient Ecoraces

The rich diversity of *Antheraea mylitta* ecoraces represents one of the most valuable biological resources for climate adaptation. Different ecoraces possess unique adaptive traits associated with thermotolerance, drought resistance, humidity tolerance, diapause flexibility, and disease resistance. Conservation and scientific utilization of these adaptive genetic resources are therefore essential for sustaining tasar production under changing climatic conditions. Conservation strategies should include both:

- In-situ conservation within natural forest habitats, and
- Ex-situ conservation through germplasm banks and breeding centers.

In situ conservation maintains ecological interactions and natural evolutionary processes, allowing ecoraces to continue adapting to environmental changes (Waldvogel *et al.*, 2020). Community-based conservation initiatives in Jharkhand, Odisha, and Chhattisgarh have emphasized preservation of important ecoraces such as Modal, Raily, Laria, and Sarihan. Ex situ conservation involving seed banks, cryopreservation, molecular characterization, and captive breeding programs can safeguard valuable genetic resources against habitat loss and climatic disturbances.

9.6.1.1. Identification of Climate-Resilient Germplasm

Modern molecular tools including like RAPD-SCAR systems, SSR markers, SNP markers, genome sequencing, and transcriptomics can facilitate identification of climate-resilient silkworm strains. Molecular characterization of thermotolerant and drought-tolerant populations provides opportunities for selective breeding and climate adaptation. Prabhu *et al.* (2023) demonstrated the use of RAPD-SCAR markers for identifying thermotolerant tasar silkworm lines, highlighting the role of molecular breeding in climate resilience.

Table 8. Conservation Strategies for Climate-Resilient Tasar Ecoraces

Strategy	Objective	Expected Outcome
In-situ conservation	Preserve natural adaptation	Maintenance of ecological resilience
Ex-situ germplasm conservation	Protect genetic resources	Long-term biodiversity security
Molecular characterization	Identify adaptive traits	Precision breeding
Community-based conservation	Strengthen local participation	Sustainable ecosystem management
Conservation genomics	Monitor genetic variability	Climate adaptation planning

9.6.1.2. Climate-Resilient Breeding and Genomics-Assisted Improvement

Traditional breeding methods alone may not be sufficient to address rapidly changing climatic conditions. Therefore, integration of genomics-assisted breeding approaches has become increasingly important for developing resilient silkworm strains capable of tolerating environmental stress.Selective breeding programs at the Central Tasar Research and Training Institute (CTRTI), Ranchi, have led to the development of improved Daba lines such as: Double Laying Silk Daba (DLSD), Plus Laying Silk Daba (PLSD), and Average Laying Silk Daba (ALSD). These improved strains exhibit enhanced fecundity, cocoon productivity, and adaptive performance under varying environmental conditions. Hybridization among genetically diverse ecoraces may further improve thermotolerance, stress resistance, disease tolerance, and productivity stability.

Advances in genomics and molecular biology have revolutionized climate-resilient breeding strategies. Technologies such as: whole genome sequencing, QTL mapping, GWAS, transcriptomics, and genomic selection enable identification of genes associated with stress adaptation and climate resilience (Abberton *et al.*, 2016). Recent genomic studies on *Antheraea mylitta* have identified stress-responsive genes associated with heat tolerance, diapause regulation, metabolic adaptation, and immunity. Marker-assisted selection using SSR and RAPD-SCAR markers can accelerate development of climate-resilient strains with improved adaptive performance.

9.6.1.3. Climate-Smart Host Plant Management

Host plants are fundamental components of tasar sericulture ecosystems. Climatic stress affecting host plants directly influences larval nutrition, cocoon quality, and silkworm survival. Therefore, climate-resilient host plant management is essential for sustainable tasar production.

Large-scale plantation programs involving drought-tolerant and locally adapted host plant varieties can improve resilience against climate variability. Species such as *Terminalia arjuna*, *T. tomentosa*, and *Shorea robusta* should be conserved and expanded through scientifically managed plantation programs. Climate-smart host plant management should include: mixed plantations, moisture conservation, soil management, and agroforestry integration. Mixed-species plantations generally exhibit greater ecological resilience than monoculture systems because they enhance biodiversity and reduce vulnerability to climatic stress. Table 9 list the describes the practices adapted for climate-smart host plant management.

9.6.1.4. Agroforestry-Based Tasar Systems

Agroforestry models integrating host plants with other forest and agricultural species provide multiple ecological benefits including: improved soil fertility, microclimate stabilization, carbon sequestration, water conservation, and biodiversity enhancement. Such systems also diversify income sources for tribal communities and reduce climate-related economic risks. Sericulture-based

agroforestry contributes significantly to carbon sequestration and environmental sustainability due to the perennial nature of host plants.

Table 9. Climate-Smart Host Plant Management Practices

Practice	Purpose	Climate Resilience Benefit
Mixed host plantations	Biodiversity enhancement	Reduced climatic vulnerability
Soil moisture conservation	Drought mitigation	Improved foliage quality
Agroforestry integration	Ecosystem stabilization	Carbon sequestration
Selection of drought-tolerant varieties	Stress adaptation	Sustained leaf production
Community forest management	Habitat conservation	Long-term sustainability

9.6.2. Improved Rearing and Microclimate Management

Climate variability significantly affects outdoor tasar rearing systems. Therefore, development of improved rearing technologies and microclimate management practices is necessary to minimize environmental stress. Microclimatic modification through shade management, proper spacing, wind barriers, and moisture conservation can reduce thermal and desiccation stress during silkworm rearing. Forest canopy management plays an important role in regulating temperature and humidity around rearing sites. Maintaining ecological vegetation cover helps buffer climatic extremes and stabilize local environmental conditions.

9.6.2.1 Crop Scheduling and Seasonal Adjustment

Adjusting brushing schedules and crop timing according to climatic forecasts can improve synchronization between silkworm development and favorable environmental conditions. Studies have shown that proper brushing dates significantly influence cocoon productivity and crop protection. Climate forecasting systems combined with indigenous ecological knowledge can help optimize crop scheduling under variable climatic conditions.

9.6.2.2. Disease and Pest Management

Climate change has increased the prevalence of diseases and pest outbreaks in tasar sericulture. Integrated disease management strategies should include: regular monitoring, early diagnosis, sanitation measures, biological control, and climate-based forecasting systems. Reducing environmental stress through proper nutrition and microclimate management can also improve silkworm immunity and disease resistance.

9.6.3. INTEGRATION OF INDIGENOUS KNOWLEDGE AND COMMUNITY PARTICIPATION

Traditional ecological knowledge possessed by tribal communities represents an important resource for climate adaptation. Indigenous rearers possess practical understanding of local climatic patterns, host plant phenology, pest occurrence, and sustainable forest management. Climate-resilient strategies should therefore integrate scientific innovations with indigenous practices. Community participation in forest conservation, plantation management, biodiversity preservation, and disease monitoring can substantially strengthen adaptive capacity and ecological sustainability. Participatory approaches also enhance adoption of climate-smart technologies among local rearers and improve livelihood resilience.

9.6.4. Digital Technologies and Climate Forecasting

Modern digital tools and environmental monitoring technologies can greatly improve climate resilience in tasar sericulture. Emerging technologies include: GIS-based habitat mapping, remote

sensing, weather forecasting systems, mobile advisory services, and AI-based disease prediction models (Table 10). Remote sensing studies have already been utilized for monitoring host plant forest dynamics and habitat conservation in regions such as the Similipal Biosphere Reserve. Integration of climate forecasting with sericultural management can help rearers optimize crop timing, reduce climatic risk, and improve productivity stability.

Table 10. Emerging Technologies for Climate-Resilient Tasar Sericulture

Technology	Application	Benefit
GIS and Remote Sensing	Habitat monitoring	Forest conservation
Climate Forecasting Systems	Crop scheduling	Reduced climatic risk
Molecular Diagnostics	Disease detection	Early intervention
Genomics and Transcriptomics	Adaptive breeding	Stress tolerance improvement
Mobile Advisory Platforms	Farmer awareness	Rapid information dissemination
AI-Based Predictive Models	Disease and climate prediction	Precision management

9.6.5. Institutional Support and Policy Interventions

Long-term sustainability of climate-resilient tasar sericulture requires strong institutional support, research investment, and policy interventions. Key policy priorities include: conservation of forest ecosystems, promotion of climate-smart sericulture, support for tribal livelihoods, funding for genomics research, and strengthening extension services. Government agencies, research institutions, NGOs, and community organizations must collaborate to: conserve adaptive germplasm, restore degraded habitats, and promote sustainable sericultural practices. Financial support for climate adaptation programs and insurance schemes may help reduce vulnerability among small-scale rearers.

Interdisciplinary approaches integrating entomology, genomics, ecology, forestry, climatology, and social sciences will be essential for sustaining tasar production under future climate scenarios. Strengthening adaptive capacity through biodiversity conservation, scientific innovation, and community participation can ensure long-term ecological and economic sustainability of tropical tasar sericulture.

9.7. EMERGING RESEARCH AREAS

Rapid advances in molecular biology, genomics, bioinformatics, environmental sciences, and precision agriculture are transforming the future of tasar sericulture research. Climate change has intensified the need for innovative scientific approaches capable of improving stress tolerance, productivity stability, biodiversity conservation, and ecosystem sustainability in non-mulberry sericulture systems. Emerging interdisciplinary research areas are therefore focusing on understanding the molecular, ecological, physiological, and environmental mechanisms underlying climate resilience in tasar silkworms and their host plants.

Modern technologies such as whole genome sequencing, transcriptomics, proteomics, metabolomics, artificial intelligence (AI), remote sensing, and microbiome analysis are opening new frontiers for climate-smart tasar sericulture (Table 11). These approaches are expected to significantly strengthen adaptive breeding, ecological conservation, disease management, and precision sericultural practices in the future.

9.7.1. Genomics and Multi-Omics Research

Genomics has emerged as one of the most promising tools for understanding climate resilience in tasar silkworms (Abberton *et al.*, 2016). Whole genome sequencing of *Antheraea mylitta* has provided valuable insights into genes associated with stress adaptation, metabolism, immunity, diapause regulation, and silk production. Recent advances in transcriptomics, proteomics, metabolomics, epigenomics, and pan-genomics are facilitating comprehensive understanding of silkworm-environment interactions under climatic stress conditions. Multi-omics integration allows identification of stress-responsive pathways, molecular adaptation mechanisms, gene regulatory networks, and metabolic signatures associated with thermotolerance and drought resistance. Such knowledge can significantly accelerate the development of climate-resilient silkworm strains through genomics-assisted breeding and marker-assisted selection (Batley & Edwards, 2016).

9.7.2. CRISPR and Genome Editing Technologies

Genome editing technologies such as CRISPR-Cas systems are increasingly being explored for precise genetic improvement in insects and agricultural systems. These tools provide opportunities for targeted gene modification, stress-resistance enhancement, disease resistance improvement, and productivity optimization. Future application of CRISPR technologies in *A. mylitta* may enable manipulation of diapause-related genes, enhancement of thermotolerance, improvement of silk quality, and regulation of immune responses. Although genome editing research in non-mulberry silkworms remains at an early stage, rapid advances in insect molecular biology indicate substantial future potential for precision breeding and adaptive improvement.

9.7.3. Climate Modeling and Ecological Forecasting

Climate modeling has become increasingly important for predicting future environmental impacts on sericulture systems. Integration of climate models with ecological and biological data can help forecast habitat suitability, disease outbreaks, host plant distribution, and crop scheduling under future climate scenarios. Geographic Information Systems (GIS), remote sensing, and ecological niche modeling are emerging as powerful tools for mapping distribution of tasar ecoraces, monitoring host plant forests, assessing habitat vulnerability, and planning conservation strategies (Reddy *et al.*, 2010). Remote sensing studies conducted in regions such as the Similipal Biosphere Reserve have demonstrated the usefulness of GIS-based approaches for monitoring forest dynamics and habitat conservation relevant to tasar sericulture.

Table 11. Emerging Technologies and Their Applications in Tasar Sericulture

Emerging Technology	Application Area	Expected Outcome
Whole Genome Sequencing	Identification of adaptive genes	Climate-resilient breeding
Transcriptomics	Stress-response analysis	Molecular adaptation studies
CRISPR-Cas Technology	Precision genome editing	Trait improvement
GIS and Remote Sensing	Habitat monitoring	Conservation planning
Artificial Intelligence	Disease prediction	Precision management
Microbiome Analysis	Gut microbial interaction	Improved immunity
Climate Modeling	Risk forecasting	Adaptive crop planning

9.7.4. Microbiome and Gut Symbiosis Research

Recent studies have highlighted the important role of gut microbiota in insect physiology, nutrition, immunity, and environmental adaptation. The silkworm gut microbiome contributes significantly

to nutrient assimilation, metabolic regulation, immune defense, and stress tolerance. Metagenomic studies are increasingly being utilized to analyze microbial diversity associated with silkworms exposed to environmental stress conditions. Understanding microbial interactions in tasar silkworms may provide opportunities for: probiotic interventions, improved digestion, enhanced immunity, and climate stress mitigation. Future microbiome engineering approaches could contribute to development of resilient silkworm populations capable of surviving under adverse environmental conditions.

9.7.5. Nanotechnology and Biomaterial Research

Tasar silk proteins such as fibroin and sericin have gained increasing attention for biomedical and nanotechnological applications. Emerging research areas include tissue engineering, wound healing, drug delivery systems, nanofiber fabrication, and biomaterials development. Studies have demonstrated the potential utility of tasar silk fibroin in regenerative medicine and biomedical engineering. Climate-resilient sericulture systems capable of sustaining silk quality under environmental stress may therefore support not only textile industries but also advanced biomaterial applications.

9.7.6. Artificial Intelligence and Precision Sericulture

Artificial Intelligence (AI), machine learning, and Internet of Things (IoT)-based technologies are gradually emerging in agricultural and sericultural systems.Potential applications include: disease prediction, automated environmental monitoring, precision crop scheduling, adaptive climate forecasting, and real-time advisory systems. AI-based predictive models can help optimize brushing schedules, host plant management, disease surveillance, and cocoon productivity. Integration of digital technologies with indigenous knowledge systems may significantly strengthen adaptive management under uncertain climatic conditions.

9.8. CHALLENGES AND RESEARCH GAPS

Despite substantial advances in climate resilience research and sericultural biotechnology, several scientific, ecological, technological, and socio-economic challenges continue to hinder the sustainable development of climate-resilient tasar sericulture. Although increasing attention has been directed toward understanding climate adaptation in non-mulberry silkworms, many adaptive traits and resilience mechanisms in *Antheraea mylitta* remain insufficiently explored (Prabhu *et al.*, 2026). At the same time, conservation of indigenous ecoraces and forest ecosystems faces growing threats from climate change, habitat degradation, and anthropogenic disturbances. Bridging these research gaps is essential for ensuring the long-term sustainability, ecological resilience, and livelihood security associated with tasar sericulture. Major research gaps in Climate-Resilient tasar sericulture is given in Table 12.

9.8.1. Limited Genomic and Molecular Resources

Although significant progress has been made in sequencing the genome of *Antheraea mylitta*, genomic resources for non-mulberry silkworms remain comparatively limited when compared with the extensively studied mulberry silkworm, *Bombyx mori*. Existing limitations include incomplete functional annotation of adaptive genes, insufficient transcriptomic and proteomic databases, limited studies on stress physiology, and inadequate molecular markers linked to climate-resilient traits. Consequently, understanding of the molecular basis of thermotolerance, drought adaptation, immunity, diapause regulation, and ecological plasticity in tasar silkworms remains incomplete.

Further research is therefore needed to identify climate-responsive genes and molecular pathways associated with heat tolerance, drought resistance, immune regulation, oxidative stress management, and epigenetic adaptation under fluctuating environmental conditions. Development of advanced genomic databases, high-throughput sequencing platforms, and multi-omics integration approaches will be essential for strengthening climate-resilience research and genomics-assisted breeding programs in tasar sericulture.

9.8.2. Inadequate Long-Term Climate and Ecological Data

One of the major limitations in climate-resilience research is the lack of long-term environmental and ecological datasets correlating climate variability with silkworm productivity, disease dynamics, host plant phenology, biodiversity changes, and ecosystem stability. Most existing studies related to tasar sericulture are region-specific and conducted over relatively short periods, thereby limiting the ability to accurately predict long-term climate impacts and adaptive responses.

The absence of comprehensive ecological monitoring systems restricts understanding of climate-induced changes in host plant distribution, ecorace survival, disease prevalence, and forest ecosystem dynamics. Long-term monitoring programs are urgently required for habitat assessment, climate-risk forecasting, ecosystem modeling, and adaptive management planning. Integration of climatic, ecological, and genomic datasets can significantly improve predictive understanding of future environmental risks affecting tasar sericulture.

9.8.3. Threats to Biodiversity and Indigenous Germplasm

Rapid deforestation, mining activities, urbanization, forest fragmentation, and habitat degradation pose serious threats to the survival of indigenous tasar ecoraces and associated host plant ecosystems. Climate change further intensifies these threats by altering forest ecology, increasing drought frequency, and disturbing ecological interactions essential for silkworm survival.

Loss of genetic diversity may substantially reduce the adaptive potential, ecological resilience, and breeding opportunities available for developing climate-resilient silkworm strains. Several localized and ecologically important ecoraces remain poorly characterized and inadequately conserved, increasing the risk of genetic erosion (Sandhya *et al.*, 2026)s. In many cases, conservation programs suffer from inadequate funding, weak policy implementation, insufficient scientific documentation, and limited participation of local communities. Strengthening biodiversity conservation through integrated ecological and molecular approaches therefore remains a major research priority (Kitching *et al.*, 2018).

9.8.4. Limited Adoption of Modern Technologies

Although advanced technologies such as genomics, GIS-based habitat mapping, molecular diagnostics, climate forecasting systems, and digital monitoring tools are increasingly available, their practical application in field-level tasar sericulture remains limited. The gap between laboratory research and field implementation continues to be a major challenge affecting climate adaptation efforts.

Several factors restrict technological adoption among tasar rearers, including lack of technical infrastructure, limited awareness and training opportunities, inadequate extension services, high implementation costs, and poor digital connectivity in remote forest regions. As most tasar cultivation areas are located in economically and geographically marginalized regions, access to advanced scientific tools and climate-smart technologies remains limited. Greater emphasis is therefore needed on technology transfer, participatory extension programs, field-level demonstrations, and

development of affordable climate-resilient sericulture technologies suitable for rural and tribal communities.

9.8.5. Socio-Economic Constraints

Socio-economic vulnerability remains one of the major barriers to climate-resilient tasar sericulture. Most tasar rearers belong to economically disadvantaged tribal communities with limited access to climate adaptation resources, irrigation facilities, institutional support, insurance schemes, disease management infrastructure, and modern sericultural technologies. Climate variability and recurring crop losses further intensify livelihood insecurity and increase economic risks among forest-dependent households (Long *et al.*, 2006).

In many regions, declining profitability and uncertain climatic conditions discourage younger generations from participating in traditional sericulture practices, thereby threatening continuity of indigenous knowledge systems and traditional ecological management practices. Additionally, inadequate integration of indigenous knowledge into formal climate adaptation policies and research programs represents a significant development gap. Sustainable climate-resilient tasar sericulture therefore requires not only scientific innovation but also inclusive socio-economic policies, livelihood support systems, institutional strengthening, and active participation of tribal communities in climate adaptation planning.

Table 12. Major Research Gaps in Climate-Resilient Tasar Sericulture

Research Gap	Limitation	Priority Need
Limited genomic resources	Poor understanding of adaptive genes	Functional genomics research
Inadequate ecological datasets	Weak climate prediction	Long-term monitoring
Poor conservation of ecoraces	Loss of adaptive diversity	Conservation genomics
Limited microbiome studies	Incomplete stress adaptation knowledge	Metagenomic research
Weak technology transfer	Low field adoption	Extension strengthening
Insufficient policy integration	Fragmented adaptation strategies	Climate-smart policy frameworks

9.9. FUTURE PROSPECTS

The future of tasar sericulture lies in the successful integration of biodiversity conservation, climate-smart technologies, genomics-assisted breeding, ecological sustainability, and community participation. Despite increasing climatic challenges, tropical tasar sericulture possesses enormous potential to emerge as a resilient and sustainable bio-based industry that supports rural livelihoods, biodiversity conservation, and green economic development. Since tasar culture is closely linked with forest ecosystems and tribal communities, future developmental strategies must emphasize adaptive and ecologically sustainable approaches capable of withstanding environmental uncertainties while maintaining productivity stability and ecological balance. Future strategies for climate-resilient tasar sericulture should focus on strengthening biodiversity conservation, improving climate-resilient silkworm breeding, integrating modern technologies with indigenous knowledge, enhancing ecosystem-based host plant management, and promoting sustainable livelihood security for tribal communities.

9.9.1. Genomics-Assisted Climate Adaptation

Advances in genomics, transcriptomics, and systems biology are expected to revolutionize future breeding strategies for climate-resilient tasar silkworms. Emerging molecular technologies may facilitate the identification of climate-responsive gene networks associated with thermotolerance,

drought resistance, immunity, and diapause regulation. Future genomics-assisted breeding programs may increasingly utilize precision breeding, genome editing, and personalized ecorace improvement to develop superior silkworm strains adapted to changing climatic conditions.

Genomics-assisted selection combined with high-throughput phenotyping can significantly accelerate the development of thermotolerant silkworm strains, drought-resistant host plants, disease-resistant populations, improved cocoon productivity, and stress-resilient tasar ecoraces. In addition, future genomic research is expected to contribute toward the identification of adaptive molecular pathways, marker-assisted selection systems, genome-wide association studies, and climate-specific breeding programs that can enhance the adaptive potential of tasar silkworms under changing environmental conditions.

9.9.2. Conservation Genomics and Biodiversity Management

Conservation genomics and biodiversity management will play a critical role in the future sustainability of tasar sericulture. Future conservation strategies are expected to increasingly incorporate molecular characterization, genomic diversity analysis, GIS-based habitat mapping, and participatory biodiversity conservation approaches. Conservation genomics can help identify ecologically important and climate-resilient populations requiring priority protection while improving management of indigenous germplasm resources.

Future biodiversity conservation efforts should emphasize in situ conservation of indigenous ecoraces, ex situ germplasm preservation, GIS-based habitat monitoring, molecular characterization of adaptive populations, restoration of degraded host plant forests, and community-based conservation programs. Simultaneously, restoration of degraded forest ecosystems and strengthening of agroforestry systems will become essential for sustaining tasar biodiversity and ecological resilience under future climate scenarios.

9.9.3. Climate-Smart and Precision Sericulture

Climate-smart and precision sericulture technologies are likely to become increasingly important in future tasar production systems. Emerging technologies such as AI-based forecasting, IoT-enabled environmental monitoring, precision crop scheduling, digital advisory platforms, and automated disease surveillance systems can substantially improve adaptive decision-making and reduce climate-induced production risks.

Future precision sericulture systems may incorporate AI-based climate forecasting, IoT-enabled environmental sensors, GIS and remote sensing technologies, automated disease detection systems, mobile-based advisory services, and precision crop scheduling tools. Integration of climate forecasting with ecological and genomic data may facilitate more efficient management of host plant cultivation, brushing schedules, disease surveillance, pest management, and cocoon productivity. Such precision sericulture approaches can help optimize resource utilization while enhancing resilience against climatic variability.

9.9.4. Integration of Indigenous Knowledge and Modern Science

The long-term sustainability of tasar sericulture will depend upon effective integration of indigenous knowledge systems with modern scientific innovations. Tribal communities inhabiting tasar-growing regions possess invaluable traditional ecological knowledge regarding local climatic adaptation, forest ecology, host plant management, and silkworm behaviours. These traditional practices have evolved through generations of interaction with forest ecosystems and often function as natural adaptation strategies under fluctuating environmental conditions (Bhatia *et al.*, 2014).

Indigenous knowledge systems contribute significantly to seasonal crop planning, host plant management, local climate prediction, sustainable forest utilization, traditional pest management, and ecological conservation. Combining such indigenous knowledge with genomics, climate modeling, digital technologies, AI-based forecasting, and precision management systems can create highly resilient and locally adaptable sericulture models capable of sustaining both ecological and socio-economic stability.

9.9.5. Policy and Institutional Support

Strong policy frameworks and institutional support will be equally important for promoting climate-resilient tasar sericulture in the future. Policy priorities should focus on strengthening biodiversity conservation, promoting climate-smart agroforestry systems, supporting tribal livelihoods, funding advanced genomics and climate research, and improving extension and advisory services in remote forest regions.

Future policy priorities should include strengthening forest and biodiversity conservation, promoting climate-smart sericulture practices, supporting tribal livelihood development, improving climate adaptation infrastructure, funding advanced genomic and ecological research, establishing climate-risk insurance schemes, enhancing extension services, and improving market access for tasar rearers. Interdisciplinary collaboration among researchers, policymakers, forest departments, NGOs, extension agencies, and tribal communities will be crucial for implementing sustainable adaptation strategies and ensuring effective transfer of scientific innovations to field-level sericulture practices.

9.9.6. Toward Sustainable and Resilient Tasar Sericulture

Tasar sericulture possesses unique ecological advantages because of its integration with forest ecosystems, biodiversity conservation, and sustainable rural livelihoods. With continued scientific innovation, ecological conservation, and community participation, climate-resilient tasar sericulture can contribute significantly to sustainable development, ecological restoration, climate adaptation, and green economic growth.

Future climate-resilient tasar sericulture systems should emphasize ecological sustainability, biodiversity conservation, adaptive breeding, climate-smart host plant management, digital and precision technologies, and participatory community-based approaches. Future interdisciplinary research integrating genomics, multi-omics technologies, conservation biology, microbiome studies, digital innovations, AI-based forecasting, and indigenous ecological knowledge is expected to play a transformative role in ensuring the long-term sustainability and resilience of tropical tasar sericulture under future climate scenarios.

9.10. CONCLUSION

Tropical tasar sericulture represents a unique bio-resource-based enterprise that integrates forest ecology, biodiversity conservation, traditional knowledge systems, and sustainable rural livelihoods. The tropical tasar silkworm, *Antheraea mylitta* Drury, exhibits remarkable ecological and genetic diversity in the form of numerous ecoraces distributed across diverse agro-climatic and forest ecosystems of India. These ecoraces constitute invaluable adaptive genetic resources that have evolved through long-term interactions with local environmental conditions, host plants, and ecological pressures (Bhatia *et al.*, 2014). Their inherent variability in thermotolerance, drought resistance, diapause behavior, disease tolerance, and ecological synchronization forms the biological foundation for climate resilience in tasar sericulture.

Climate change, however, has emerged as a major challenge threatening the sustainability of tasar-based production systems. Rising temperatures, erratic rainfall patterns, prolonged droughts, humidity fluctuations, forest degradation, and increased disease incidence are adversely affecting silkworm physiology, host plant productivity, cocoon quality, and tribal livelihoods dependent on tasar culture. Since tasar silkworms are reared under outdoor forest conditions, they are particularly vulnerable to environmental disturbances and ecosystem instability. Climate-induced disruption of host plant phenology, silkworm development, and ecological synchronization further intensifies production risks and threatens the long-term sustainability of the sector.

Despite these challenges, the adaptive potential of tasar silkworm ecoraces offers significant opportunities for developing climate-resilient sericulture systems. Physiological flexibility, metabolic plasticity, diapause regulation, behavioral adaptation, and stress-responsive genetic mechanisms collectively contribute to the resilience of different ecoraces under fluctuating environmental conditions. Advances in genomics, transcriptomics, molecular marker technologies, and conservation biology have substantially improved understanding of the molecular basis of stress adaptation and opened new avenues for climate-resilient breeding and precision sericulture.

The chapter also highlights the critical importance of biodiversity conservation and indigenous ecological knowledge in strengthening climate resilience. Forest biodiversity, host plant diversity, and traditional tribal practices provide ecological stability and adaptive capacity essential for sustainable tasar production. Indigenous communities possess valuable knowledge regarding seasonal climatic adaptation, host plant management, ecological forecasting, and sustainable forest utilization, which can significantly complement modern scientific innovations. Integration of traditional ecological wisdom with genomics, digital technologies, climate forecasting, and precision management systems can create highly resilient and locally adaptable sericulture models.

Future sustainability of tasar sericulture will depend upon integrated climate-smart strategies involving conservation of adaptive ecoraces, genomics-assisted breeding, climate-resilient host plant management, agroforestry-based systems, disease forecasting, digital monitoring technologies, and participatory community-based conservation. Strengthening interdisciplinary collaboration among researchers, policymakers, forest departments, extension agencies, and tribal communities will be essential for translating scientific advances into practical adaptation strategies at the field level.

Furthermore, emerging research areas such as conservation genomics, microbiome studies, CRISPR-based genome editing, artificial intelligence, GIS-based habitat monitoring, and precision sericulture are expected to transform the future of climate-resilient tasar production. These advanced approaches can significantly improve stress adaptation, disease management, productivity stability, and ecological sustainability under future climate scenarios.

In conclusion, climate resilience in tasar sericulture is fundamentally dependent upon the conservation and scientific utilization of the rich diversity of tasar silkworm ecoraces and associated forest ecosystems. Sustainable management of these biological resources, combined with technological innovation and indigenous ecological knowledge, can ensure long-term ecological stability, livelihood security, and sustainable silk production under changing climatic conditions. Tropical tasar sericulture thus possesses immense potential to emerge as a model climate-resilient bioeconomy system contributing simultaneously to biodiversity conservation, ecological restoration, tribal welfare, and sustainable rural development in the era of global climate change.

9.11. REFERENCE

Abberton M, Batley J, Bentley A, Bryant J, Cai H, Cockram J, Costa de Oliveira A, Cseke LJ, Dempewolf H, De Pace C, Edwards D (2016) Global agricultural intensification during climate change: a role for genomics. Plant Biotechnol J 14(4):1095–1098.

Alam K, Raviraj VS, Paul M, Ghosh S, Nalvadi C, Kar PK, Saha S (2024) Wild silk insect of Simlipal biosphere and its molecular genetic diversity for conservation. Biologia Futura 75(4):459–475.

Batley J, Edwards D (2016) The application of genomics and bioinformatics to accelerate crop improvement in a changing climate. Curr Opin Plant Biol 30:78–81.

Bhatia NK, Yousuf M (2014) Effect of rearing season, host plants and their interaction on economical traits of tropical tasar silkworm, *Antheraea mylitta* Drury—an overview. Int J Ind Entomol 29(1):93–119.

Gedam PC, Bawaskar DM, Chowdary NB, Venugopal A, Ingale AD (2023) Perception of tasar silkworm rearers about the climate change impact on the tasar silk production of Maharashtra. Asian J Agric Ext Econ Sociol 41(7):153–164.

Giacomin AM, Garcia JB Jr, Zonatti WF, Silva-Santos MC, Laktim MC, Baruque-Ramos J (2017) Silk industry and carbon footprint mitigation. In: IOP Conference Series: Materials Science and Engineering, vol 254, no 19. IOP Publishing, p 192008.

Intergovernmental Panel on Climate Change (2023) AR6 synthesis report: climate change 2023. IPCC.

Jolly MS et al (1974) Studies on the taxonomy and distribution of tropical tasar silkworm ecoraces.

Kitching IJ, Rougerie R, Zwick A, Hamilton CA, St Laurent RA, Naumann S, Mejia LB, Kawahara AY (2018) A global checklist of the Bombycoidea (Insecta: Lepidoptera). Biodivers Data J 6:e22236.

Long SP, Ainsworth EA, Leakey AD, Nosberger J, Ort DR (2006) Food for thought: lower-than-expected crop yield stimulation with rising CO2 concentrations. Science 312(5782):1918–1921.

Mazumdar SM, Reddy BT, Chandrashekharaiah M, Chowdary NB, Chattopadhyay S, Rathore MS, Sathyanarayana K (2023) Influence of abiotic factors on seasonal and nonseasonal emergence of Tasar silkworm, *Antheraea mylitta* Drury. J Environ Biol 44:445–451.

Nagaraju J (2002) Application of genetic principles for improving silk production. Curr Sci 83:409–414.

Prabhu IG, Dogra A, Prasad R, Sukhija N, Gadad HS, Chowdary NB (2025) Ecology, distribution and conservation of tropical tasar silkworm ecoraces. CSB-Central Tasar Research and Training Institute, Ranchi.

Prabhu IG, Manjappa MM, Baig N, Kumar AK, Sinha A, Kutala S (2023) Molecular cloning and development of RAPD-SCAR markers for the selection of thermo-tolerant line of tropical tasar silkworm. J Environ Biol 44(3):464–471.

Prabhu IG, Sukhija N, Kumar V, Gadad H, Chowdary NB (2026) Climate resilience in non-mulberry sericulture: a genomic perspective. In: Sustainable Sericulture in India: Climate Change Impacts and Mitigation Strategies. Springer Nature Switzerland, Cham, pp 427–471.

Ray PP, Barala B, Dash P (2024) Cytochrome b gene as a potential DNA barcoding marker in ecoraces of tropical Tasar silkworm *Antheraea mylitta* Drury. Gene Rep 35:101922.

Reddy RM, Suryanarayana N, Rao MK, Sinha MK, Prasad BC, Alok S (2010) Distribution and ecological niche analysis of tropical tasar silkworm ecoraces. J Entomol 7(3):152–159.

Renuka G, Shamitha G (2016) Genetic variation in ecoraces of tropical tasar silkworm, *Antheraea mylitta* using SSR markers. J Genet 95(4):777–785.

Sahoo A, Dandapat J, Samanta L (2015) Oxidative damaged products, level of hydrogen peroxide, and antioxidant protection in diapausing pupa of Tasar silk worm, *Antheraea mylitta*: a comparative study in two voltine groups. Int J Insect Sci 7:IJIS-S21326.

Sandhya N, Karur AS, Bharath KB (2026) Wild silkworms and climate resilience: why non-mulberry sericulture matters today. Int J Agric Food Sci 8(4):380–390.

Sarwat M, Das S, Srivastava PS (2011) AFLP and SAMPL markers for characterization of genetic diversity in *Terminalia arjuna*: a backbone tree of Tasar silk industry. Plant Syst Evol 293(1):13–23.

Sharma A, Chanotra S, Gupta R, Kumar R (2020) Influence of climate change on cocoon crop loss under subtropical conditions. Int J Curr Microbiol Appl Sci 9(5):167–171.

Sonmez MC, Ozgur R, Uzilday B, Turkan I, Ganie SA (2023) Redox regulation in C3 and C4 plants during climate change and its implications on food security. Food Energy Secur 12(2):e387.

Takeda M, Kobayashi J, Kamimura M, Prakash PJ (2014) Introduction of diapause trait into the muga silkmoth, *Antheraea assamensis*: a scientific collaboration over the Himalayas. Int J Wild Silkmoth Silk 18:39–54.

Tsurumaki J, Ishiguro J, Yamanaka A, Endo K (1999) Effects of photoperiod and temperature on seasonal morph development and diapause egg oviposition in a bivoltine race (Daizo) of the silkmoth, *Bombyx mori* L. J Insect Physiol 45(2):101–106.

Vijayan K, Nair CV, Kar PK, Mohandas TP, Saratchandra B, Raje US (2005) Genetic variability within and among three ecoraces of the tasar silkworm *Antheraea mylitta* Drury, as revealed by ISSR and RAPD markers. Int J Ind Entomol Biomater 10(1):51–59.

Waldvogel AM, Feldmeyer B, Rolshausen G, Exposito-Alonso M, Rellstab C, Kofler R, Mock T, Schmid K, Schmitt I, Bataillon T, Savolainen O (2020) Evolutionary genomics can improve prediction of species' responses to climate change. Evol Lett 4(1):4–18.

CHAPTER 10: CLIMATE CHANGE AND ITS IMPLICATIONS FOR OAK TASAR CULTURE: CHALLENGES, IMPACTS AND ADAPTIVE STRATEGIES

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10.1. INTRODUCTION

Climate change is a major shift in either the mean state of the climate or its variability that lasts for a long time and may be brought on by internal natural processes, external forcing, or persistent anthropogenic changes in the atmosphere's composition or in how land is used. Worldwide, ecosystem integrity and species survival may be seriously threatened by climate change. It is widely acknowledged as the most imminent and pressing problem threatening human survival in the twenty-first century. An increase in worldwide atmospheric temperature rise is the key factor determining greenhouse gas (GHG) concentrations, such as those of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (NO_2). The burning of fossil fuels, rapid industrialization, deforestation, agricultural activities, luxury lifestyles, space explosion, grazing, wetland destruction, and land use change are all associated with rising GHG emissions. According to the Intergovernmental Panel on Climate Change (IPCC), if global temperatures increase by about 2°C over the next 100 years, adverse effects would start to spread to most parts of the world. It is also anticipated that 20-30% of plant and animal species will likely face an increased risk of extinction. Industrialization and families directly contribute more than two thirds of the greenhouse gas emissions. The stock of greenhouse gases in the atmosphere would quadruple its pre-industrial levels by 2050 or 550 ppm CO_2, even if the yearly flow of emissions did not increase above its current rate. It has been reported that over the past century or so, the atmospheric buildup of greenhouse gases caused by human activity has caused the average temperature in India to increase by roughly 0.5°C.

10.2. NATIONAL SCENARIO OF CLIMATE CHANGE

In India, the distribution of greenhouse gas (GHG) emissions across various sectors reveals that Energy, Industry, Agriculture and Waste contribute 58%, 22%, 17% and 3% to the net CO2 equivalent emissions respectively. Disturbingly certain coastal areas face the imminent threat of complete disappearance. The reliability of the summer monsoon, vital for 75% of India's rainfall and critical for agriculture is expected to diminish, resulting in unpredictable weather patterns, leading to floods in some regions and droughts in others. Over the past century the average temperature in India has increased by approximately 0.5°C due to the accumulation of anthropogenic greenhouse gases in the atmosphere. The repercussions of recent emissions will unfold over several decades and if current trends persist the temperature rise is projected to surpass 2.0°C. Various researchers from Indian institutions predict a temperature increase ranging from 0.5 to 4.0°C in different parts of the country over the next few decades due to the continued accumulation of anthropogenic greenhouse gases.

10.3. OVERVIEW OF OAK TASAR CULTURE

Oak tasar silkworm, *Antheraea proylei* Jolly, also commonly known as temperate tasar silkworm are exploited commercially in India. *A .proylei* is wild in nature and produces silk known as oak tasar silk. It is a holometabolous insect consisting of four stages viz. egg, larva, pupa & adult or moth, having variation in their morphology, behaviour and physiology. The larval period is the only feeding stage in the life cycle of the silkworm. The silkworm larva feeds on the primary food plants

viz., *Quercus serrata, Q. griffithii* and *Lithocarpus dealbata.* Silkworm rearing starts from hatching of the larva which starts eating food after coming out of the egg shell. The period of eating food or larval stages consist of five instars and four moulting periods. The period of eating food prior to first moult is called first instar or stadium (black in colour) and then the larva cast off its skin (ecdysis) to grow to the second stage (green colour).



Figure 1. Host plants of Oak tasar, *A. proylei*, commonly available in Manipur.

A. Quercus serrata and B. ***Lithocarpus dealbata***

In this way, it crosses second, third and fourth moulting stages and larva grows through five successive larval instars to reach the cocoon stage. Thus, the activity of feeding and growth starts from the time of hatching from egg until when the larva undergoes metamorphosis into pupa after formation of cocoon is known as silkworm rearing technology. The successful rearing for good harvest depends on the proper planning and following of rearing techniques.

B

The nutritional element of oak leaves determines the growth and development of the oak tasar silkwom and cocoon production. The quality of the leaves has a profound effect on the superiority of silk produced by *A. proylei*. It has also been demonstrated that the dietary nutritional management has a direct influence on quality and quantity of silk production in oak tasar. Nutrition is an important growth-regulating factor in silkworm. Therefore, proper management of host plants for production of quality and quantity leaves should be done timely.



Figure 2. A. ***A. proylei*** **silkworm** **B. Cocoon and Silkmoth**

C

10.4. DIVERSITY OF OAK FED SILKMOTHS IN NORTH EAST

The oak forest in the sub-Himalayan belt of North-East India is the natural abode of various oak *Antheraea* species. Out of the thirty five species of *Antheraea* reported (Crotch 1956), thirty-one species have been recorded in the Indo- Australian biographic region (Seitz 1933). Albough (1986) recorded the world wide distribution of thirty six saturniids along with their food plant and distribution of certain oak fed *Antheraea* spp. have been reported by (Singh et al 2000). The genus *Antheraea* is very important from economic point of view since these species produce silk and has a bearing on sustainable resource management and ecosystem development in the hilly areas. Systematic survey, collection and characterization of all t oak fed *Antheraea* species available in this region are needed for proper utilization in conducting systematic breeding research to improve the economic characters. China and India are the two major countries producing Oak tasar raw silk in the global context. *Anthereae pernyi* Guerim Menevelli and Anthereae *proylei* Jolly are the two species mainly producing oak tasar silk. In India, *A. roylei* Moore and *A. frithi* Moore are also conserved in the germplasm bank along with some evolved lines for utilization in the breeding and production of tasar silk of commerce.



A. **B.** **C.**

Figure 3. Important wild silkmoths found in Manipur- A. *Antheraea frithi*

B. *Antheraea helferi* **and C.** *Antheraea roylei*

10.5. BIOLOGY AND ENVIRONMENTAL REQUIREMENTS OF OAK TASAR SILK-WORM REARING

Antheraea proylei is poikilothermic (ectothermic), so its growth, development, survival, reproduction, and silk yield are highly sensitive to temperature, humidity, photoperiod, and host plant quality. Optimal conditions include:

- **Temperature**: Larval development thrives at 22–28°C (ideally ~23–28°C for productivity). Shorter developmental duration (26–36 days) and higher survival occur in this range. Temperatures above ~30–32°C (common in summer extremes) reduce feeding, increase mortality, and lower cocoon quality. Lower temperatures slow development.
- **Relative Humidity (RH)**: 70–90% is favorable; extremes cause stress.
- **Photoperiod**: Influences diapause, emergence, and voltinism (typically univoltine or bivoltine in temperate zones). For Oak tasar silkworm (*Antheraea proylei*) rearing, photoperiod of 12 hours light:12 hours dark (12L:12D) is commonly recommended and used successfully.
- **Host plants**: Oak leaves must provide adequate nutrition (protein, moisture). Leaf quality depends on plant health, which is affected by the climatic condition.



Figure 4. Oak tasar silkworm rearing at the hillside in Manipur

10.6. CLIMATE CHANGE ITS IMPACT ON OAK TASAR CULTURE

Climate change poses significant challenges to the sericulture industry, impacting various aspects of silk production from silkworm rearing to mulberry cultivation. Climate change affects sericulture, including its influence on silkworm behaviour, cocoon production, food plant growth and the prevalence of diseases and pests. Climate change has directly or indirectly affected Oak Tasar culture in Manipur, leading to declining silkworm fecundity, shrinking oak forests and increased vulnerability of sericulture communities. Rising temperatures, erratic rainfall and habitat degradation threaten the survival of Oak Tasar silkworms, but targeted mitigation, such as forest conservation, microclimate management and climate-resilient sericulture practices can help sustain this traditional livelihood.

10.6.1 Climate Change Trends Relevant to Oak Tasar Regions

Global warming drives rising temperatures (projected ~1.4–5.8°C increase by 2100, with ~2°C rise in India by 2050), altered rainfall patterns (more extreme events, potential overall decrease in some projections), increased CO_2 (from ~280 ppm pre-industrial to >400 ppm), and shifts in humidity/extreme weather. Himalayan/sub-Himalayan zones face amplified effects: faster warming, glacial melt, habitat shifts, and deforestation pressures.

10.6.2 Direct and Indirect Impacts on Oak Tasar Culture

10.6.2.1 Effects on Silkworm Physiology and Life Cycle

Temperature plays a critical role in the growth and development of silkworms. As climate change leads to temperature fluctuations, it directly affects the life cycle of silkworms. High temperatures can accelerate silkworm development, leading to premature emergence and lower silk quality. Conversely, low temperatures can prolong the larval stage, delaying cocoon formation and reducing silk yield. Research by Zhang *et al.* (2019) found that even slight deviations from optimal temperatures can significantly impact silkworm growth rates.

- **Heat stress**: Elevated temperatures disrupt larval feeding, growth, and metamorphosis. They increase oxidative stress, reduce survival, and lead to smaller/lower-quality cocoons with poorer silk yield and filament quality. Extreme heat (>35–41°C in summer) causes high larval mortality.
- **Reproductive decline**: Fecundity (egg-laying) drops sharply. In sub-Himalayan areas, only ~4% of moths may now lay viable eggs (average ~174 eggs per laying female), signaling imminent local extinction risks for *A. proylei* populations. This links to warming and associated stresses.

- **Phenology and voltinism mismatches**: Altered temperature/photoperiod disrupts brood timing, emergence, and synchronization with host leaf availability.
- **Disease and pest susceptibility**: Warmer, more humid or erratic conditions favor pathogens (e.g., nucleopolyhedrovirus causing tiger band disease, fungi like powdery mildew on hosts, bacteria). Outdoor rearing exposes worms to uzi flies and predators. Crop losses from diseases can reach ~40% in tasar systems.

10.6.2.2 Erratic Emergence of Seed Cocoon

Oak Tasar silkworms exhibit weak voltinism (tendency toward univoltine or weak bivoltine behavior) and facultative pupal diapause. After the main spring crop (March-April), pupae enter diapause for about 9 months (roughly May to January). During this long preservation period, environmental fluctuations trigger irregular termination of diapause, which is known as Erratic emergence. Erratic (or unseasonal/erratic) emergence in Oak Tasar cocoons refers to premature or irregular adult moth emergence from seed cocoons during storage/preservation, rather than synchronized emergence during the proper grainage (moth emergence and egg-laying) period. This phenomenon of erratic emergence of silkmoth from seed cocoons is more prevalent when there is unprecedented temperature high or fluctuation of weather condition, thereby causing loss of seed cocoons.

10.6.2.3 Impact on Host Plants (Oak tree)

Oaks face reduced regeneration, drought stress, altered phenology (e.g., leaf flush timing), and increased pest/disease pressure (e.g., powdery mildew thriving in warm-dry day/humid night cycles). Deforestation and poor regeneration have already reduced oak forests dramatically (from ~2.9 million ha historically in sub-Himalayas to much lower levels). Lower leaf quality (reduced moisture/nutrients) impairs larval nutrition, leading to slower growth and inferior cocoons. Late or irregular rainfall affects sprouting pattern of Oak tasar host plants, which cause delay in silkworm rearing, chances for pest attack and disease occurrence.



Figure 5. Watering at Oak tasar rearing farm due to no rain at the right time.

10.6.2.4 Increased Incidence of Pests and Diseases

Climate change contributes to the proliferation of pests and diseases, pest outbreak, posing significant threats to both silkworms and host plants. Warmer temperatures create favourable conditions for the breeding and spread of insect pests or diseases. These infestations not only directly harm silkworms and host plants but also reduce silk quality and yield. Effective pest management strategies, including integrated pest management approaches, are essential to mitigate these impacts (Gong *et al.*, 2018).

10.6.2.5 Common Insect pests and Disease occurrence in Oak Tasar Ecosystem:

1) Stem borer, *Batocera lineolata* deposit eggs in the crevices of bark and young larvae make tunnel into the bark consequently wood sap oozes out and fine brash first appears on the

host plants which are ejected from the entrance holes. There is little mining under the bark. Galleries are made in the wood and pupation occurs therein. Higher infestation (4.1% population density/plant) occurs during the month of March-April.



Figure 6. Stem borer, *Batocera lineolata*, infesting *Quercus serrata*

Control:

Plug holes with cotton soaked in 0.05% Nuvan to kill the larvae and adults of *Batocera lineolata*

2) Hairy caterpillar, *Phalera raya* Moore are observed round the year. Highest infestation observed during the month of July (12.1 population density/plant).



Figure 7. *Phalera raya Moore* infesting *Quercus serrata*

Control the hairy caterpillar infestation by spraying of Bioneem (5ml/l) if the infestation of *P.raya* crosses Economic threshold level (ETL) 1.08 larvae/ plant

3) **Tiger Band Disease (Caused by: Nuclear Polyhedrosis Virus)**

Occurrence: During 4th and 5th stage of larvae throughout the year.



Symptoms: Larvae show restlessness, starvation, and black spots appear on cuticles at the initial stage. As the infection advances, black spots appear on the dorsal side of the cuticle. Thereafter, black spot becomes enlarged in the form of dark bands (Tiger Band)

And Quickly the whole body becomes black and the larvae die within 24 hours of the appearance of symptom. The dead silkworm hangs on the branches of the tree and if the body membrane ruptures, brownish fluid oozes out emitting stringent foul smell.

Route of infection: Per-oral/Trans-ovum/Trans-ovarial

4) Changes in Precipitation Patterns and host plant Cultivation

Host plant leaves are the primary food source for silkworms and any changes in precipitation patterns, directly affect their cultivation. Alterations in rainfall patterns, such as prolonged droughts or excessive rainfall, can disrupt the growth and sprouting pattern of oak tasar food plants, leading to unavailability of leaves at the right time, delaying silkworm rearing schedule and decreased leaf quality and quantity. This, in turn, affects the health and productivity of silkworms. It can be referred the studies of Li *et al.* (2020), highlighted the vulnerability of mulberry plants to water stress and the need for adaptive irrigation strategies in sericulture.

5) Host Plant Vulnerability

Oak species experience habitat contraction under warming scenarios, with projected losses of 23-100% suitable areas linked to reduced precipitation and temperature range shifts. Poor leaf quality from foliar stress like chlorosis and necrosis limits summer crop rearing, restricting viable production to spring cycles. Depletion of oak forests due to climate change and injudicious exploitation of Oak forest such as deforestation, cutting down of trees in large scale for firewood further threatens food availability for tasar ecoraces.



Figure 8. Excessive cutting down of Oak trees for firewood in hilly areas of Manipur

6) Soil Degradation and Changes in Soil Fertility

Climate change exacerbates soil degradation through increased erosion, salinization, and nutrient depletion. These alterations directly influence mulberry growth and silk production. Studies indicate that rising temperatures and erratic rainfall patterns can diminish soil fertility, impeding mulberry cultivation. Additionally, elevated CO2 levels may alter nutrient uptake mechanisms in mulberry plants, further affecting silk quality. To mitigate these impacts, implementing soil conservation measures such as contour plowing, cover cropping, and organic amendments is crucial (Smith *et al.*, 2019).

7) Altered Ecosystems and Biodiversity Loss Impacting Sericulture

Climate change disrupts ecosystems, leading to biodiversity loss and habitat degradation. This, in turn, affects the natural predators and prey of silk-producing insects, thereby disrupting the delicate ecological balance essential for sericulture. For instance, alterations in temperature and precipitation regimes may favor the proliferation of pests and diseases detrimental to silkworms. Conservation efforts aimed at preserving biodiversity hotspots and restoring

degraded habitats are imperative for safeguarding sericulture-dependent ecosystems (Thomas *et al.*, 2020).

8) Socio-economic Impacts on Communities Dependent on Oak tasar culture

Communities reliant on sericulture for livelihoods face multifaceted socio-economic challenges exacerbated by climate change. Fluctuations in silk production due to environmental variability directly impact income stability and food security among sericulture-dependent populations. Moreover, extreme weather events like floods and droughts can devastate silk farms, leading to economic losses and exacerbating poverty. Strengthening community resilience through diversification of income sources, access to climate-smart agricultural practices, and social safety nets is essential for mitigating the socio-economic impacts of climate change on sericulture dependent communities (Khan *et al.*, 2021). The indirect impacts of climate change on sericulture underscore the need for holistic adaptation strategies encompassing soil conservation, biodiversity preservation, and socio-economic resilience building. By addressing these facets, policymakers, researchers, and stakeholders can forge pathways towards sustainable sericulture amidst a changing climate. Collaboration among diverse stakeholders, coupled with innovative technologies and policy interventions, is imperative for safeguarding this ancient yet fragile industry.

10.7. MITIGATION AND ADAPTATION STRATEGIES

- **Rearing techniques**: Shift to indoor/polyhouse rearing for early instars or sensitive periods to control temperature (e.g., 25±2°C) and humidity (70 ±5 %). Nylon nets can be used to protect pests and predators, hailstorm etc. Polyhouse and indoor rearing for early (chawki) instars protect vulnerable larvae from weather extremes and predators, with late-age transfer to outdoor oak trees or shaded nets. In northwest India (e.g., Himachal Pradesh, Uttarakhand), polyhouses regulate temperature (optimal 25±3°C) and humidity, boosting cocoon yields and economic traits while cutting costs. Northeast regions favor outdoor rearing with green shade nets and ventilation for grainage to maintain stable conditions amid climate variability.

  Successful indoor oak tasar rearing in Uttarakhand leverages controlled conditions at research stations and development projects, improving larval growth, economic traits, and disease resistance amid climate challenges.

- **Regional Tasar Research Station (RTRS), Bhimtal**

  Trials from 2015-2018 at RTRS Bhimtal (29°21'N, 79°33'E) shifted from semi-domestic to full indoor rearing of *Antheraea proylei* during spring crops. Conditions maintained 25±2°C and 70-75% RH with 12:12 L:D photoperiod, yielding higher fecundity (174.8 eggs/female vs. 148.3 outdoor), better larval weight, and improved silk traits like shell weight. This reduced production costs and disease risks from handling, outperforming pure outdoor methods (41 vs. 23 cocoons/DFL).

- **Uttarakhand Oak Tasar Development Project, Chamoli**

  Implemented in Joshimath block (Chamoli district) since 2018 with Central Silk Board funding, the project established chawki rearing centers for indoor rearing up to 2nd instar. Supported by Dept. of Sericulture and RTRS Bhimtal, it empowered tribal families via controlled seed production, cold storage and MGNREGA oak plantations, achieving self-sufficiency in basic/commercial seeds and value chain integration. Outcomes include stable infrastructure, employment, and minimized disease losses through disinfectants and appliances.

- **Broader Indoor Techniques in Northwest Uttarakhand**

  Polyhouse hybrids dominate, with indoor chawki (25±2°C, 70-75% RH) transitioning to shaded late-age rearing, as trialed in Uttarakhand/Himachal. Spring (March-April) crops excel,

with research showing superior growth over full indoor due to ventilation, aiding commercial viability for hill farmers.

- **Cost and Return Benefits**

  Indoor systems cut production costs through lower mortality, disease control (via 25±2°C, 70-75% RH), and reduced handling losses, yielding higher net returns per cycle. Outdoor rearing faces 50-55% losses from predators/weather, increasing re-rearing needs and costs, though it requires minimal infrastructure. Polyhouse hybrids (indoor chawki + shaded outdoor late-age) balance this, enhancing cocoon traits like shell weight and farmer income.

- **Breeding and selection**: Developing thermo-tolerant breeds through selective breeding enhances survival under heat stress, prioritizing polyvoltine strains with better thermal tolerance. Research promotes host-compatible ecoraces like those on *Quercus serrata* or *Q. incana* for higher emergence and nutrition. Use of genetic diversity from wild relatives can be taken up in breeding programmes.
- **Host plant management**: Agroforestry, conservation of oak stands, supplemental nutrition (e.g., foliar urea), and disease-resistant planting.
- **Seasonal adjustments**: Focus on optimal spring rearing; adjust schedules for changing climate.
- **Monitoring and technology**: Early warning for pests/diseases, climate-resilient practices, and biodiversity conservation (e.g., maintaining forest mosaics).
- **Integrated Pest and Disease Management**: Climate change can exacerbate the prevalence and distribution of pests and diseases in sericulture systems, posing significant threats to silk production. Integrated pest and disease management approaches, which combine biological, cultural, and chemical control methods, are essential for mitigating these risks sustainably. For example, introducing natural predators of common silk pests or employing pheromone-based traps can help control pest populations without relying solely on chemical pesticides, which may become less effective due to shifting pest dynamics under climate change (Gopalakrishnan *et al.*, 2021).
- **Policy/support**: Combine technological upgrades with training on climate perceptions to scale resilient practices, including genetic studies for drought/pest-tolerant oaks. Research into climate modeling for specific regions, subsidies for protected rearing, and livelihood diversification.

10.8. REFERENCES

Albough, D. (1986): Food plants of thirty six world wide saturniidae. Youth Entomol Soc. 39-43.

Crotch, W.J.B. (1956): A silkmoth rearers handbook. Amat. Entomol. Soc. 12 pp 165 (1969 reprint).

Gong, Z., Yang, J., Zhao, X., & Chen, Q. (2018). Advances in integrated pest management of the silkworm (Bombyx mori) in China. Journal of Pest Science, 91(3), 701-709. https://doi.org/10.1007/s10340-018-0963-2.

Khan, M. R., Ahmed, S., & Rahman, M. M. (2021). Climate change and its impact on socio economic aspects of sericulture. Journal of Agroforestry and Environment, 5(2), 143-156.

Li, X., Wang, Y., Liu, J., Zhang, H., & Chen, G. (2020). Effects of water stress on growth, photosynthetic characteristics and chloroplast ultrastructure of mulberry (Morus alba L.). Journal of Forestry Research, 31(5), 1787-1798. https://doi.org/10.1007/s11676-019 00987-3.

Seitz Z. A. (1933): The macrolepidoptera of the world. Palearetic fauna. Stuttgurt Alfred Kernel. 10: 509:516.

Singh N.I.; Singh N.I.; Keisa T.J.; Singh Y.R. & Singh K.C. (2000): Conservation and utilization of Indian oak fed *Antheraea* fauna. Int. J. of Wild Silkmoth & Silk. 5: 330-331.

Smith, A. B., Jones, C., & Taylor, M. (2019). Soil management in the face of climate change: A review of current knowledge. Journal of Soil and Water Conservation, 74(6), 520-530. https://doi.org/10.2489/jswc.74.6.520.

Thomas, C. D., Anderson, B. J., & Rondinini, C. (2020). Biodiversity conservation: Climate change and habitat loss are serious threats to biodiversity. Science, 350(6267), 490-491. https://doi.org/10.1126/science.aad4960.

Zhang, Y., Wang, S., Liu, Q., & Chen, W. (2019). Impact of temperature fluctuation on the growth and development of silkworm (Bombyx mori L.) based on Drosophila DDTF model. Journal of Thermal https://doi.org/10.1016/j.jtherbio.2019.01.011



MUGA AND ERI



CHAPTER 1: CLIMATE CHANGE AND MUGA SILK ECOSYSTEMS: MECHANISTIC UNDERSTANDING OF IMPACTS ON BIODIVERSITY, HOST PLANTS, SILKWORM BIOLOGY, SILK QUALITY, TRADITIONAL HERITAGE AND ADAPTATION STRATEGIES

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1.1. INTRODUCTION

India is the world's second-largest silk producer and the only country producing all four major commercial silk varieties, namely mulberry, tasar, eri, and muga silk. Among these, muga silk, popularly known as the "Golden Silk of Assam," is endemic to the Brahmaputra Valley and adjoining regions of Northeast India. According to the Central Silk Board, mulberry silk contributes approximately 75.68% of total silk production in India, whereas non-mulberry or vanya silk accounts for 24.32%; within this sector, muga silk contributes only about 0.56% of total national silk production (Central Silk Board, 2023). Despite its relatively low production share, muga silk possesses immense ecological, cultural, traditional, and economic significance for the indigenous communities of Assam and neighboring northeastern states.

Muga sericulture represents not merely an economic activity but also a symbol of Assamese cultural identity and heritage (Fig. 1). Traditional muga silk fabrics are extensively used in religious ceremonies, marriage rituals, festivals such as Bihu, and preparation of traditional attire including mekhela chador and ceremonial garments. The natural golden lustre, durability, and unique texture of muga silk make it internationally valued and culturally irreplaceable. However, climate change has emerged as one of the greatest threats to the sustainability of the muga silk industry, affecting host plant ecology, silkworm biology, cocoon productivity, reeling performance, weaving traditions, and rural livelihoods (Kumar and Shabnam, 2022).

Sericulture is highly climate-sensitive because temperature, relative humidity, rainfall, and seasonal variations directly influence host plant growth, silkworm physiology, disease incidence, and silk quality (Bukhari *et al.*, 2026). In Assam alone, nearly 3.53 lakh rural families across more than 20,000 villages depend on sericulture and allied activities for livelihood support (Central Silk Board, 2023). Therefore, climatic disturbances directly threaten socio-economic stability in the region. The muga silkworm, *Antheraea assamensis* Helfer, is highly sensitive to environmental stress due to its poikilothermic nature. The optimum temperature and relative humidity required for successful muga rearing are approximately 25–27°C and 75–85%, respectively. Exposure to temperatures above 35–40°C severely affects larval metabolism, feeding behaviour, moulting, silk gland development, and cocoon formation (Rahmathulla, 2012; Manzoor and Qayoom, 2024; Saini *et al.,* 2023).

The impact of climate change on muga host plants, particularly som (*Persea bombycina*) and soalu (*Litsea monopetala*), is equally severe. High temperature and moisture stress reduce leaf moisture, chlorophyll content, and protein availability, thereby lowering nutritional quality for silkworm larvae. Studies have shown that drought and elevated temperature significantly reduce leaf yield

and physiological efficiency in host plants (Guha, Rasineni and Reddy, 2010). Jigyasu *et al.* (2023) reported that som plants exposed to environmental stress showed increased antioxidant activity and altered physiological responses, indicating severe oxidative stress conditions. Irregular rainfall patterns further disrupt synchronization between leaf flushing and silkworm brushing operations, causing poor larval growth and increased crop failure.

Climate change also intensifies disease and pest incidence in muga ecosystems. Heavy rainfall, fluctuating humidity, and elevated temperature favour outbreaks of viral, bacterial, and fungal diseases such as flacherie, grasserie, and muscardine. Surveys have indicated that nearly 72% of farmers observed increased pest and disease incidence under changing climatic conditions. Seasonal crops such as Aherua and Bhadia are particularly vulnerable to pathogen outbreaks and predator attacks due to excessive rainfall and humidity fluctuations. Consequently, cocoon productivity, seed multiplication, and larval survival are severely reduced.



Figure 1: Muga Silk production under changing environmental condition along with survival strategies, limitation and opportunities

The traditional six annual crop cycles of muga silkworm Jethua, Aherua, Bhadia, Kotia, Jarua, and Chatua are increasingly disrupted by climatic irregularities. Floods, droughts, prolonged winter, and erratic monsoon patterns alter voltinism, larval duration, cocoon quality, and seed availability. Reduced cocoon production directly affects silk reeling and weaving industries, particularly in traditional weaving centres such as Sualkuchi, often referred to as the "Manchester of the East." Decline in raw silk availability has increased production costs and reduced employment opportunities among traditional weavers and artisans dependent on muga silk processing and textile production.

Climate change additionally threatens the genetic diversity and ecological distribution of muga silkworm populations. Although distinct ecoraces are not well defined in muga silkworms, significant morphological and genetic variability exists among geographically isolated populations.

Variations in larval colouration, cocoon characteristics, and adaptability have been reported across Northeast India. Molecular studies using RAPD and ISSR markers demonstrated considerable genetic diversity within native populations, highlighting the importance of in situ conservation for long-term sustainability (Singh *et al.*, 2012; Sarmah *et al.*, 2011). However, habitat degradation, deforestation, pollution, and climatic stress are rapidly eroding this valuable genetic resource.

To sustain the muga silk industry under changing climatic conditions, integrated adaptation and mitigation strategies are essential. Conservation of indigenous germplasm, development of thermotolerant breeds, climate-resilient host plant management, disease forecasting systems, and relocation of seed crops to climatically suitable regions are critical interventions (Mondal *et al.*, 2023; Kumar *et al.*, 2025). Adoption of indoor rearing technologies, eco-friendly disinfection protocols, and scientific pest management practices can further reduce climatic risks. Strengthening traditional ecological knowledge with modern biotechnology and climate-smart sericulture practices will be vital for preserving the ecological, economic, and cultural heritage associated with the "Golden Silk" industry of Northeast India (Bhatia *et al.*, 2022).

1.2. DIVERSITY AND DISTRIBUTION OF Antheraea assamensis

Muga silkworm (*Antheraea assamensis* Helfer; Family: Saturniidae) is an economically and culturally significant semi-domesticated silkmoth species endemic to northeastern India. It is exclusively responsible for producing the famous golden-yellow muga silk, internationally valued for its natural lustre, strength, durability, and unique texture (Gull *et al.*, 2026). Muga silk represents an important component of the traditional heritage and rural economy of Assam and adjoining northeastern states, where sericulture supports the livelihoods of thousands of farming and weaving households. Assam alone contributes more than 90% of total muga silk production in India, making it the principal centre of muga culture (Bindroo and Deb, 2006).

The geographical distribution of *A. assamensis* is largely confined to the Brahmaputra Valley and adjoining hill regions due to its narrow ecological adaptability and dependence on specific environmental conditions. Besides Assam, the species occurs in Meghalaya, Nagaland, Arunachal Pradesh, Manipur, Mizoram, and parts of West Bengal, with limited distribution reported from neighbouring Bhutan under similar agro-climatic conditions (Bindroo and Deb, 2006). The silkworm thrives under subtropical climatic conditions characterized by high humidity, moderate rainfall, and temperatures ranging from 20°C to 30°C. Seasonal climatic variation strongly influences larval growth, cocoon development, fecundity, and silk productivity.

The diversity of *A. assamensis* is reflected through differences in voltinism, ecological adaptation, host plant preference, cocoon morphology, and genetic variability. Traditionally, six commercial crops are reared annually in Assam, namely Jethua, Aherua, Bhodia, Kotia, Jaruwa, and Chotua, each adapted to specific seasonal environmental conditions (Chowdhury, 1982). Seasonal fluctuations significantly affect larval survival, cocoon weight, shell ratio, filament quality, and silk yield. Although the species exhibits some physiological adaptability to varying environmental conditions, extreme climatic fluctuations negatively affect cocoon productivity and survival rates.

The primary host plants of muga silkworm are som (*Persea bombycina*) and soalu (*Litsea monopetala*), while several secondary host plants including *Litsea salicifolia*, *Cinnamomum glaucescens*, and *Actinodaphne* species also support larval development under natural conditions (Singh and Das, 2015). Diversity in host plant utilization contributes to ecological adaptation and influences larval duration, cocoon weight, shell thickness, filament properties, and silk quality.

Considerable variability has also been observed in cocoon colour, size, shell thickness, and filament characteristics among different ecological populations of muga silkworm across northeastern India.

Molecular studies using RAPD, ISSR, and mitochondrial DNA markers have revealed substantial genetic diversity among geographically isolated populations of *A. assamensis* (Sarmah *et al.*, 2011). Such genetic variability is highly valuable for breeding programmes, conservation efforts, and development of climate-resilient strains suitable for changing environmental conditions. However, habitat degradation, deforestation, declining host plant resources, disease outbreaks, and climate change are increasingly threatening the natural diversity and distribution of muga silkworm populations.

Conservation and sustainable utilization of *A. assamensis* diversity therefore require integrated scientific and ecological approaches. Strengthening in situ and ex situ conservation programmes, establishment of germplasm banks, molecular characterization of diverse populations, and preservation of natural habitats are essential for long-term sustainability of muga sericulture. Improvement of host plant resources, development of climate-resilient silkworm strains, adoption of scientific rearing technologies, and climate-smart sericulture practices will be crucial for mitigating climate-related risks and ensuring sustainable muga silk production under changing environmental conditions.

1.3. IMPACT OF CLIMATE CHANGE ON DIVERSITY AND DISTRIBUTION OF MUGA SILKWORM, CONSEQUENCES AND ADAPTATION STRATEGIES

Climate change has emerged as a serious threat to the diversity, distribution, survival, and productivity of muga silkworm populations because the species is highly sensitive to environmental fluctuations. Rising temperature, erratic rainfall, prolonged drought, floods, and increased humidity variability are altering the ecological suitability of traditional muga-growing regions and affecting both host plants and silkworm biology. Climate change has emerged as one of the most critical challenges affecting the sustainability of muga sericulture. According to the Intergovernmental Panel on Climate Change (IPCC), global temperatures are projected to increase by approximately 1.5°C between 2030 and 2052, which may intensify environmental stress on silkworms and their host plants (IPCC, 2023). Rising temperatures, irregular rainfall patterns, prolonged droughts, floods, and increased frequency of extreme weather events are adversely affecting host plant growth, silkworm rearing cycles, cocoon productivity, and disease incidence in traditional muga-growing regions. Elevated temperature and humidity fluctuations reduce larval survival, disturb moulting and feeding behaviour, and negatively affect cocoon quality and voltinism patterns.

Climate-induced deterioration in cocoon quality also affects silk reeling efficiency, weaving performance, and market value of muga silk products. Reduced filament strength, uneven denier formation, and lower silk lustre increase processing losses and reduce the commercial competitiveness of the muga silk industry. Since muga sericulture is largely practiced by rural and tribal communities, climate-related decline in silk productivity directly threatens livelihood security and socio-economic stability in northeastern India

Recent climatic observations in northeastern India indicate an increase of approximately 0.8–1.0°C in mean annual temperature over the last century, accompanied by irregular monsoon patterns and frequent extreme weather events (Karur and Narmada, 2026). Muga silkworm performs optimally at temperatures between 24–28°C and relative humidity of 75–85%. Exposure to temperatures above 32°C significantly reduces larval survival, feeding efficiency, cocoon weight, and silk gland development (Manjunatha *et al.*, 2010). High temperature stress also disturbs larval metabolism

and moulting behaviour, resulting in poor cocoon formation and reduced silk yield. Studies have shown that prolonged exposure to heat stress may reduce cocoon productivity by 20–35% and increase larval mortality by nearly 15–25% in tropical sericulture systems (Kumar and Nath, 2024).

Climate variability also affects the geographical distribution and seasonal occurrence of muga silkworm populations. Increased flooding and changes in rainfall distribution in Brahmaputra valley ecosystems have adversely affected the availability and productivity of primary host plants such as som (*Persea bombycina*) and soalu (Litsea *polyantha*). Drought stress and excessive rainfall reduce leaf moisture, nutrient composition, and biomass production of host plants, ultimately affecting larval nutrition and cocoon quality (Guha *et al.*, 2010). Reduction in host plant availability forces migration or contraction of traditional muga culture zones, thereby threatening the genetic diversity and ecological stability of indigenous muga populations.

Climate-induced environmental stress has further increased the incidence of pests and diseases in muga culture ecosystems. Warmer and humid conditions favour the multiplication of pathogenic microorganisms causing pebrine, grasserie, muscardine, and bacterial infections. Disease outbreaks during summer and rainy seasons frequently lead to heavy crop losses in northeastern sericulture regions. Environmental instability also affects silk fibre quality by reducing filament length, lustre, tensile strength, and shell ratio, thereby lowering commercial value of muga silk products.

The socio-economic consequences are substantial because muga culture supports thousands of rural and tribal households in northeastern India. Declining cocoon productivity and increased crop failures reduce farmer income, threaten traditional livelihoods, and weaken the cultural heritage associated with muga silk production. Reduced silk quality also decreases market competitiveness and export potential of premium golden muga silk fabrics.

Adaptation and mitigation strategies are therefore essential for sustaining muga sericulture under changing climatic conditions. Development of climate-resilient host plant varieties tolerant to drought and flooding can improve ecosystem stability and leaf availability. Scientific plantation management, mulching, rainwater harvesting, and micro-irrigation systems can help conserve soil moisture during dry periods. Introduction of climate-resilient silkworm strains with improved thermo-tolerance and disease resistance is also becoming increasingly important.

Microclimate management technologies such as fogging systems, shade-net plantations, and humidity regulation in rearing houses can substantially reduce heat stress during extreme summer conditions. Early warning systems for disease outbreaks and climatic anomalies can help farmers adopt timely preventive measures. Integration of biodiversity conservation programmes and in situ preservation of indigenous muga germplasm are necessary to protect the genetic diversity of this unique silkworm species. Furthermore, government support through climate-smart sericulture policies, crop insurance, farmer training, and technological modernization will play a critical role in ensuring long-term sustainability of muga silk production under climate change scenarios.

Table 1: Impact of climate change on diversity and distribution of muga silkworm, respective consequences and adaptation/mitigation strategies

Climate Change Factor	Impact on Diversity and Distribution of *Antheraea assamensis*	Consequences for Muga Sericulture	Adaptation / Mitigation Strategies	Supporting References
Rising temperature	Increase in average temperature alters larval metabolism, feeding behaviour, growth duration, voltinism and survival of *Antheraea assamensis*. Temperatures above optimum levels reduce fecundity and cocoon quality.	Decline in cocoon productivity, reduced silk quality, lower larval survival and increased crop failure during summer seasons.	Development of thermo-tolerant silkworm races, climate-controlled rearing houses and improved microclimate management.	Karur and Narmada (2026); Manjunatha *et al.* (2010); Rahmathulla (2012)
Erratic rainfall patterns	Irregular rainfall affects the availability and seasonal flushing of host plants such as som (*Persea bombycina*) and soalu (*Litsea polyantha*), thereby disturbing the natural distribution of muga silkworm populations.	Reduced food availability, asynchronous larval development and decline in cocoon yield.	Rainwater harvesting, irrigation support and climate-resilient host plant management.	Sudan *et al.* (2025); Guha *et al.* (2010)
Drought stress	Drought reduces leaf moisture, chlorophyll content and nutritional quality of host plants, negatively influencing silkworm feeding and growth.	Poor larval development, reduced cocoon weight and increased susceptibility to diseases.	Drought-tolerant host plant varieties and mulching practices.	Jiao *et al.* (2021); Sun *et al.* (2023); Susheelamma *et al.* (1990)
Habitat alteration and forest degradation	Climate change accelerates habitat fragmentation and ecological degradation in northeastern India, affecting the natural habitat range of wild and semi-domesticated muga silkworm populations.	Loss of genetic diversity and shrinking distribution of indigenous muga ecotypes.	Conservation of host plant biodiversity and establishment of climate-resilient gene banks.	Saha and Mondal (2026); Karur and Narmada (2026)
Increased pest and disease incidence	Warmer and humid conditions favour multiplication of pathogens, parasitoids and predators affecting *A. assamensis*.	Increased larval mortality and decline in cocoon productivity.	Integrated pest and disease management and environmental monitoring systems.	Savitha *et al.* (2026); Manzoor and Qayoom (2024)

Climate Change Factor	Impact on Diversity and Distribution of *Antheraea assamensis*	Consequences for Muga Sericulture	Adaptation / Mitigation Strategies	Supporting References
Seasonal instability	Changes in seasonal cycles disturb synchronization between silkworm life cycle and host plant phenology.	Irregular broods, poor cocoon formation and unstable silk production.	Adjustment of crop calendars and climate-based forecasting systems.	Rahmathulla (2012); Reddy *et al.* (2013)
Increased extreme weather events	Floods, storms and heat waves damage host plantations and outdoor rearing environments in Assam and adjoining regions.	Sudden crop losses and reduction in traditional muga-producing areas.	Climate-resilient plantation models and disaster preparedness systems.	Tiwari *et al.* (2018); Sudan *et al.* (2025)
Elevated atmospheric CO_2 and environmental stress	Elevated CO_2 and climatic variability alter host plant physiology and secondary metabolites, influencing feeding preference and larval performance.	Variability in cocoon quality, filament strength and silk colour.	Research on host plant physiology under climate stress and nutritional supplementation.	Lüthy *et al.* (2025); Guha *et al.* (2010)

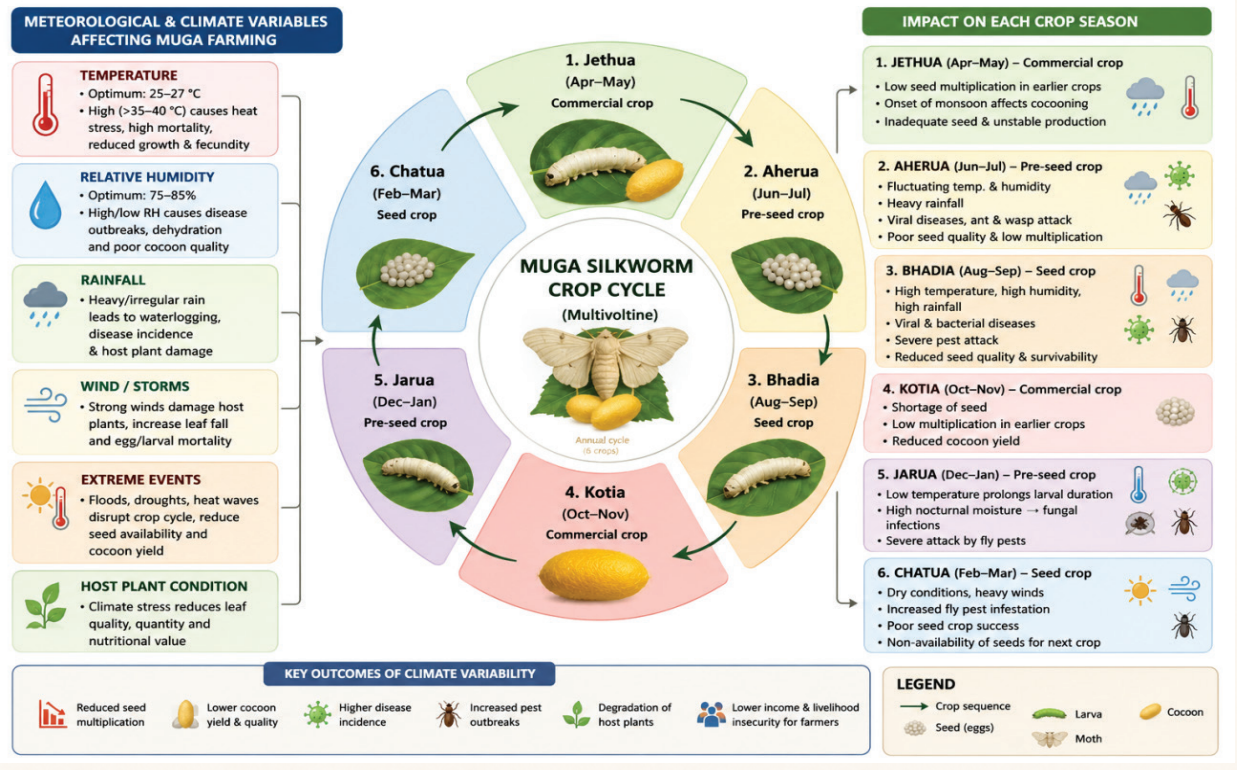


Figure 2: Crop cycling of muga silkworm as well as meteorological and climate variables that affect farming conditions.

(c) Yellow Coloured larva

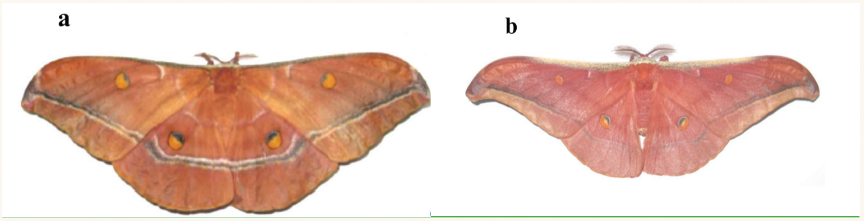
(Rarely found in nature)



(a) Green Coloured larva (Most abundantly found in nature)

(b) Blue Coloured larva (Rarely found in nature)

(c) Yellow Coloured larva (Rarely found in nature)



(d) Female moth

(e) Male moth

Figure 3: Colour variants in Muga larvae (a) green coloured larva is most abundantly found in nature, (b) blue, and (c) yellow colour can also be seen in nature but their occurrence is rare. Size and colour of (d) female moths and(e) male moth.

1.3.1. Impact On Silkworm Biology And Physiology

Muga silkworms are highly sensitive poikilothermic organisms whose physiological and metabolic activities are directly regulated by ambient environmental conditions. Climatic fluctuations, particularly rising temperature, erratic rainfall, drought, and humidity imbalance, significantly affect silkworm growth, silk gland development, nutrient assimilation, water balance, respiration, moulting, spinning behaviour, and reproductive performance. Since muga silkworm rearing is conducted under outdoor semi-natural conditions, climate variability has emerged as a major threat to sustainable cocoon production and silk quality.

1.3.2. Thermal Stress

Temperature stress is one of the most critical climatic factors affecting silkworm biology. Elevated temperature disrupts cellular homeostasis by impairing protein synthesis and damaging vital biomolecules including DNA, RNA, membrane lipids, and enzymes, whereas low temperature prolongs larval duration and suppresses growth rates. Studies indicate that optimum environmental conditions of 25–27°C temperature and 75–85% relative humidity are essential for normal growth and development of muga silkworms (Singh *et al.*, 2024). Exposure to temperatures above 30°C significantly reduces feeding efficiency, larval weight, cocoon formation, and survival percentage. Similarly, temperatures below 20°C slow metabolic activity and prolong developmental duration, thereby reducing productivity (Jigyasu *et al.*, 2024).

Research findings showed that exposure of silkworm larvae to high temperature stress (36 ± 1°C) combined with low humidity (35 ± 5%) reduced larval survival by nearly 25–30%, cocoon weight by 18–22%, and shell ratio by approximately 15% compared with optimum environmental conditions (Kumar and Nath, 2024). High temperature also affects digestive physiology by disturbing gut microbial equilibrium, reducing digestive enzyme activity, and impairing nutrient absorption and assimilation (Gull *et al.*, 2025). Sun *et al.* (2022) reported that thermal stress altered intestinal

microbial diversity and reduced nutrient utilization efficiency in silkworms, ultimately affecting silk protein synthesis and cocoon quality. Climatic stress additionally weakens the immune system of larvae, increasing susceptibility to bacterial, viral, fungal, and protozoan diseases.

1.3.3. Molecular Response

At the molecular level, silkworms activate several stress-responsive mechanisms to tolerate adverse environmental conditions. Heat shock proteins (Hsps) play an important role in protecting cells against thermal injury by stabilizing *proteins*, preventing denaturation, and maintaining metabolic functions. Molecular studies conducted in *Antheraea mylitta*, which shares ecological similarities with muga silkworm, demonstrated significant upregulation of heat shock proteins under elevated temperature stress. Expression of Hsp70 increased approximately fourfold, whereas Hsp21 showed nearly 2.5-fold upregulation under heat stress conditions, indicating the dominant role of Hsp70 in conferring thermal tolerance (Mahesh *et al.*, 2024). These molecular adaptations help maintain protein folding, cellular integrity, and metabolic stability during environmental stress. However, prolonged exposure to severe climatic conditions may exceed physiological tolerance limits and lead to irreversible cellular damage.

1.3.4. Reproductive Response

Temperature and humidity strongly influence reproductive physiology, fecundity, egg viability, and fertility of muga silkworms. Being exothermic organisms, silkworm reproductive processes exhibit a sigmoidal response to temperature, with maximum reproductive efficiency occurring within the optimum range of 25–28°C (Rahmathulla, 2012). Deviations beyond this range adversely affect reproductive performance. Biram *et al.* (2009) observed that exposure to elevated temperature significantly reduced egg production and hatching percentage in silkworms. Similarly, Verma *et al.* (2011) and Dinesh and Balkhande (2013) reported that prolonged thermal stress reduced oviposition rate, induced partial sterility, and lowered reproductive efficiency.

Experimental observations indicated that temperatures exceeding 32°C reduced fecundity by approximately 20–35% and decreased egg hatchability by nearly 15–25% compared with optimum rearing conditions (Keshan *et al.*, 2014). Low humidity conditions further impair embryonic development and increase egg mortality. Such reproductive abnormalities directly affect seed cocoon production and continuity of commercial muga crops.

1.3.5. Spinning Behaviour And Cocoon Formation

Climatic stress significantly influences spinning behaviour and cocoon quality in silkworms. High temperature adversely affects silk gland physiology and fibroin secretion, often causing mature larvae to die before cocoon spinning. Heat stress also reduces spinning efficiency, cocoon compactness, filament continuity, and shell thickness. In contrast, low temperatures slow spinning activity and produce loose, weak cocoons with inferior filament quality. Studies revealed that exposure to temperatures above 35°C reduced spinning success by nearly 30% and significantly lowered filament length and cocoon shell weight (Shabnam *et al.*, 2024).

1.3.6. Field-Level Observations Under Climate Variability

Field observations across northeastern India indicate that increasing climatic variability, including erratic rainfall, drought, floods, and declining winter moisture, has adversely affected host plant quality, silkworm health, and cocoon productivity. Farmers have reported increased incidence of pests and diseases along with substantial reductions in cocoon yield and silk quality under fluctuating climatic conditions. Exposure to temperatures above 30°C or below 20°C negatively affects larval

survival, moulting, feeding behaviour, spinning efficiency, and seed cocoon production, ultimately reducing the Effective Rate of Rearing (ERR). In several muga-growing regions, climate-induced stress has reduced cocoon productivity by approximately 20–40%, threatening the long-term sustainability of traditional sericulture systems (Singh *et al.*, 2024).

1.4. IMPACT ON HOST PLANT MAINTENANCE

The quality and nutritional status of host plant foliage are among the most critical determinants of successful muga cocoon production. Climate change-induced alterations in temperature, rainfall, humidity, and atmospheric pollution have significantly affected the physiology, phenology, and nutritional composition of the primary host plants of Muga silkworm, namely Som (*Persea bombycina*) and Soalu (*Litsea monopetala*). Heat stress conditions reduce leaf moisture content, protein concentration, chlorophyll stability, and photosynthetic efficiency, thereby directly affecting silkworm growth and cocoon productivity.

During summer, exposure of Som and Soalu plants to temperatures above the optimum physiological threshold induces stomatal closure, which restricts transpiration and reduces carbon assimilation and photosynthetic efficiency (Jigyasu *et al.*, 2023). Elevated temperature also accelerates tissue desiccation and water loss from foliage, substantially lowering leaf moisture content. Since Muga silkworm larvae are highly dependent on moisture-rich leaves for digestion and nutrient assimilation, feeding on dehydrated leaves prolongs larval duration, reduces feed conversion efficiency, and lowers cocoon yield. Experimental studies have reported that high-temperature stress may reduce leaf moisture content by 15–25%, resulting in significant decline in larval growth and cocoon weight (Karur and Narmada, 2026).

To counteract oxidative and thermal stress, Som plants enhance the production of antioxidant compounds, particularly ascorbic acid (vitamin C), in their foliage. Jigyasu *et al.* (2023) observed significantly higher ascorbic acid concentration and Air Pollution Tolerance Index (APTI) values in Som leaves collected from polluted industrial regions compared with non-polluted areas. The study further revealed that APTI values were higher during summer than winter, indicating comparatively greater physiological tolerance under warmer conditions. A strong positive correlation between APTI and ascorbic acid content highlighted the protective role of antioxidant mechanisms against oxidative damage caused by atmospheric pollutants and environmental stress.

Climate variability also increases the incidence of host plant diseases. High temperature combined with elevated humidity creates highly favourable conditions for pathogenic infection in Som and Soalu plantations. Grey blight disease, one of the most destructive foliar diseases of muga host plants, exhibits maximum virulence at approximately 25°C under high humidity conditions, causing severe lesions on tender leaves and rendering them unsuitable for silkworm feeding (Singh and Das, 2015). Such disease outbreaks substantially reduce the availability of healthy foliage during critical rearing periods.

During winter months, low ambient temperatures significantly reduce metabolic activity in *P. bombycina*, restricting leaf expansion and increasing leaf shedding. Consequently, the availability of tender leaves required for early instar chawki silkworms becomes limited. Unseasonal fluctuations in temperature further disrupt natural phenological cycles, causing mismatch between silkworm egg hatching and emergence of fresh foliage. Surveys in Assam reported that nearly 83% of farmers observed phenological mismatch between leaf flushing and silkworm brushing due to erratic rainfall and altered seasonal patterns (Saha and Mondal, 2026).

1.4.1. Effect of Climate Change on Persea bombycina and Litsea monopetala, Physiological and Biochemical Responses, Consequences on Muga Silkworm Rearing and Adaptation Strategies

Muga silk (obtained from *Antheraea assamensis)* is indigenous to Assam and holds deep cultural and traditional significance in Assamese Society. This multivoltine and polyphagous species primarily feeds on the aromatic leaves of Som (*Persea bombycina*). Optimal rearing conditions for Muga silkworms require temperatures ranging between 24–32 °C and relative humidity of 80–85%. Climate projections by IPCC indicate a global surface temperature rise of ~1.5 °C, with CO_2 concentrations reaching 560–700 ppm by 2100. In India's northeastern region, including Assam, temperatures are projected to increase by 1.8–2.1 °C posing significant threats to the sustainability of the age-old Muga silk tradition (Karur and Narmada, 2026).

Despite these risks posed on Muga sericulture, systematic research examining the specific effects of climate change particularly elevated CO_2 and temperature on Muga culture remains limited in India. A study was undertaken at CSB-CMER&TI, Lahdoigarh, Jorhat, Assam, to assess both the beneficial and adverse effects of climate change on Muga sericulture. The research specifically aimed to quantify its impact on the quality and yield of Som leaves and Muga seed crop production, with a focus on promoting climate-resilient sericulture practices. The experiment was carried out over three years using four Open Top Chambers (OTCs) simulating distinct environmental conditions: elevated CO_2 (eCO_2: 550 ± 20 ppm), elevated temperature (eTemp: +1.5 °C above ambient), a combination of eCO_2 and eTemp, and ambient conditions (aCO_2: 400 ± 20 ppm) as the control.

In the host plant, total carbohydrates and carotenoids increased by ~46% and ~11%, respectively, while key quality parameters such as protein, amino acids, ascorbate, chlorophyll *b* and leaf moisture content declined by 10-25%. In silkworms, haemolymph carbohydrates increased, but protein and lipid levels decreased. Adverse effects were also observed by reduced larval duration, cocoon and pupal weights (reduced by ~45%), effective rearing rate (2%) and fecundity (reduced by 14.2%), highlighting the potential threat of climate change to sustainable Muga silk production.

High temperature and moisture stress directly affect the physiological functioning of *Persea bombycina* and *Litsea monopetala*. Drought conditions reduce stomatal conductance, chlorophyll content, leaf water potential, and photosynthetic efficiency, ultimately lowering leaf biomass production and nutritional quality. Studies on climate-stressed host plants indicated reductions of 25–40% in leaf moisture content and 18–32% decline in chlorophyll concentration under severe heat and water stress conditions (Sun *et al.*, 2023). Elevated temperature also accelerates transpiration and oxidative stress, leading to membrane damage and accumulation of reactive oxygen species (ROS). Biochemical analyses revealed increased activity of stress-related enzymes such as peroxidase, catalase, and superoxide dismutase in drought-affected host plants, indicating physiological attempts to tolerate climatic stress (Jiao *et al.*, 2021).

Climate variability further alters the biochemical composition of host leaves by reducing protein, carbohydrate, amino acid, and mineral concentrations essential for muga silkworm nutrition. Decline in nitrogen metabolism and soluble protein content adversely affects larval digestion, growth rate, and silk gland development. Under high-temperature conditions exceeding 38–40°C, host plant leaves become coarse, fibrous, and nutritionally deficient, reducing palatability and feed conversion efficiency in muga larvae (Guha *et al.*, 2010). Heat stress also increases premature leaf senescence and defoliation, thereby reducing leaf availability during critical silkworm rearing periods.

The consequences of climatic stress on muga silkworm rearing are substantial. Poor host plant quality directly affects larval growth, survival, cocoon formation, and silk quality. High temperature combined with low humidity weakens larval immunity and increases susceptibility to bacterial, viral, fungal, and protozoan diseases. Studies reported that elevated temperatures above 35°C reduced larval survival by 20–30% and decreased cocoon yield by nearly 25–40% in tropical sericulture systems (Manzoor and Qayoom, 2024). Climatic stress also reduces cocoon shell ratio, filament length, and silk lustre, thereby lowering the commercial value of muga silk. Frequent droughts and floods in Assam have further disrupted traditional outdoor rearing systems by damaging host plantations and affecting synchronization between leaf availability and silkworm crop cycles (Sudan *et al.*, 2025).

Adaptation strategies are therefore essential for sustaining muga sericulture under changing climatic conditions. Development and cultivation of drought-tolerant and heat-resilient Som and Soalu genotypes can improve host plant survival and leaf productivity under climatic stress. Improved agronomic practices such as mulching, drip irrigation, rainwater harvesting, and organic soil management help conserve soil moisture and reduce heat stress. Agroforestry-based plantation systems and mixed host plant cultivation can further moderate microclimatic fluctuations and enhance ecosystem resilience.

Climate-resilient silkworm management practices including seasonal crop adjustment, shaded rearing, microclimate regulation, and disease surveillance are increasingly important for maintaining cocoon productivity. Adoption of climate forecasting and early warning systems can help farmers avoid exposure of silkworm crops to extreme weather events. In addition, conservation of genetic diversity in muga host plants and silkworm races through germplasm preservation programs is essential for long-term climate adaptation. Integration of scientific research, farmer training, and climate-smart sericulture technologies will play a critical role in ensuring sustainable muga silk production under future climate scenarios.

Table 2: Effect of climate change on *Persea bombycina* and *Litsea monopetala,* respective physiological/ biochemical effects, consequences of muga silkworm rearing and adaptation strategies

Climate Change Factor	Impact on Muga Host Plants (*Persea bombycina* and *Litsea monopetala*)	Physiological / Biochemical Effects	Consequences for Muga Silkworm Rearing	Adaptation / Mitigation Strategies	References
Rising temperature	Reduced leaf production and accelerated leaf senescence in som (*Persea bombycina*) and soalu (*Litsea monopetala*)	Decline in chlorophyll content, photosynthetic efficiency and moisture retention	Poor leaf quality reduces larval feeding efficiency, cocoon weight and silk yield	Development of heat-tolerant host plant genotypes, microclimate management and mulching	Karur and Narmada (2026); Tiwari *et al.* (2018)

Climate Change Factor	Impact on Muga Host Plants (*Persea bombycina* and *Litsea monopetala*)	Physiological / Biochemical Effects	Consequences for Muga Silkworm Rearing	Adaptation / Mitigation Strategies	References
Drought stress	Reduced vegetative growth, shoot development and leaf biomass	Reduced stomatal conductance, relative water content and nutrient uptake	Nutritional deficiency in larvae leading to weak growth and lower cocoon productivity	Drip irrigation, rainwater harvesting and drought-resistant varieties	Guha, Rasineni and Reddy (2010); Sun *et al.* (2023)
Irregular rainfall	Waterlogging and root damage affecting host plant survival	Root hypoxia, reduced nutrient absorption and leaf yellowing	Reduced availability of healthy leaves during critical silkworm rearing periods	Proper drainage systems and raised bed plantation	Sudan *et al.* (2025); Savitha *et al.* (2026)
Low atmospheric humidity	Rapid desiccation and wilting of leaves	Loss of leaf moisture and reduced succulence	Poor digestibility and reduced food conversion efficiency in silkworm larvae	Fogging systems and maintenance of shade trees around plantations	Rahmathulla (2012); Sujatha *et al.* (2024)
Elevated atmospheric CO_2	Increased vegetative growth but altered nutrient composition	Increased carbohydrate accumulation and reduced nitrogen concentration in leaves	Imbalanced nutrition affecting larval metabolism and silk protein synthesis	Nutrient management and balanced fertilization	Lüthy *et al.* (2025); Jiao *et al.* (2021)
Heat waves	Scorching and drying of tender leaves	Cellular membrane damage and oxidative stress	Severe reduction in leaf palatability and larval feeding	Shade-net cultivation and agroforestry approaches	Ashrith *et al.* (2025); Karur and Narmada (2026)
Increased pest and disease incidence	Higher susceptibility of host plants to fungal pathogens and insect pests	Tissue necrosis and reduction in healthy foliage	Transmission of pathogens and reduced leaf availability for silkworm feeding	Integrated pest management and biological control measures	Savitha *et al.* (2026); Sudan *et al.* (2025)
Soil moisture fluctuation	Poor root establishment and nutrient imbalance	Reduced mineral uptake and physiological stress	Inferior leaf quality affecting cocoon shell ratio and filament quality	Soil moisture conservation and organic mulching	Guha, Rasineni and Reddy (2010); Tiwari *et al.* (2018)
Extreme climatic events (storms and floods)	Physical damage to plantations and uprooting of host plants	Destruction of canopy architecture and root systems	Disruption in continuous leaf supply for muga silkworm crops	Climate-resilient plantation design and shelterbelts	Manzoor and Qayoom (2024); Saha and Mondal (2026)

Climate Change Factor	Impact on Muga Host Plants (*Persea bombycina* and *Litsea monopetala*)	Physiological / Biochemical Effects	Consequences for Muga Silkworm Rearing	Adaptation / Mitigation Strategies	References
Seasonal variability	Altered flushing pattern and asynchronous leaf availability	Disturbance in phenological cycles	Mismatch between leaf availability and silkworm rearing schedule	Climate-based crop scheduling and plantation diversification	Karur and Narmada (2026); Savitha *et al.* (2026)

1.4.2. Disease Incidence and Pest Prevalence:

Climate change has significantly increased the prevalence of diseases and insect pests in muga sericulture ecosystems. Rising temperature, excessive humidity, and irregular rainfall create favourable environmental conditions for pathogens and pests to survive and proliferate throughout the year. Recent field studies indicated that approximately 72% of muga farmers observed increased outbreaks of fungal diseases and higher infestation of uzi fly associated with climatic stress and changing environmental conditions (Sudan *et al.*, 2025). Seasonal mortality due to diseases such as pebrine, flacherie, and grasserie is considerably higher during summer and monsoon seasons because environmental stress weakens larval immunity and increases susceptibility to infection. Excessive humidity during monsoon favours rapid multiplication of pathogenic microorganisms, while heat stress during summer disturbs larval physiology and digestive metabolism, enhancing disease vulnerability (Sujatha *et al.*, 2024). These disease outbreaks significantly reduce effective rate of rearing (ERR), cocoon quality, and silk productivity. Furthermore, applications of silkworm crop products, such as sericin in food coating or functional textiles, are bound to suffer if quality diminishes due to climate anomalies (Ravindra *et al.*, 2024).

Table 3: Impact of climate change in disease of muga host plant and muga silkwom and suggestive ameliorative measures

Climate change factor	Disease / pest affected	Impact on muga host plant / silkworm	Quantitative observations	Suggestive ameliorative measures	Key references
Increased temperature (≥35°C) and prolonged heat waves	Flacherie disease in muga silkworm	Heat stress weakens larval metabolism, reduces immunity, and increases pathogen susceptibility	High temperature and low RH conditions reduced larval survival by 20–35% and increased disease incidence during summer crops	Maintenance of optimum rearing temperature (24–28°C), fogging systems, shaded plantation, indoor rearing during extreme summer	Flacherie Rahmathulla (2012); Manzoor and Qayoom (2024); Sudan *et al.* (2025)

Climate change factor	Disease / pest affected	Impact on muga host plant / silkworm	Quantitative observations	Suggestive ameliorative measures	Key references
High humidity (>85%) and monsoon rainfall	Muscardine (fungal disease)	Excess moisture favours fungal sporulation on larvae and rearing surfaces	Monsoon crops experience 25–40% higher fungal infection compared with winter crops	Proper ventilation, bed disinfectants, spacing of larvae, regular cleaning and lime application	Muscardine Sujatha *et al.* (2024); Sarkhel *et al.* (2017)
Temperature fluctuation and humid conditions	Grasserie disease	Viral multiplication increases under stressful environmental fluctuations	Disease outbreaks increase significantly during humid summer and rainy seasons, causing major cocoon crop loss	Hygienic rearing, temperature stabilization, use of disease-free layings (DFLs), periodic disinfection	Grasserie Rahmathulla (2012); Sudan *et al.* (2025)
Climatic stress and poor nutrition	Pebrine disease	Weak larvae become more susceptible to microsporidian infection and reproductive failure	Pebrine incidence rises during nutritionally stressed crops and may reduce cocoon harvest substantially	Mother moth examination, certified seed production, nutritional supplementation, environmental monitoring	Pebrine Manzoor and Qayoom (2024); Sujatha *et al.* (2024)
Irregular rainfall and warm humid climate	Uzi fly infestation	Climatic instability enhances survival and multiplication of parasitoid pests	Around 72% of farmers reported increased pest and disease outbreaks linked to climate variability	Uzi traps, biological control, synchronized brushing, net covering, field sanitation	Uzi fly Borah and Goswami (2026); Sudan *et al.* (2025)
High humidity and moderate temperature (~25°C)	Grey blight disease of Som plant	Severe lesions develop on tender leaves, reducing leaf quality for feeding	Grey blight pathogen shows maximum virulence near 25°C under high humidity conditions	Resistant host plant varieties, pruning, fungicidal spray, improved drainage and aeration	Grey blight Jigyasu *et al.* (2023); Singh and Das (2015)

Climate change factor	Disease / pest affected	Impact on muga host plant / silkworm	Quantitative observations	Suggestive ameliorative measures	Key references
Drought and low soil moisture	Leaf wilting and nutritional decline in Som and Soalu	Reduced photosynthesis, leaf moisture, protein content, and leaf biomass	Drought stress significantly lowers leaf moisture and affects larval growth and cocoon weight	Irrigation scheduling, mulching, drought-tolerant host plant genotypes, agroforestry approaches	Drought stress Guha *et al.* (2010); Sun *et al.* (2023)
Air pollution and oxidative stress	Physiological injury in Som host plant	Increased oxidative stress reduces foliage quality and affects larval feeding	Higher ascorbic acid and APTI values observed in polluted areas indicating stress adaptation	Plantation belts, pollution monitoring, antioxidant management, conservation plantations	Air Pollution Tolerance Index Jigyasu *et al.* (2023)
Extreme climatic variability and habitat degradation	Decline in wild muga populations	Reduced biodiversity, altered voltinism, and disrupted ecological adaptation	Population decline and cocoon productivity loss reported in traditional muga belts of Assam	In situ and ex situ conservation, germplasm banks, climate-resilient breeding programmes	Antheraea assamensis Sarmah *et al.* (2011); Saha and Mondal (2026)
Elevated CO_2 and changing seasonal patterns	Host plant phenological mismatch	Asynchrony between leaf flushing and egg hatching affects chawki larvae survival	Erratic rainfall reported by nearly 83% of farmers causing brushing mismatch	Climate forecasting, adjusted crop calendar, controlled chawki rearing, phenology monitoring	Phenology Lüthy *et al.* (2025); Borah and Goswami (2026)

1.4.3. Effect of Climate Change on Muga Silk Reeling, Weaving, Silk Quality, Economy and Mitigation Strategies:

Climate change has emerged as a serious challenge to the sustainability of muga sericulture in northeastern India, particularly in Assam where muga silk production is geographically concentrated. Muga silkworm (*Antheraea assamensis* Helfer) is highly sensitive to environmental fluctuations because its rearing is entirely outdoor and host plant dependent. Rising temperature, erratic rainfall, prolonged droughts, floods, and increased humidity variability have significantly affected cocoon production, silk reeling efficiency, weaving performance, and overall economic returns from the muga silk industry. Climatic abnormalities have also intensified pest and disease incidence in muga host plants such as som (*Persea bombycina*) and soalu (*Litsea monopetala*), thereby reducing leaf quality and silkworm productivity (Karur and Narmada, 2026).

High temperature stress above 35°C and excessive rainfall during rearing seasons adversely affect larval survival, cocoon formation, shell ratio, and filament continuity in muga silkworms. Studies

reported that elevated temperature and humidity fluctuations can reduce cocoon productivity by 25–40% and significantly decrease effective rate of rearing (ERR) under field conditions (Sudan *et al.*, 2025). Climatic stress also affects cocoon compactness and silk gland physiology, leading to poor filament extraction during reeling. Under unfavourable environmental conditions, filament breakage frequency increases considerably, thereby reducing reeling efficiency and raw silk recovery. Variability in temperature and atmospheric moisture also alters the natural golden lustre, tensile strength, elasticity, and fibre uniformity of muga silk, which directly affects weaving quality and fabric durability (Sarkhel *et al.*, 2017).

The weaving sector is equally vulnerable to climate-induced deterioration in silk quality. Poor filament continuity and uneven denier formation reduce loom efficiency and increase yarn breakage during weaving operations. Excessive moisture absorption under humid conditions weakens yarn strength and reduces fabric smoothness, while high temperature exposure may cause brittleness in silk fibres. Traditional muga weaving industries in Assam have reported increased production losses and higher labour requirements due to declining raw silk quality under changing climatic conditions (Saha and Mondal, 2026). Since muga silk is globally valued for its natural golden colour, durability, and luxury appeal, even slight reductions in lustre and fibre quality significantly affect market demand and export potential.

The economic consequences of climate change on the muga silk industry are substantial because the sector supports thousands of rural households, tribal communities, and women artisans engaged in host plant cultivation, silkworm rearing, reeling, spinning, dyeing, and weaving. Reduced cocoon yield and inferior silk quality lower market prices and increase processing costs. Floods and droughts frequently damage host plantations, disrupting the continuity of cocoon production cycles and threatening livelihood security in rural Assam. Studies have indicated that climate variability can reduce annual muga cocoon productivity by nearly 30% in highly vulnerable districts of northeastern India (Karur and Narmada, 2026). Increased energy requirements for maintaining suitable storage and processing conditions further add to production costs, reducing profitability for small-scale silk producers.

Several mitigation and adaptation strategies are being promoted to reduce climate-related risks in muga sericulture. Development of climate-resilient som and soalu host plant varieties tolerant to drought and excess moisture is becoming increasingly important. Improved silkworm breeding programmes focusing on thermo-tolerant and disease-resistant muga strains are also essential for sustaining cocoon productivity under changing climatic conditions. Adoption of scientific rearing practices, shade-net plantations, microclimate regulation, and rainwater harvesting systems can help maintain favourable environmental conditions for outdoor silkworm rearing (Sujatha *et al.*, 2024).

Technological interventions such as climate monitoring systems, automated humidity management, solar-powered drying units, and improved reeling machines are enhancing resilience and silk quality. Community-based plantation management, agroforestry approaches, and integrated pest management are further contributing to sustainable muga production systems. Government support through climate adaptation programmes, crop insurance, infrastructure development, and skill training for rural weavers is also crucial for protecting the socio-economic stability of the muga silk industry under future climate change scenarios.

Table 4: Impact of climate change on muga silk reeling, weaving, silk quality, economy and mitigation strategies

Climate Change Factor	Impact on Muga Silk Reeling	Impact on Muga Silk Weaving	Consequences for Silk Quality and Economy	Adaptation / Mitigation Strategies	Key References
Rising temperature and heat waves	Increased brittleness of cocoons and filament breakage during reeling; reduced reelability and lower raw silk recovery	Reduced yarn strength and elasticity causing warp breakage during weaving	Poor lustre, uneven denier, decline in fabric durability and reduced market value of muga silk	Climate-controlled reeling units, evaporative cooling systems, heat-tolerant silkworm strains and improved cocoon storage	Karur and Narmada (2026); Rahmathulla (2012)
Low relative humidity during summer	Rapid drying of cocoons during storage and cooking, causing irregular filament unwinding	Increased yarn roughness and difficulty in maintaining weaving tension	Reduced fibre smoothness, poor weaving efficiency and inferior fabric texture	Automated humidity regulation systems and fogging technology in rearing and reeling houses	Manzoor and Qayoom (2024); Sujatha *et al.* (2024)
Erratic rainfall and drought	Decline in quality of host plant leaves (*Machilus bombycina* and *Litsea polyantha*) affecting cocoon shell weight and filament quality	Irregular yarn thickness affects loom performance and fabric uniformity	Reduction in cocoon yield and shortage of weaving-grade silk yarn	Rainwater harvesting, drought-tolerant host plant varieties and mulching practices	Guha *et al.* (2010); Sudan *et al.* (2025)
Excess rainfall and flooding	Increased fungal contamination and cocoon spoilage during storage and transportation	Delays in dyeing and weaving due to excess atmospheric moisture	Increased post-harvest losses and reduction in raw silk quality	Improved drainage systems, climate-resilient storage infrastructure and early warning systems	Savitha *et al.* (2026); Karur and Narmada (2026)
Increased disease and pest incidence	Greater occurrence of pebrine, flacherie and fungal infections affecting cocoon quality and reelability	Poor yarn continuity and increased wastage during weaving	Economic losses due to reduced silk productivity and increased management cost	Disease-resistant silkworm breeds, disinfection measures and environmental monitoring	Ashrith *et al.* (2025); Rahmathulla (2012)

Climate Change Factor	Impact on Muga Silk Reeling	Impact on Muga Silk Weaving	Consequences for Silk Quality and Economy	Adaptation / Mitigation Strategies	Key References
Fluctuating seasonal conditions	Variability in cocoon cooking behaviour and filament extraction efficiency	Seasonal inconsistency in yarn texture and weaving quality	Lower consistency in premium-quality muga fabric production	Standardized cocoon conditioning and controlled reeling technologies	Kumar *et al.* (2025); Sarkhel *et al.* (2017)
Increased energy requirement under extreme climate	Higher electricity consumption for cooling, ventilation and cocoon processing	Increased operational costs in weaving and dyeing units	Reduced profitability of small-scale muga silk industries	Solar-powered reeling machines and energy-efficient weaving technologies	Liu *et al.* (2025); Saha and Mondal (2026)
Climate-induced reduction in cocoon productivity	Reduced availability of quality cocoons for reeling operations	Insufficient raw silk supply for handloom and textile industries	Loss of livelihood for tribal and rural households dependent on muga silk production	Climate-smart sericulture practices and diversification of income sources	Central Silk Board (2023); Ortiz-Bobea *et al.* (2021)

1.5. SOCIO-ECONOMIC VULNERABILITY

Climate change poses serious socio-economic challenges to the muga silk industry in Assam and northeastern India. Assam has been identified as a highly climate-vulnerable region with a climate vulnerability index of approximately 0.72, placing thousands of sericulture-dependent households at risk (Karur and Narmada, 2026). Declining cocoon productivity and increasing crop failure directly affect the livelihoods of farmers, reelers, weavers, and rural artisans associated with muga culture. Commercial muga production has consistently struggled to achieve the targeted annual production level of 150 metric tons. Individual farmers have reported substantial declines in cocoon harvests, with annual cocoon production decreasing from nearly 30,000 cocoons to less than 18,000 cocoons under severe climatic stress, resulting in almost 40–50% reduction in annual household income (Saha and Mondal, 2026). In Sualkuchi, popularly known as the "Manchester of the East," declining raw silk availability has adversely affected weaving activities, leading to reduced employment opportunities and economic instability among traditional weaving communities.

1.5.1. Effect of climate change on traditional and cultural aspect of muga producing communities, socio-cultural consequences and required respective adaptation measures:

Muga silk, produced by the silkworm *Antheraea assamensis*, is deeply associated with Assamese cultural heritage and is traditionally used in ceremonial attire such as mekhela chador, gamosa, and religious textiles. The production system is highly climate-sensitive because the silkworm is semi-domesticated and depends on specific host plants and stable environmental conditions.

Increasing temperature, erratic rainfall, floods, prolonged droughts, and humidity fluctuations have significantly affected muga silkworm survival and cocoon productivity. Studies indicate that high temperature above 32–34°C and excessive rainfall increase larval mortality, disease incidence,

and crop failure in muga culture (Karur and Narmada, 2026). Climate variability has reduced the availability and quality of primary host plants such as som (*Persea bombycina*) and soalu (*Litsea polyantha*), leading to decline in cocoon production and household income among traditional rearers (Sujatha *et al.*, 2024). In Assam, repeated flood events and changing rainfall patterns have caused substantial losses in muga cultivation areas, with some districts reporting cocoon yield reduction of 30–40% during extreme climatic years (Sudan *et al.*, 2025).

The socio-cultural consequences are equally significant. Muga silk production traditionally involves family-based labour systems in which women play a central role in silkworm rearing, spinning, dyeing, and weaving. Climate-induced decline in productivity has reduced participation of younger generations in sericulture due to economic uncertainty and migration toward alternative occupations. This gradual withdrawal threatens the transmission of indigenous weaving skills, traditional motifs, and cultural practices associated with muga textiles. Studies have shown that nearly 60–70% of rural households engaged in muga sericulture depend partly or fully on silk-related activities for livelihood security in several regions of Assam (Central Silk Board, 2023). Declining productivity therefore directly affects cultural continuity, social identity, and rural economy.

Climate change also threatens traditional festivals and ceremonial uses of muga silk because reduced production increases market prices and limits accessibility of authentic handwoven textiles. Consequently, climate stress not only affects biological production systems but also endangers the socio-cultural heritage and traditional knowledge networks of muga silk producing communities.

Table 5: Impact of climate change on traditional and cultural aspect of muga producing communities, socio-cultural consequences and required respective adaptation measures.

Climate Change Factor	Impact on Traditional and Cultural Aspects of Muga Silk Producing Communities	Socio-cultural Consequences	Required Adaptation Responses	Supporting References
Rising temperature and prolonged heat waves	Decline in survival and productivity of muga silkworm (*Antheraea assamensis*) reared traditionally in open environments	Reduced continuation of traditional family-based sericulture practices and weakening of intergenerational knowledge transfer	Adoption of improved host plant management, climate-resilient silkworm strains and altered rearing calendars	Bhattacharya and Goswami (2020); Karur and Narmada (2026)
Erratic rainfall and drought	Reduced availability and quality of host plants such as som (*Persea bombycina*) and soalu (*Litsea monopetala*) used in traditional muga culture	Disruption of seasonal rearing festivals and customary livelihood cycles among Assamese tribal communities	Rainwater harvesting, agroforestry and drought-resilient host plant cultivation	Goswami *et al.* (2019); Sudan *et al.* (2025)

Climate Change Factor	Impact on Traditional and Cultural Aspects of Muga Silk Producing Communities	Socio-cultural Consequences	Required Adaptation Responses	Supporting References
Floods and extreme weather events	Destruction of outdoor silkworm rearing systems and host plantations in Assam and Northeast India	Loss of household income affecting traditional weaving households and community-based silk enterprises	Elevated rearing platforms, community nurseries and climate-risk insurance schemes	Baruah *et al.* (2018); Savitha *et al.* (2026)
Increased pest and disease incidence	Frequent outbreaks of pebrine, virosis and fungal diseases under humid conditions	Decline in ceremonial use of authentic muga silk garments in marriages, festivals and cultural rituals due to reduced availability and rising prices	Improved disease surveillance, hygienic rearing and scientific extension support	Rahmathulla (2012); Manzoor and Qayoom (2024)
Loss of biodiversity and forest degradation	Reduction in natural habitat supporting traditional muga ecosystem and wild silkworm populations	Erosion of indigenous ecological knowledge and weakening of ethnic identity linked with muga culture	Conservation of traditional host plant biodiversity and community-based forest management	Das and Das (2014); Sun *et al.* (2023)
Seasonal variability affecting cocoon quality	Inferior cocoon colour, lustre and filament quality affecting authenticity of traditional muga textiles	Reduced market value of culturally significant muga products such as mekhela chador and ceremonial fabrics	Scientific rearing practices and improved post-harvest processing technologies	Datta and Nanavaty (2005); Kumar *et al.* (2025)
Migration and livelihood insecurity	Declining profitability in traditional sericulture forcing youth migration to urban occupations	Decline in participation of younger generations in traditional weaving and spinning occupations	Skill development, value addition and promotion of sustainable silk entrepreneurship	Saha and Mondal (2026); Central Silk Board (2023)
Climate-induced economic stress	Increased production costs and unstable cocoon yield reduce financial sustainability of traditional weaving communities	Weakening of women-led household weaving traditions and indigenous craft-based rural economy	Financial support, women-centric sericulture cooperatives and climate-smart livelihood diversification	Mahimasanthi *et al.* (2016); Ortiz-Bobea *et al.* (2021)

1.5.2. Remedial and Mitigation Measures:

Mitigation of climate change impacts on muga sericulture requires integrated scientific, technological, and ecological approaches. Conservation of genetic diversity through in situ conservation sites in

Assam, Bodoland Territorial Council (BTC), Meghalaya, and Arunachal Pradesh plays an important role in preserving wild muga populations and climate-resilient genetic resources. Molecular marker-assisted breeding programmes are being utilized to identify thermo-tolerant strains exhibiting higher heat shock protein (HSP) expression and improved climatic adaptability (Sarmah *et al.*, 2011). Technological interventions such as shifting early-stage rearing to controlled indoor environments can reduce exposure to adverse climatic conditions. Adoption of solar-powered reeling machines may reduce carbon emissions by nearly 60% while improving energy efficiency. Diversification of silkworm by-products also provides additional economic resilience because muga pupae are rich in proteins, oils, and bioactive compounds such as 1-Deoxynojirimycin (DNJ), which possesses blood glucose-lowering properties. Afforestation using host plants such as Som and Soalu contributes to carbon sequestration and functions as a natural "negative emission technology." Additional strategies include development of high-yielding and climate-tolerant muga breeds, implementation of strict disinfection and disease management protocols, establishment of pest and disease forecasting systems, and relocation of seed and pre-seed crops to comparatively cooler regions during adverse seasons. Experimental studies have further demonstrated the feasibility of rearing muga silkworm outside the Northeast region under suitable climatic conditions, offering new opportunities for sustainable seed production under changing climate scenarios.

1.6. CONCLUSION

Muga sericulture represents a unique amalgamation of biodiversity, traditional ecological knowledge, cultural heritage, and rural livelihood security in northeastern India, particularly in Assam, which contributes more than 90% of the country's total muga silk production. The semi-domesticated muga silkworm (*Antheraea assamensis*) is globally renowned for producing the naturally golden-coloured muga silk characterized by exceptional lustre, durability, elasticity, and texture. Beyond its economic value, muga silk occupies an important cultural and traditional position among the indigenous and tribal communities of Northeast India, where rearing, reeling, spinning, dyeing, and weaving practices have been preserved for generations. Traditional weaving centres such as Sualkuchi, popularly known as the "Manchester of the East," are closely associated with the socio-cultural identity and artisanal heritage of Assam. The species exhibits remarkable ecological and genetic diversity reflected through its voltinism, seasonal crop adaptation, host plant utilization, cocoon morphology, and silk characteristics. The existence of multiple seasonal crops such as Jethua, Aherua, Bhodia, Kotia, Jaruwa, and Chotua demonstrates the adaptive potential of the species under varying environmental conditions. The diversity available among different muga morphotypes and geographically isolated populations provides valuable genetic resources for future breeding and conservation programmes. However, the restricted geographical distribution of *A. assamensis* within the Brahmaputra Valley and adjoining hill ecosystems also makes the species highly vulnerable to climatic disturbances and habitat degradation.

Climate change has emerged as one of the most serious threats to the sustainability and productivity of muga sericulture. Rising temperatures, erratic rainfall, prolonged droughts, floods, humidity fluctuations, and increasing frequency of extreme climatic events have adversely affected silkworm physiology, reproductive performance, host plant growth, cocoon formation, and silk quality. High temperature stress reduces larval feeding efficiency, disturbs moulting and metabolic processes, and increases mortality, while low humidity rapidly desiccates host plant foliage, reducing leaf moisture and nutritional quality. Such physiological stress weakens larval immunity and enhances susceptibility to diseases such as pebrine, flacherie, grasserie, and fungal infections. Simultaneously, pathogenic outbreaks and pest infestations such as uzi fly have intensified under changing climatic conditions. Climate-induced deterioration in host plant quality and cocoon characteristics has

also negatively affected muga silk reeling and weaving industries. Reduced cocoon compactness, filament continuity, shell ratio, tensile strength, and natural golden lustre lower reeling efficiency and weaving performance, resulting in inferior fabric quality and higher production losses. Declining raw silk availability has significantly affected traditional weaving sectors, increasing economic vulnerability among rural households dependent on sericulture-based livelihoods. In several muga-growing regions, farmers have experienced substantial reductions in cocoon productivity and annual income due to climatic stress and crop failure. Despite these challenges, the rich genetic diversity available in muga silkworm populations provides significant opportunities for developing climate-resilient strains and sustainable adaptation strategies. Conservation of indigenous germplasm through in situ and ex situ approaches, molecular characterization of diverse populations, and development of thermo-tolerant and disease-resistant breeds are crucial for long-term sustainability. Scientific management of host plants, integrated nutrient and disease management, indoor and semi-indoor rearing practices, and climate-controlled seed production systems can substantially reduce environmental stress during critical rearing periods.

Technological interventions such as automated climate monitoring systems, pest and disease forecasting models, solar-powered and energy-efficient reeling technologies, and eco-friendly processing infrastructure can improve productivity while reducing environmental impact. Relocation of seed and pre-seed crops to climatically favourable regions, adoption of agroforestry-based host plant cultivation, and utilization of silkworm by-products for value addition may further enhance economic resilience. In addition, strengthening extension services, farmer training programmes, climate-smart sericulture policies, and community-based conservation initiatives will be essential for sustaining the muga silk industry.

Therefore, sustainable development of muga sericulture under changing climatic scenarios requires a multidisciplinary and integrated approach combining traditional ecological knowledge, biodiversity conservation, modern biotechnology, climate-resilient management practices, and strong policy support. Protecting the ecological diversity and cultural legacy of the “Golden Silk” industry is essential not only for maintaining rural livelihoods and economic stability in Northeast India, but also for preserving one of the world’s most unique and valuable natural silk traditions for future generations.

1.7. FUTURE PROSPECTS

The future sustainability of muga sericulture will largely depend on the successful integration of climate-resilient technologies, biodiversity conservation, and scientific management practices. Strengthening adaptive capacity through multidisciplinary research and farmer-oriented interventions can help preserve the ecological, economic, and cultural significance of the “Golden Silk” industry under changing climatic conditions.

- **Development of climate-resilient muga silkworm breeds** through selective breeding and molecular approaches for tolerance to high temperature, humidity fluctuations, and emerging diseases.
- **Conservation of indigenous genetic diversity** through in situ and ex situ germplasm preservation programmes to safeguard valuable muga morphotypes and wild populations.
- **Expansion of host plant improvement programmes** for Som (*Persea bombycina*) and Soalu (*Litsea monopetala*) to develop drought-tolerant, disease-resistant, and high leaf-yielding varieties.

- **Adoption of climate-smart rearing technologies**, including indoor and semi-indoor rearing systems, microclimate regulation, and automated environmental monitoring for reducing climatic stress.
- **Strengthening pest and disease forecasting systems** using GIS, remote sensing, artificial intelligence, and weather-based early warning models for timely management interventions.
- **Relocation of seed and pre-seed crops to climatically favourable regions** during adverse seasons to ensure uninterrupted production of healthy disease-free layings (DFLs).
- **Promotion of eco-friendly and energy-efficient silk reeling technologies**, including solar-powered reeling systems and low-carbon processing infrastructure to reduce environmental impact.
- **Development of integrated host plant management systems** involving agroforestry, rainwater harvesting, soil moisture conservation, and organic nutrient management for sustainable foliage production.
- **Utilization of silkworm by-products for value addition**, including extraction of proteins, oils, bioactive compounds, and medicinal products from pupae to diversify farmer income sources.
- **Strengthening traditional weaving industries and rural entrepreneurship** through improved raw silk supply chains, skill development, branding, and market support for muga silk products.
- **Enhancement of research in biotechnology and molecular genetics** for identification of thermo-tolerant genes, heat shock proteins (HSPs), and stress-responsive markers associated with climate resilience.
- **Implementation of strong policy support and community-based conservation programmes** to promote sustainable sericulture, livelihood security, biodiversity conservation, and preservation of the cultural heritage associated with muga silk production.

The future progress in muga sericulture will require coordinated efforts among researchers, policymakers, extension agencies, and farming communities to ensure sustainable production, climate resilience, and long-term conservation of this globally unique silk ecosystem.

1.8. REFERENCES

Ashraf, H. and Qamar, A. (2023) 'A review on heat stress altering the insect life history strategies and underlying mechanisms: Special reference to an economically important Lepidoptera, *Bombyx mori* (L.) (Lepidoptera: Bombycidae)', *SHILAP Revista de Lepidopterología*, 51(202), pp. 339–357. https://doi.org/10.57065/shilap.468

Ashrith, S., Pavithra, M.R., Harish Reddy, C., Jekinakatti, B., Arun Kumar, M.R. and Suhas, B.V. (2025) 'Climate change and its impact on sericulture: A brief review', *International Journal of Advanced Biochemistry Research*, 9(8), pp. 656–661.

Atlantis Press (2024) *Sustainable entrepreneurship in the silk sector of Northeast India*.

Baishya, M., Barman, H. and Rahman, S.A.S. (2019) 'Present status of eri-muga culture in NE region and related biodiversity resources as tool for sustainable economic uplifting of seri-stakeholders', *SSRG International Journal of Life Sciences*, 5(3), pp. 2284–2290. https://doi.org/10.21276/ssr-iijls.2019.5.3.3

Bhatia, A., Ghosh, A., Kumar, A. and Bhattacharyya, R., 2022. Greenhouse gas emission and carbon sequestration in conservation agriculture. In Conservation Agriculture in India (pp. 223-242). Routledge.

Bindroo, B.B. and Deb, D.C. (2006) *Manual on Muga Culture*. Bangalore: Central Silk Board, Ministry of Textiles, Government of India.

Borah, P. and Goswami, R. (2026) 'Changing climatic patterns and their implications for muga sericulture in Jorhat, Assam, India', *International Journal of Environment and Climate Change*, 16(4), pp. 422–429.

Bukhari, R., Gull, A., Rohela, G.K., Kumar, A. and Shabnam, A.A., 2026. Climate-Resilient Sericulture: Challenges, Prospects, and Opportunities in Temperate Mulberry Silk Production. In Sustainable Sericulture in India: Climate Change Impacts and Mitigation Strategies (pp. 51-77). Cham: Springer Nature Switzerland.

Central Silk Board (2023) *Annual Report 2022–23*. Bengaluru: Ministry of Textiles, Government of India.

Chowdhury, S.N. (1982) *Muga Silk Industry*. Shillong: Directorate of Sericulture and Weaving, Government of Assam.

Dewangan, S.K. (2013) 'Livelihood opportunities through sericulture: A model of Gharghoda tribal block, Raigarh district', *American Journal of Environmental Science*, 9(4), pp. 343–347.

Guha, A., Rasineni, G.K. and Reddy, A.R. (2010) 'Drought tolerance in mulberry (*Morus* spp.): A physiological approach with insights into growth dynamics and leaf yield production', *Experimental Agriculture*, 46(4), pp. 471–488.

Gull, A., Kumar, M.N.A. and Kumar, A., 2025. Influence of metal ions on the economic parameters of mulberry silkworm Bombyx mori (Lepidoptera: Bombycidae). Biologia Futura, 76(4), pp.521-533.

Gull, A., Mysore Nagaraj, A.K., Braxton, T., Kumar, A., Padhan, D., Bukhari, R., Koppa Rameshjois, S. and Aurade, R., 2026. Techno-mechanical and structural properties of Indian mulberry silkworm fibers: an insight into the structure–property relationship. Fibers, 14(5), p.53.

Hussain, M., Ahmad Khan, S., Naeem, M. and Nasir, M.F. (2011) 'Effect of rearing temperature and humidity on fecundity and fertility of silkworm, *Bombyx mori* L. (Lepidoptera: Bombycidae)', *Pakistan Journal of Zoology*, 43(5), pp. 979–985.

Indialogs (2025) *The socio-economic hurdles of the Muga industry in a changing world*.

Jiao, Y. *et al.* (2021) 'Molecular mechanism of mulberry response to drought stress revealed by complementary transcriptomic and iTRAQ analyses', *BMC Plant Biology*, 21, Article 488. https://doi.org/10.1186/s12870-021-03410-x

Jigyasu, D., Kumar, A., Shabnam, A., Begum, R., Singh, S., Malyan, S.K., Neog, K. and Vijayakumari, K.M. (2023) 'Air pollution tolerance index of *Persea bombycina*: Primary food plant of endemic muga silkworm (*Antheraea assamensis*)', *Heliyon*, 9(11), e21184.

Jigyasu DK, Patidar OP, Kumar A and Shabnam AA. (2024). Muga Silk Insect (Antheraea assamensis). In: Omkar (Ed.), Commercial Insects. CRC press, Taylor & Francis Group, pp 126-144, DOI: 10.1201/9781003454960

Karur, A.S. and Narmada, M. (2026) 'Climate change impacts on sericulture: Evidence from mulberry physiology, silkworm biology and northeast Indian muga ecosystems', *International Journal of Environment and Climate Change*, 16(4), pp. 281–291. https://doi.org/10.9734/ijecc/2026/v16i45360

Kumar, A. and Shabnam, A.A., 2022. Sericulture: prospect to address the global challenges of climate change and microplastic in textile sector. Plant Archives (09725210).

Kumar, A., Moharana, P.C., Jena, R.K., Malyan, S.K., Fagodiya, R.K., Shabnam, A.A., Vinodakumar, S.N., Jigyasu, D.K., Gull, A., Vijaya Kumari, K.M. and Subramaniam, G.D., 2025. Prediction of Soil Available Nitrogen Using Machine Learning and Digital Mapping Techniques in Northeast India. Environmental Challenges, p.101375.

Kumar, A., Singhal, N., Hore, N. and Tripathi, A. (2025) 'Impact of seasonal variations on filament length and non-broken filament length in relation to silk reeling performance', *UPJOZ*, 46, pp. 1–10.

Kumar, V. and Nath, B. (2024) 'Impact of high temperature (36±1°C) and low humidity (35±5%) on overall performance of *Bombyx mori* L.', *International Journal of Science and Research*, 13(8), pp. 818–821.

Liu, C. *et al.* (2025) 'Carbon footprint calculation and evaluation of mulberry silk quilts', *Textile Research Journal*.

Lüthy, L., Chapman, C.A., Lauer, P., Omeja, P. and Kalbitzer, U. (2025) 'Solar radiation and atmospheric CO_2 predict young leaf production in a moist evergreen tropical forest: Insights from 23 years', *arXiv*.

Manjunatha, H.B., Rajesh, R.K. and Aparna, H.S. (2010) 'Silkworm thermal biology: A review of heat shock response, heat shock proteins and heat acclimation in the domesticated silkworm, *Bombyx mori*', *Journal of Insect Science*, 10(204), pp. 1–31.

Manjunatha, M.H. (2006) 'Impact of heat shock on heat shock proteins expression, biological and commercial traits of *Bombyx mori*', *Insect Science*, 13(1), p. 243.

Manzoor, S. and Qayoom, K. (2024) 'Impact of climate change on sericulture', *Asian Research Journal of Agriculture*, 17(3), pp. 107–113. https://doi.org/10.9734/arja/2024/v17i3477

Mondal, R., Kumar, A. and Gnanesh, B.N., 2023. Crop germplasm: Current challenges, physiological-molecular perspective, and advance strategies towards development of climate-resilient crops. Heliyon, 9(1)

Ortiz-Bobea, A., Ault, T.R., Carrillo, C.M., Chambers, R.G. and Lobell, D.B. (2021) 'Anthropogenic climate change has slowed global agricultural productivity growth', *Nature Climate Change*, 11, pp. 306–312.

Prabhu, I.G., Bakshi, M., Jappa, M., Baig, M.M., Srivastava, P.P., Lokesh Kumar, N. and Sahay, A. (2018) 'Differential expression of heat shock proteins during heat stress in tropical tasar silkworm, *Antheraea mylitta*', *International Journal of Current Microbiology and Applied Sciences*, 7(12), pp. 2451–2457. https://doi.org/10.20546/ijcmas.2018.712.278

Rahmathulla, V.K. (2012) 'Management of climatic factors for successful silkworm (*Bombyx mori* L.) crop and higher silk production: A review', *Psyche: A Journal of Entomology*, 2012, Article ID 121234.

Ravindra, M.A., Gull, A., Padhan, D., Chandrakanth, N., Sobhana, V., Kumar, A., Thirupathaiah, Y. and Gandhi Doss, S., 2024. Application of Sericin in Food Industries and Coating of Fruits and Vegetables. In Biotechnology for Silkworm Crop Enhancement: Tools and Applications (pp. 289-302). Singapore: Springer Nature Singapore.

Reddy, A.P., Rao, C.G.P. and Suresh Kumar, N. (2013) 'Adaptive management practices in tropical sericulture under climate variability', *International Journal of Industrial Entomology*, 27(1), pp. 123–130.

Saha, S. and Mondal, R. (eds.) (2026) *Sustainable Sericulture in India: Climate Change Impacts and Mitigation Strategies*. Singapore: Springer Nature.

Saini, P., Rohela, G.K., Kumar, J.S., Shabnam, A.A. and Kumar, A. (2023) 'Cultivation, utilization, and economic benefits of Mulberry', in *The Mulberry Genome*. Cham: Springer International Publishing, pp. 13–56.

Sarkhel, S., Shrivastava, S. and Pouranik, M. (2017) 'The effective influence of temperature on the varied characteristic of silkworm: A review', *International Journal of Current Advanced Research*, 6(1), pp. 1745–1750.

Sarmah, M.C., Chakravorty, R., Neog, K., Das, R., Kumar, R. and Bindroo, B.B. (2011) 'Genetic diversity studies in muga silkworm (*Antheraea assamensis* Helfer) using molecular markers', *African Journal of Biotechnology*, 10(63), pp. 13752–13757.

Savitha, G., Moulidharshan, R., Nandha Kumar, R., Susikaran, S. and Akash, M. (2026) 'Climate change and sericulture sustainability: Impacts on mulberry production, silkworm biology, disease dynamics and silk productivity', *International Journal of Agricultural and Food Science*, 8(3), pp. 474–481.

Shabnam, A.A., Arunkumar, K.P., Kumar, A. and Jigyasu, D.K. (2024) *Handbook of Muga Culture*. 1st edn. Jorhat, Assam: Central Muga Eri Research and Training Institute, Central Silk Board.

Silk Beyond Fabric: Exploring the Diversity of Tasar Byproducts (2024) Ranchi: CSB-Central Tasar Research and Training Institute.

Singh, K.C. and Das, P.K. (2015) *Host Plants of Muga Silkworm and Their Management*. Jorhat: Central Muga Eri Research and Training Institute.

Singh, Y.T., Leighton, S.M., Saikia, M., Pant, P., Kashung, S., Neog, K., Chakravorty, R., Nair, S., Nagaraju, J. and Babu, C.R. (2012) 'Genetic variation within native populations of endemic silkmoth *Antheraea assamensis* from Northeast India indicates need for in situ conservation', *PLoS ONE*, 7(11), pp. 1–13.

Sudan, N., Devi, S., Qadir, J. and Naan, T. (2025) 'From mulberry to cocoon: The influence of climate variability on sericulture', *Journal of Biology and Nature*, 17(2), pp. 347–355. https://doi.org/10.56557/joban/2025/v17i29689

Sujatha, G., Gadde, A.K., Sai Teja, K.S. and Devi, D.L. (2024) 'A comprehensive review of the effect and mitigation of climate change on sericulture', *International Journal of Environment and Climate Change*, 14(7), pp. 776–788.

Sun, Z., Yin, Y., Zhu, W. and Zhou, Y. (2023) 'Morphological, physiological, and biochemical composition of mulberry (*Morus* spp.) under drought stress', *Forests*, 14(5), p. 949. https://doi.org/10.3390/f14050949

Susheelamma, B.N., Jolly, M.S., Giridhar, K. and Sengupta, K. (1990) 'Evaluation of germplasm genotypes for drought resistance in mulberry', *Sericologia*, 30(3), pp. 327–346.

Tiwari, G.S., Pareek, N. and Raverkar, K.P. (2018) 'Increased heat and drought stress under climate change and their impact on physiological growth and development of crops: A review', *Indian Journal of Agricultural Sciences*, 88(12), pp. 1793–1801.

CHAPTER 2: CHANGING CLIMATE AND ITS EFFECTS ON MUGA AND ERI SILK SECTORS: STRATEGIES FOR RESILIENCE

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2.1. INTRODUCTION

Climate change is one of the most serious global environmental challenges, exerting profound impacts on agriculture, forestry, biodiversity, ecosystem stability, and rural livelihoods. Continuous rise in global average temperature, erratic rainfall, prolonged droughts, floods, heat waves, and fluctuations in atmospheric humidity are increasingly disrupting natural and agricultural systems across the world. These environmental changes directly influence the crop productivity, soil health, water availability, and biological interactions within ecosystems. Among various agricultural and allied sectors, sericulture is considered highly climate sensitive because silkworms, being poikilothermic organisms, are extremely responsive to variations in environmental conditions. Even small changes in temperature and humidity may significantly affect silkworm growth, survival, cocoon production, and silk quality.

India occupies a unique position in global sericulture as it is the only country producing all four major commercial varieties of natural silk, namely mulberry, tasar, muga, and eri silk. Among these, muga and eri silks are traditionally practiced in the North Eastern states of India, particularly in Assam, Meghalaya, Nagaland, Arunachal Pradesh, and neighbouring areas. These non-mulberry silks are not only economically important but also deeply connected with the cultural traditions, ethnic identity, and rural livelihood systems of indigenous communities inhabiting the region.

Muga silk, popularly known as the "*the Golden Silk*," is produced by the semi-domesticated silkworm *Antheraea assamensis Helfer,* a species endemic to North East India. The species thrives only under specific ecological and climatic conditions and is highly sensitive to environmental fluctuations. Eri silk, produced by the domesticated silkworm *Samia ricini (*Donovan*)*, is another valuable non-mulberry silk recognized for its thermal insulation properties, durability, comfort, and eco-friendly nature. Eri silkworms are mainly reared on castor (*Ricinus communis L.*) and Kesseru (*Heteropanax fragrans*) along with several secondary host plants.

The sustainability and productivity of both muga and eri silk sectors are closely reliant on favourable climatic conditions because host plant quality, rearing and reproductive performance, and disease incidence are strongly regulated by environmental factors. Climatic abnormalities such as rising temperature, irregular rainfall, humidity fluctuations, floods, and prolonged dry periods adversely affect host plant physiology, silkworm health, and grainage operations, ultimately reducing cocoon yield and silk quality. In addition, changing climate conditions promote the proliferation of pests and pathogens, further increasing crop vulnerability and production losses. Therefore, climate variability has emerged as a major threat to the long-term sustainability, economic viability, and ecological stability of the muga and eri silk industries in North Eastern India.

2.2. CLIMATE CHANGE SCENARIO IN NORTH EASTERN INDIA

The North Eastern region of India is recognized as one of the biodiversity hotspots of the world. However, the region is highly vulnerable to climate change because of its fragile ecosystem, mountainous terrain, and dependence on rain-fed agriculture. The region comprising Assam, Arunachal Pradesh, Meghalaya, Manipur, Mizoram, Nagaland, Tripura, and Sikkim, is recognized

as one of the most ecologically sensitive and biodiversity-rich regions in the world. Agriculture is the primary livelihood source for a large proportion of the population in this region. However, the agricultural especially sericulture sector of NE India are highly vulnerable to changing climatic conditions because of their dependence on monsoon rainfall, fragile hilly ecosystems, shifting cultivation practices, and limited irrigation facilities. In recent decades, the region has experienced visible climatic abnormalities, including rising temperatures, erratic rainfall, prolonged dry spells, flash floods, landslides, and increased frequency of extreme weather events.

Several studies indicate that the average temperature in the NE region has been gradually increasing, while rainfall patterns have become increasingly unpredictable. Traditional rainfall cycles, which once supported stable agricultural operations, are now frequently disrupted. Delayed monsoon onset, uneven rainfall distribution, and sudden heavy precipitation events have adversely affected crop sowing, flowering, and harvesting periods. In the Brahmaputra and Barak valley of Assam, recurrent floods and riverbank erosion have become major constraints to agricultural sustainability, whereas hill states frequently face soil erosion, nutrient depletion, and landslides due to intense rainfall. Climate change is also influencing soil health, water availability, pest and disease infestation, and crop productivity. Raising temperatures and humidity fluctuations favour the outbreak of insect pests, diseases, and invasive weeds, resulting in higher crop losses. Plantation-based farming systems like sericulture are increasingly affected by climatic stress. The region is particularly vulnerable because of limited access to modern irrigation systems, climate-resilient technologies, crop insurance, and market infrastructure. Sectors closely associated with agriculture, such as sericulture, livestock, fisheries, and agroforestry, are also facing increasing environmental stress.

Recent climatic trends in the North Eastern region indicate a gradual increase in average annual temperature along with erratic rainfall distribution, prolonged dry spells, and a higher frequency of heavy rainfall and floods (Fig. 1). In addition, the region has been experiencing shorter winter periods, increased fluctuations in atmospheric humidity, and frequent storms accompanied by strong winds. These climatic abnormalities have serious implications for sericulture, as both silkworms and their host plants require relatively stable environmental conditions for optimum growth, survival, cocoon formation, and overall productivity.



Figure 1. A flood affected muga rearing field in Upper Assam

Despite these challenges, the North Eastern region possesses significant opportunities for climate-resilient sericulture due to its rich biodiversity, traditional practices, diverse agro-climatic zones, and scope for sustainable farming systems. Promotion of climate-smart integrated sericulture

farming systems and agro-forestry can help improve resilience and sustainability. Strengthening sericulture extension services, early warning systems and climate advisories, and policy support will be essential to minimize climate risks and ensure long-term stability in the region

2.3. EFFECT OF CLIMATE CHANGE ON MUGA SECTOR

Muga silkworms primarily feed on som (*Persea bombycina*) and soalu (*Litsea monopetala*) leaves. Climate change significantly affects the physiology, phenology, and overall health of these host plants through increased temperature, irregular rainfall, drought, and humidity fluctuations. Drought conditions reduce leaf moisture and succulence, while moisture stress often leads to premature leaf fall and delayed sprouting or flushing. In addition, climatic stress lowers leaf protein and nutrient content and increases the incidence of fungal diseases in host plants. Heavy rainfall and soil erosion further contribute to nutrient depletion in the soil, adversely affecting host plant growth and productivity. Since, host plant quality directly influences the larval growth, cocoon characteristics, and silk yield, poor nutritional status of leaves results in weak larvae, prolonged larval duration, reduced cocoon quality, and inferior silk production.

The silkworm is highly sensitive to environmental conditions, particularly temperature and humidity fluctuations. Since muga silkworms are reared in outdoor, even slight climatic abnormalities can significantly affect silkworm growth, survival, and cocoon production. Rising temperatures, irregular rainfall, prolonged dry periods, and sudden humidity changes associated with climate change have emerged as major constraints to sustainable muga sericulture. Extreme temperatures adversely affect egg viability and reduce hatchability, leading to crop loss. Heat stress during larval stages often increases larval mortality and weakens the physiological condition of the silkworms. This also disrupts normal moulting processes, resulting in irregular development, prolonged larval duration, and various developmental abnormalities. In addition, high temperature and moisture imbalance reduce feeding efficiency and digestion, thereby affecting nutrient utilization and silk protein synthesis. As such, weather parameters are regularly monitored in the muga silkworm rearing field under natural environmental conditions (Fig. 2).



Figure 2. Monitoring weather parameter in a muga silkworm rearing field

Changes in climatic conditions further affect cocoon characteristics, leading to reductions in cocoon shell ratio, shell weight, and overall silk quality. High temperatures accelerate larval metabolism, which increases energy consumption and reduces the conversion efficiency of nutrients into silk proteins. As a result, cocoons become lighter and less compact with inferior reelability. Such stresses also affect moth emergence, mating behaviour, and fecundity, ultimately reducing seed production and disease-free layings (DFLs). Overall, climate-induced physiological stress in muga silkworms

directly affects cocoon productivity, seed quality, and economic returns to farmers, posing a serious threat to the sustainability of the muga silk industry.

2.4. EFFECT OF CLIMATE CHANGE ON ERI SECTOR

Castor (*R. communis*) and Kesseru (*H. fragrans*) is the primary host plant of eri silkworms. Climatic stress such as irregular rainfall, drought, temperature, and humidity fluctuations significantly affect host plant cultivation affecting and its growth, leaf yield, and nutritional quality. Drought conditions reduce lea f biomass and moisture content, leading to poor leaf succulence and reduced palatability for silkworm feeding. Moisture stress also accelerates leaf senescence and alters the nutritional composition of leaves by reducing protein and essential nutrient content. In addition, climatic instability increases the susceptibility of castor plants to various pests and diseases, thereby affecting overall plant health and leaf availability.

Although eri silkworms are comparatively more adaptable to environmental variations than muga silkworms, changing climatic conditions still have considerable effects on their growth, development, and productivity. Temperature fluctuations, irregular humidity, and environmental stress negatively influence larval physiology and metabolic activities. Climatic abnormalities often result in reduced larval survival, prolonged larval duration, and poor larval growth due to decreased feeding efficiency and physiological stress. In addition, adverse climatic conditions reduce cocoon weight, shell recovery, and overall silk quality, thereby lowering economic returns to rearers. Extreme temperatures may further disrupt metabolic processes and impair silk gland development, resulting in poor silk protein synthesis and inferior cocoon characteristics. Climatic stress also contributes to a lower effective rate of rearing (ERR), making eri culture increasingly vulnerable under changing environmental conditions.

2.5. SEED PRODUCTION AND GRAINAGE

Silkworm seed production in both muga and eri is reliant on favourable climatic conditions, as environmental factors directly influence moth emergence, mating behaviour, oviposition, egg viability, and overall grainage efficiency. Abnormal weather conditions such as elevated temperature, irregular rainfall, excessive humidity, and dry weather adversely affect grainage operations and seed quality in both sectors. Climatic stress often reduces reproductive efficiency due to impaired mating behaviour, physiological stress, and moth longevity. In addition, unstable environmental conditions negatively influence on embryo development, resulting in poor egg quality, reduced hatchability (especially in muga sometimes ≤60%), and lower production of good quality seeds. Climate-induced disturbances also disrupt synchronized moth emergence, which is essential for successful mating and efficient seed production. Irregular emergence patterns create operational difficulties during grainage activities and affect the timely availability of quality seed for commercial rearers.

Further, environmental instability significantly affects seed crop performance and cocoon productivity in muga sericulture. Similarly, climatic stress influences egg viability, larval health, and round the year seed production in eri sericulture. Overall, climatic abnormalities pose serious challenges to grainage management both in muga and eri sectors by reducing the availability of healthy, quality seeds and affecting cocoon yield.

2.6. PEST AND DISEASE INCIDENCE

Rearing environment significantly influences the pest and disease dynamics both in muga and eri sericulture creating favourable conditions for the growth, survival, multiplication, and spread of pathogens and insect pests. Rising temperatures, rainfall, humidity, and extreme weather events increase the vulnerability of silkworm crops to biological stress and disease outbreaks. Fluctuations

in environmental conditions also increase the incidence of bacterial, fungal, viral, and parasitic diseases. Bacterial and viral infections are becoming more frequent during periods of excessive heat and humidity in muga culture. The rapid multiplications and infestations of the uzi fly (*Exorista sorbillans*) in muga culture are also influenced by climatic abnormalities (Fig. 3).

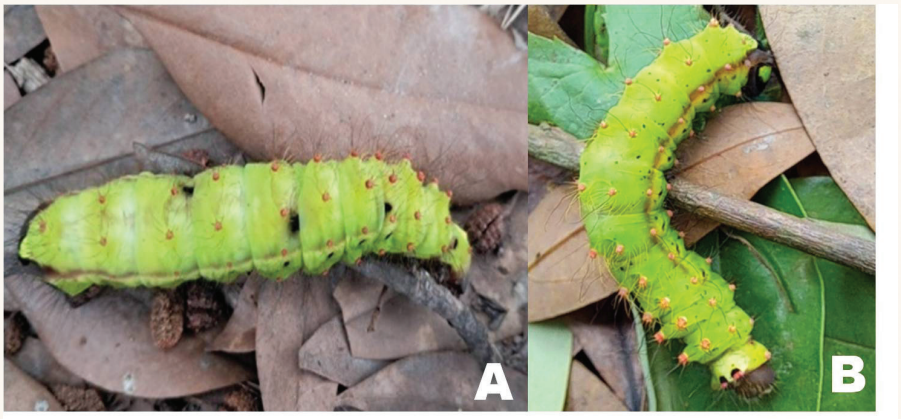


Figure 3. A-Uzi fly infested muga silkworm larva; B-Pebrine infected muga silkworm larva

In addition, outbreaks of predatory insects and parasitoids are becoming increasingly common in outdoor muga rearing. Similarly, bacterial flacherie incidence has become more prevalent under high temperature and humid conditions in eri sericulture causing substantial larval mortality. Humid environmental conditions further promote fungal contamination in rearing environments and host plant leaves. Furthermore, environmental changes may alter host–pathogen interactions and disease epidemiology by influencing pathogen virulence, transmission, and susceptibility. Overall, climate-driven changes in pest and disease incidence pose serious challenges to muga and eri silk production by increasing crop vulnerability, reducing cocoon productivity, and affecting the economic stability to the farmers.

2.7. SOCIO-ECONOMIC IMPACT

The muga silk sector plays a significant role in supporting the rural economy of North Eastern India, particularly among women, tribal communities, and small-scale farmers. Environmental stresses directly affect the income and economic stability of rearers by lowering the yield and increasing production costs associated with host plant management, disease control, and seed procurement. Repeated crop losses also discourage farmers from continuing sericulture activities, leading to a gradual decline in interest toward traditional muga culture. In many rural areas, reduced profitability and livelihood insecurity may further contribute to migration of younger populations to urban regions in search of alternative employment opportunities. Since muga culture is closely linked with the cultural and traditional identity of Assam, climate change poses not only an economic challenge but also a threat to the preservation of traditional knowledge and heritage associated with muga sericulture.

On the other hand, eri culture is an important cottage-based and eco-friendly rural industry that supports economically weaker sections of society, particularly women and small household-based entrepreneurs. The sector provides additional income, employment opportunities, and livelihood security through activities such as silkworm rearing, spinning, weaving, and value addition. However, climate-related production losses caused by drought, irregular rainfall, pest outbreaks, and reduced host plant availability significantly affect eri silk productivity and rural income generation. In addition, climatic stress may contribute to food and nutritional insecurity among

vulnerable farming communities that rely heavily on agriculture and allied sectors for survival. Since women constitute a major workforce in eri-based cottage industries, reduced production also limits employment opportunities and negatively impacts socio-economic empowerment in rural areas. Overall, climate change has emerged as a serious challenge to the livelihood security and sustainability of communities dependent on eri sericulture.

2.8. MITIGATION AND ADAPTATION STRATEGIES

Mitigation and adaptation strategies are essential to minimize the adverse impacts of climate change on sericulture sustainability, silkworm health, and silk productivity (Fig. 4). Effective implementation of climate-resilient management practices, conservation of host plant resources, development of stress-tolerant silkworm breeds, and adoption of sustainable sericulture technologies will be crucial to ensure the long-term sustainability and productivity of the sericulture sector under changing climatic conditions. A few important such strategies aimed at reducing the adverse effects of climatic abnormalities on sericulture and ensuring sustainable silk production are discussed below-

Development and conservation of climate-resilient host plant are essential for ensuring sustainable muga and eri sericulture under changing environmental conditions. Selection and cultivation of drought-tolerant host plant varieties can improve resilience against moisture stress and temperature fluctuations. Promotion of mixed cropping and agroforestry-based farming systems may further enhance ecological stability and reduce climate-induced risks. Sustainable soil management practices such as organic farming, mulching, application of biofertilizers, and vermicomposting can improve soil fertility, moisture retention, and microbial activity. In addition, rainwater harvesting and micro-irrigation systems can ensure better water availability during prolonged dry periods and support healthy host plant growth.

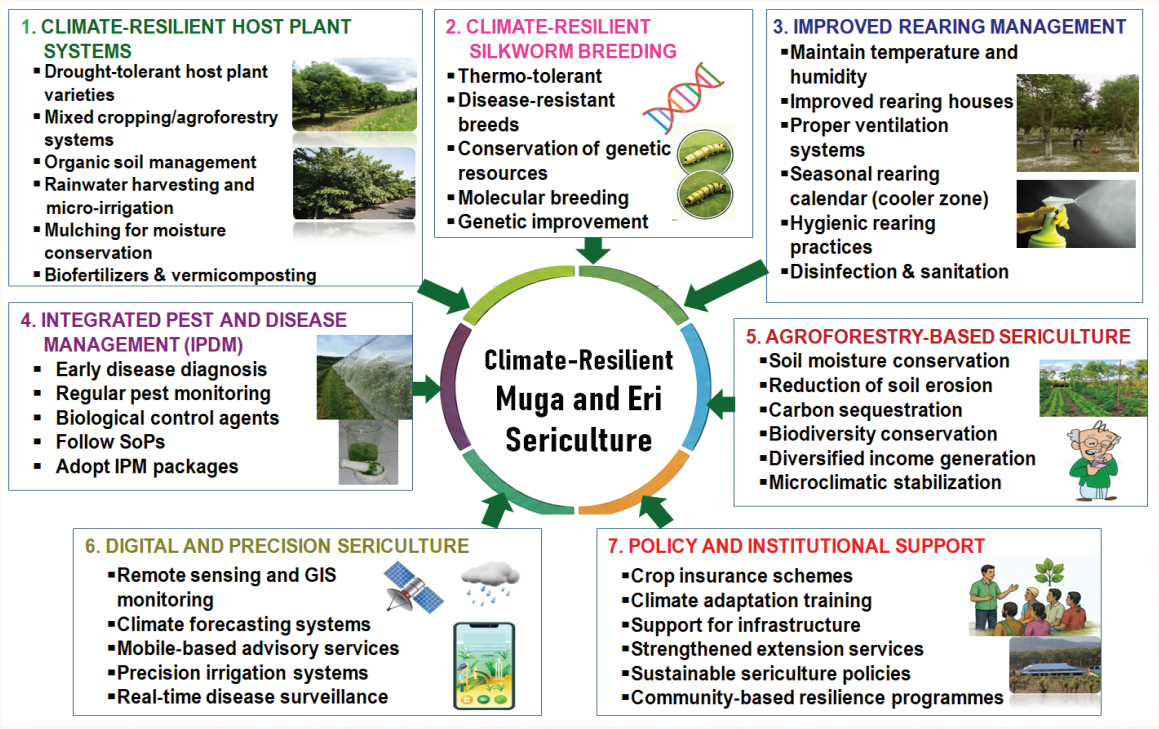


Figure 4. Climate-resilient mitigation strategies for sustainable muga and eri sericulture under changing climatic conditions

Development of climate-resilient silkworm races and strains is an important strategy for adapting sericulture to changing climate. Breeding programmes focusing on thermo-tolerant, disease-resistant, and stress-adaptable silkworm strains can improve survival, cocoon productivity, and silk quality under adverse environmental conditions. Conservation of indigenous genetic resources is equally important because local silkworm populations often possess natural adaptability to regional climatic variations. Approaches like molecular breeding and genetic improvement programmes may further support the development of superior silkworm breeds with enhanced tolerance to temperature fluctuations, humidity stress, and emerging diseases.

Rearing management plays a crucial role in minimizing climatic stress and improving silkworm health and productivity. Maintenance of optimum temperature and humidity during rearing is essential for proper larval growth, moulting, cocoon formation, and moth emergence. Use of improved rearing houses with adequate ventilation systems can help regulate environmental conditions and reduce the impact of excessive heat and humidity in Eri culture. Adjustment of seasonal rearing calendars according to changing climatic patterns may also improve crop stability and survival. In addition, hygienic rearing practices, timely disinfection, and proper sanitation are necessary to minimize disease incidence and maintain healthy rearing conditions.

Integrated pest and disease management (IPDM) is essential for sustainable and eco-friendly sericulture under climate-stressed conditions. Climate change often increases the prevalence of pests and pathogens, making regular monitoring and early disease diagnosis extremely important. Adoption of biological control agents, botanical pesticides, and environmentally safe formulations can reduce dependence on chemical pesticides and minimize ecological risks. Removal and destruction of infected larvae, diseased host plant parts, and contaminated materials is very much necessary. Implementation of integrated disease management packages combining cultural, biological, and preventive approaches can significantly improve crop protection and sustainability.

Agroforestry-based sericulture systems can enhance ecological stability and improve climate resilience in muga and eri cultivation. Integration of host plants with perennial tree species provides better microclimatic regulation, reduces soil erosion, and improves soil moisture conservation. Agroforestry based cultivation practices will also contribute to carbon sequestration, biodiversity conservation, and sustainable land utilization. In addition, diversified farming systems generate supplementary income. Such approaches are particularly important in the fragile ecosystems of North Eastern India, where environmental sustainability and livelihood security are closely interconnected.

Digital technologies and precision farming approaches have considerable potential to improve climate adaptation in sericulture. Remote sensing and GIS-based monitoring systems can assist in assessing host plant health, climatic stress, and disease distribution over large areas. Climate forecasting and early warning systems help farmers to take timely preventive measures against adverse weather conditions and disease outbreaks. Mobile-based advisory services can provide real-time support to farmers regarding crop management, irrigation, pest control, and rearing practices.

Strong policy and institutional support are essential for developing climate-resilient sericulture systems and protecting the livelihoods of farming communities. Government interventions such as crop insurance schemes, financial assistance for infrastructure, and skill development training programmes can help reduce economic vulnerability among sericulture farmers. Strengthening extension services and technology dissemination systems is also important for improving farmer awareness and adoption of scientific practices. Promotion of sustainable sericulture policies, community-based climate resilience programmes, and region-specific adaptation strategies can

support long-term ecological and economic sustainability of the muga and eri silk sectors under changing climatic conditions.

2.9. FUTURE PRIORITIES

Climate change poses a serious threat to the sustainability of muga and eri silk sectors in North Eastern India by affecting host plant growth, silkworm health, cocoon yield, and silk quality. However, the sector still possesses strong potential for adaptation through scientific management practices, resilient host plant systems, improved seed production, integrated pest management, and supportive policies. Adoption of sustainable and climate-smart sericulture approaches will be crucial for protecting rural livelihoods, preserving the traditional silk heritage of the region, and ensuring long-term ecological and economic sustainability.

Considering the growing impact of climate change on sericulture, identifying future research priorities and sustainable adaptation approaches has become essential for the long-term resilience of the muga and eri silk sectors. Future research in muga and eri sericulture should focus on understanding the impacts of climate change on host plants, silkworm biology, pest dynamics, and ecosystem sustainability. Studies involving physiological, molecular, and biochemical responses of silkworms to environmental stress are essential for developing climate-resilient and disease-tolerant breeds. Greater emphasis should also be given to the development of stress-tolerant host plant varieties, climate-driven disease forecasting systems, and sustainable production technologies. The integration of advanced tools such as artificial intelligence, GIS, remote sensing, and automated environmental monitoring can further support climate-smart sericulture management and improve production efficiency.

2.10. REFERENCES

Altman GH, Farrell BD (2022) Sericulture as a sustainable agro-industry. Clean Circ Bioeconomy 2:100011

Anonymous (2018) Assam's muga silkworm battles climate change. Retrieved on 31st October 2021.

Chattopadhyay C, Birah A, Jalali BL (2019) Climate change: impact on biotic stresses afflicting crop plants. In: Peshin R, Dhawan A (eds), Natural resource management: ecological perspectives. Sustainability in plant and crop protection. Springer, Cham, pp 133–146

Fawzy S, Osman AI, Doran J, Rooney DW (2020) Strategies for mitigation of climate change: a review. Environ Chem Lett 18:2069–2094

Gani MNA, Ghosh MK (2018) Impact of climate change on agriculture and sericulture. J Entomol Zool Stud 6:426–429

Gowda BN, Reddy NM (2007) Influence of different environmental conditions on cocoon parameters and their effects on reeling performance of bivoltine hybrids of silkworm, Bombyx mori. International Journal of Industrial Entomology, 14: 15-21

Lavanya C, Ashoka J, Sreenivasa AG, Sushila N, Beladhadi BV (2017) Effect of elevated carbon dioxide and temperature on growth, yield and quality parameters of mulberry. Entomol Ornithol Herpetol 6:1–3

Malhi GS, Kaur M, Kaushik P (2021) Impact of climate change on agriculture and its mitigation strategies: a review. Sustainability 13(3):1318

Neelaboin BK, Khan GA, Kumar S, Gani M, Ahmad MN, Ghosh MK (2018) Impact of climate change on agriculture and sericulture. Journal of Entomology and Zoology Studies, 6(5): 426-429

Parrey IR (2018) Impact of temperature on crop and higher silk production: silkworm (Bombyx mori L.). MOJ Food Process Technology, 6(2): 182-187

Rahmathulla VK (2012) Management of climatic factors for successful silkworm (Bombyx mori L.) crop and higher silk production: a review. Psyche: A Journal of Entomology, 121234, 1-12

Ram RL, Maji C, Bindroo BB (2016) Impact of climate change on sustainable sericultural development in India. International Journal of Agriculture Innovations and Research, 4(6): 2319-1473

Tripathi VK, Tiwari AK (2017) The effects of climate change on the Mulberry Insect Fauna in India's temperate and subtropical regions. J lNX 3(11):58–66

Wenjiang H, Yue S, Yingying D, Huichun Y, Mingquan W, Bei C, Linyi L (2019) Progress and prospects of crop diseases and pests monitoring by remote sensing. Nat Remote Sens Bulletin 25(1):403–422

CHAPTER 3: VULNERABILITY OF INDIA'S WILD SILK MOTHS TO CLIMATE CHANGE: BIODIVERSITY, ECOLOGY, AND CONSERVATION CHALLENGES

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3.1. INTRODUCTION

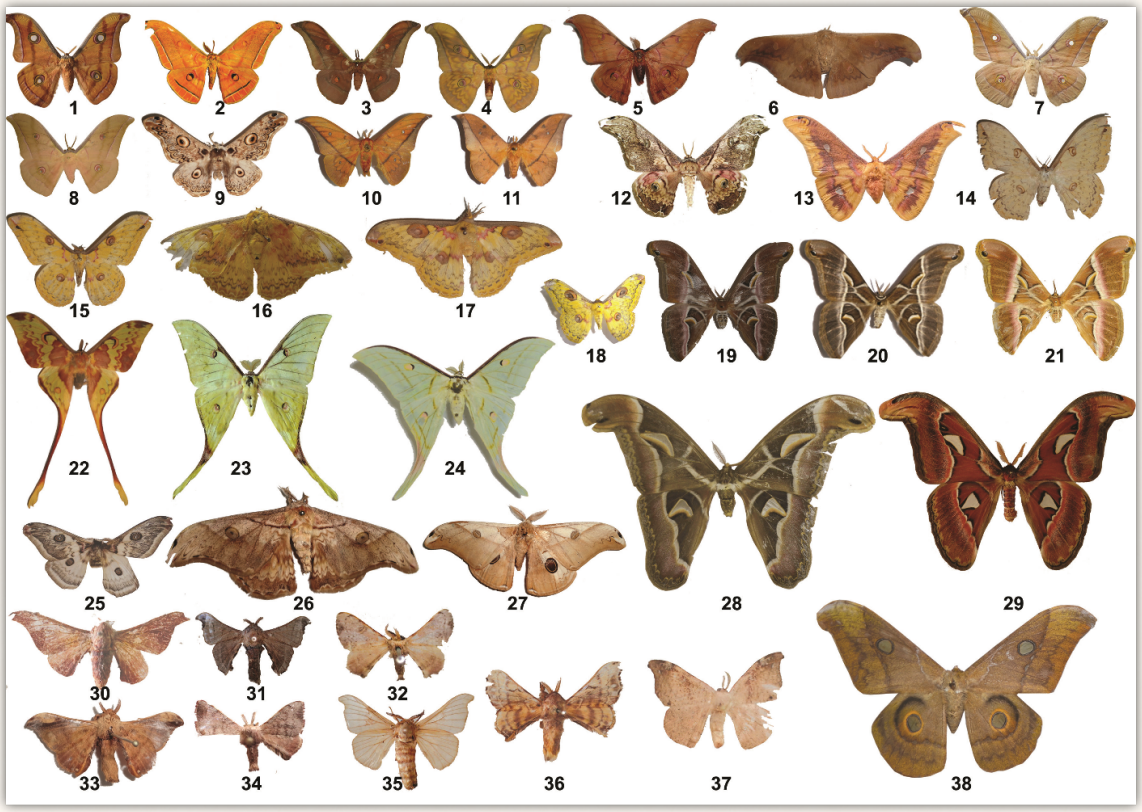
India is recognized as one of the world's richest centres of wild silk moth diversity and is uniquely positioned as the only country producing all four commercially important silk types, namely mulberry, tasar, muga and eri silk (Jolly *et al.*, 1979; Central Silk Board, 2023). Among these, tasar, muga and eri are collectively referred to as *Vanya silks* because they are produced by wild or semi-domesticated silkworms belonging predominantly to the family Saturniidae under the order Lepidoptera (Benchamin and Jolly, 1986; Thangavelu, 2002). The extraordinary diversity of wild silk moths in India is closely linked to the country's varied climatic regimes, extensive forest cover, diverse vegetation types and abundance of host plants, which provide suitable habitats for numerous sericigenous insects (Arora and Gupta, 1979; Singh and Benchamin, 2002).

Wild silk moths constitute an important component of forest biodiversity and contribute substantially to rural livelihoods and the sericulture economy. The principal commercially exploited species include the tropical tasar silkworm *Antheraea mylitta* Drury, the golden muga silkworm *Antheraea assamensis* Helfer and the eri silkworm *Samia ricini* Donovan (Jolly *et al.*, 1974; Thangavelu, 2002). In addition, several other silk-producing species such as *Cricula trifenestrata*, *Antheraea proylei*, *Antheraea frithi* and *Actias selene* occur across different ecological regions of the country and represent valuable genetic resources for future silk improvement programmes (Arora and Gupta, 1979; Nässig *et al.*, 1996). These species exhibit considerable variation in morphology, ecological adaptation, host-plant utilization, voltinism and silk quality traits, thereby contributing to the rich diversity of Indian sericulture resources (Singh and Benchamin, 2002).

The tropical tasar silkworm (*A. mylitta*) is widely distributed throughout central and eastern India and is represented by more than 44 eco-races adapted to distinct ecological conditions and host plant species (Suryanarayana and Srivastava, 2005; Reddy *et al.*, 2010). Such extensive eco-racial diversity makes *A. mylitta* one of the most genetically diverse silkworm species reported from the Indian subcontinent (Arunkumar *et al.*, 2006). Similarly, the muga silkworm (*A. assamensis*), endemic to the northeastern region of India, produces the globally renowned golden muga silk and occupies a unique evolutionary position among saturniid moths (Rajkhowa, 2013; Chakravorty *et al.*, 2015). The eri silkworm (*S. ricini*) is another economically important species known for its polyphagous feeding behaviour and adaptability to a wide range of agro-climatic conditions across northeastern and eastern India (Benchamin and Jolly, 1986; Sarkar *et al.*, 2018).

The northeastern Himalayan region, which forms part of the globally significant Indo-Burma biodiversity hotspot, supports exceptionally high diversity of wild silk moths owing to its heterogeneous vegetation and favourable climatic conditions (Myers *et al.*, 2000; Chakravorty *et al.*, 2015). Numerous endemic and rare saturniid species have been reported from the states of Assam, Arunachal Pradesh, Meghalaya, Nagaland and Manipur, making the region an important reservoir of genetic resources for silk production and conservation (Singh and Benchamin, 2002). Recent biodiversity assessments have documented several wild silk moth populations that remain inadequately characterized from taxonomic, ecological and molecular perspectives, highlighting the

need for systematic exploration and documentation (Chakravorty *et al.*, 2015; Das and Rajkhowa, 2019).



1. *Antheraea mylitta*
2. *Antheraea compta*
3. *Antheraea assamensis*
4. *Antheraea frithi*
5. *Antheraea helfer*
6. *Antheraea andamana*
7. *Antheraea pernyi*
8. *Antheraea roylei*
9. *Saturnia* sp.
10. *Cricula andrei*
11. *Cricula trifenestrata*
12. *Saturnia thibeta*
13. *Rhodinia newara*
14. *Loepa miranda*
15. *Loepa megacore*
16. *Loepa diffunoccidentalis*
17. *Loepa katinka*
18. *Loepa sikkima*
19. *Samia canningii*
20. *Samia ricini*
21. *Samia kohlli*
22. *Argema maenas*
23. *Argema sinensis*
24. *Actias selene*
25. *Satrunia pyretorum*
26. *Saturnia thibeta*
27. *Caligula simla*
28. *Archaeoattacus edwardsii*
29. *Attacus atlas*
30. *Andraca* sp.
31. *Bombyx incomposita*
32. *Ocinara bifurcula*
33. *Norasuma javanica*
34. *Trilocha varians*
35. *Bombyx mori*
36. *Gunda ochracea*
37. *Triuncina* sp.
38. *Salasa tonkiniana*

Figure 1: Photographic montage illustrating the diversity of moth species belonging to multiple families of the order Lepidoptera, with emphasis on commercially important silk-producing taxa and ecologically significant non-sericultural species. The figure presents 38 representative moth species arranged in a numbered grid format, encompassing major genera such as *Antheraea*, *Samia*, *Saturnia*, *Actias*, *Attacus*, *Bombyx*, *Loepa*, and others. Key economically important species include *Antheraea mylitta*, *Antheraea assamensis*, *Antheraea pernyi*, and *Bombyx mori*, which form the backbone of tropical, muga, temperate tasar, and mulberry sericulture systems, respectively. The assemblage also includes a wide range of wild Saturniidae and related moth taxa, highlighting morphological variation in wing shape, coloration, patterning, and size. This visual compilation underscores the extensive biodiversity within Lepidoptera, illustrating evolutionary divergence and adaptation across ecological zones in India and surrounding regions. The figure further emphasizes the taxonomic richness of moth fauna and provides a comparative reference for identification, biodiversity documentation, and sericulture-related research

India, recognized as a mega-diverse nation, harbours four of the world's major biodiversity hotspots, including the Himalaya, Indo-Burma, Western Ghats–Sri Lanka, and Sundaland (represented by the Nicobar Islands) (Myers *et al.*, 2000; CEPF, 2023). These biodiversity-rich landscapes support a remarkable diversity of wild sericigenous insects. All silk-producing moths belong to the order Lepidoptera and are mainly represented by the families Bombycidae and Saturniidae (Arora and Gupta, 1979). Globally, approximately 534 species of Bombycidae and more than 3,500 species of Saturniidae have been documented (LEPINDEX, 2017), of which over 70 species are estimated

to occur within the Indian subcontinent extending from the Himalayas to Sri Lanka (Venakumari *et al.*, 1992; LEPINDEX, 2017). Recent compilations have reported 62 species and subspecies of silk moths from India, including 44 species recorded from northeastern India and an additional 18 species documented from other parts of the country (Venakumari *et al.*, 1992; LEPINDEX, 2017).

Beyond their economic significance, wild silk moths play vital ecological roles as herbivores, pollinators, prey organisms and contributors to nutrient cycling within forest ecosystems (Scoble, 1995). However, rapid habitat degradation, deforestation, forest fragmentation, climate change and unsustainable exploitation of natural resources pose serious threats to their survival and genetic integrity (Thomas *et al.*, 2004; Sarkar *et al.*, 2018). Consequently, conservation of wild silk moth diversity has become increasingly important for sustaining the sericulture sector, maintaining ecosystem services and safeguarding valuable genetic resources for future breeding and improvement programmes (FAO, 2010). Recent advances in molecular biology, DNA barcoding and genomics have revealed substantial levels of genetic variation both within and among populations of Indian wild silk moths, emphasizing the need for comprehensive conservation, characterization and sustainable utilization strategies (Arunkumar *et al.*, 2006; Chakraborti *et al.*, 2019).

The rich diversity of wild silk moths in India represents an invaluable biological, ecological and economic resource that supports traditional livelihoods, contributes to rural development and strengthens the conservation of forest biodiversity. A comprehensive understanding of their taxonomy, distribution, ecology, genetics and evolutionary relationships remains fundamental for ensuring the sustainable development and long-term resilience of the Indian wild silk sector (Thangavelu, 2002; Central Silk Board, 2023).

3.2. COMMERCIALLY EXPLOITED SILKMOTHS OF INDIA

India possesses a rich sericultural heritage and is recognized as one of the world's major producers of both domesticated and wild silks. Among the approximately 62 recorded silk-producing moth species, only five have attained significant economic importance and are commercially exploited, namely the mulberry silkworm (*Bombyx mori*), tropical tasar silkworm (*Antheraea mylitta*), oak tasar silkworm (*Antheraea pernyi*), eri silkworm (*Samia ricini*), and muga silkworm (*Antheraea assamensis*) (Jolly *et al.*, 1974; Singh and Benchamin, 2002).

The mulberry silkworm, *Bombyx mori*, is the only fully domesticated silkworm species and forms the backbone of Indian sericulture. Mulberry cultivation and silkworm rearing are practiced throughout the country, with southern states such as Karnataka, Andhra Pradesh, Tamil Nadu and Telangana contributing the major share of silk production. In recent decades, bivoltine sericulture has expanded into the North-Eastern region, particularly in Tripura, while other states are gradually adopting improved mulberry-based production systems (CSB, 2023).

The tropical tasar silkworm, *Antheraea mylitta*, is commercially exploited in the forested regions of central India, particularly in Jharkhand, Chhattisgarh, Odisha, Maharashtra and Madhya Pradesh. This species exhibits remarkable intraspecific diversity, comprising numerous geographically and host plant-specific eco-races. Such ecological specialization provides an excellent model for studying insect–plant interactions, adaptation and co-evolution in natural ecosystems (Suryanarayana and Srivastava, 2005).

The eri silkworm, *Samia ricini*, is predominantly reared in North-Eastern India and is valued for producing the non-violent or "ahimsa" silk. Several eco-races have been documented based on their endemic distribution, while distinct strains have been identified from the Borduar and Titabar populations on the basis of larval colouration and marking patterns (Chakravorty *et al.*, 2011).

The muga silkworm, *Antheraea assamensis*, is endemic to North-East India and is globally renowned for producing the lustrous golden-yellow muga silk. The species is semi-domesticated and largely confined to Assam and adjoining regions, where it has immense cultural, economic and ecological significance. Muga silk has received Geographical Indication (GI) status and is often regarded as the "Golden Silk of Assam" owing to its natural golden sheen and durability (Arunkumar *et al.*, 2012; Singh *et al.*, 2012).

The oak tasar silkworm, *Antheraea pernyi*, inhabits the oak forest ecosystems of the sub-Himalayan belt extending from Jammu & Kashmir to the North-Eastern states. Commercial rearing is primarily undertaken in the temperate and hilly regions of Jammu & Kashmir, Himachal Pradesh, Uttarakhand and Manipur, where various species of oak (*Quercus* spp.) serve as principal host plants. Oak tasar culture provides an important livelihood option for tribal and hill communities while contributing to the conservation and sustainable utilization of forest resources (Singh and Benchamin, 2002).

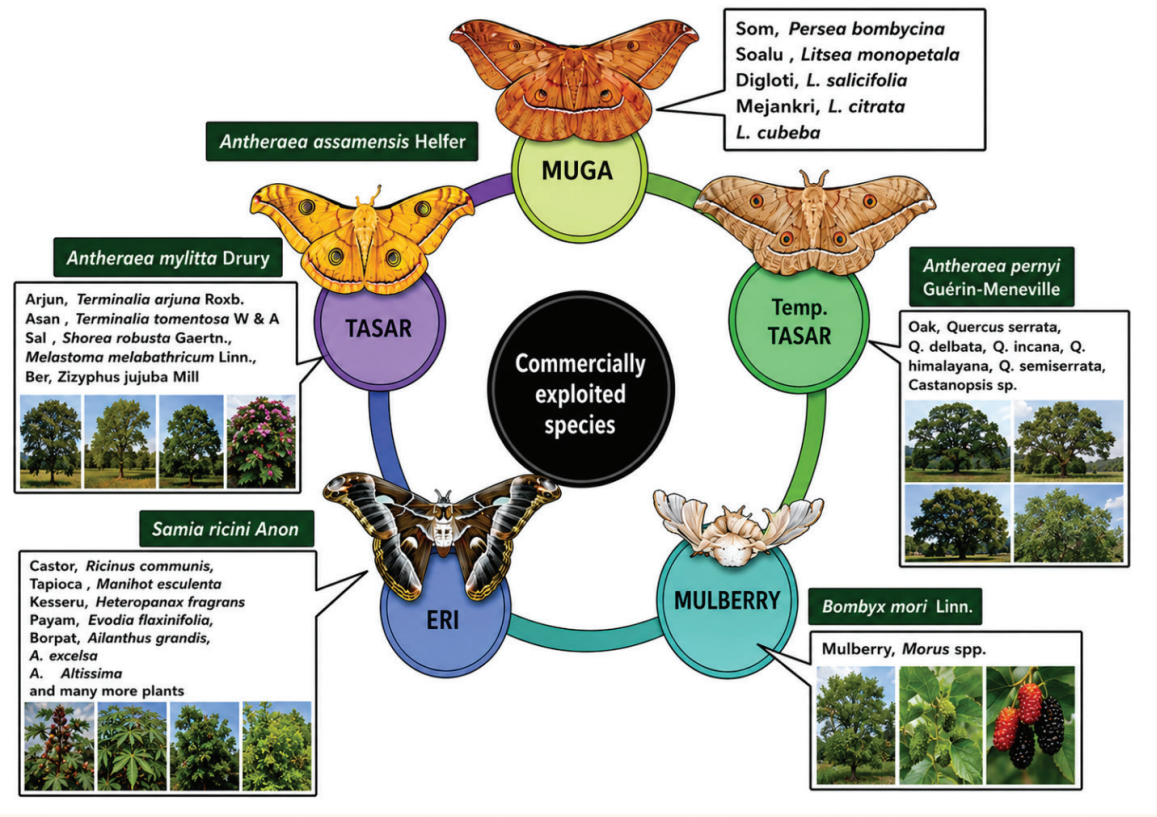


Figure 2: Schematic representation of the major commercially exploited silk moth species and their associated host plants used in tropical and temperate sericulture. The figure highlights the four principal silk-producing groups: Muga silk (*Antheraea assamensis* Helfer), Tropical Tasar silk (*Antheraea mylitta* Drury), Temperate Tasar silk (*Antheraea pernyi* Guérin-Méneville), Eri silk (*Samia ricini* Donovan/Anon.), and Mulberry silk (*Bombyx mori* Linnaeus). Representative photographs of the moths are linked to images of their primary host plant species. Muga silkworms are reared mainly on Som (*Persea bombycina*) and Soalu (*Litsea monopetala*), along with related *Litsea* species. Tropical Tasar silkworms utilize Arjun (*Terminalia arjuna*), Asan (*T. tomentosa*), Sal (*Shorea robusta*), and several associated host plants. Temperate Tasar silkworms feed predominantly on oak species (*Quercus* spp.) and Castanopsis spp. Eri silkworms are polyphagous and are commonly reared on castor (*Ricinus communis*), tapioca (*Manihot esculenta*), kesseru (*Heteropanax fragrans*), payam (*Evodia flaxinifolia*), and Ailanthus species. Mulberry silkworms are exclusively associated with mulberry (*Morus* spp.). The circular arrangement emphasizes the diversity of silk-producing insects and their host plant resources that collectively support the sericulture industry, rural livelihoods, biodiversity conservation, and sustainable bioresource utilization across different agroecological regions.



Figure 3: Comparative representation of the five commercially important silk production systems, illustrating the progression from adult moth to larval stage, cocoon formation, and the resulting silk fiber. The figure includes Mulberry silk produced by *Bombyx mori* (Linnaeus), Tropical Tasar silk produced by *Antheraea mylitta* Drury, Eri silk produced by *Samia ricini* (Donovan/Anonymous), Muga silk produced by *Antheraea assamensis* Helfer, and Temperate Tasar silk produced by *Antheraea pernyi* Guérin-Méneville. For each silk type, representative photographs depict (i) the adult moth, (ii) the feeding larva (silkworm), (iii) the cocoon, and (iv) the processed silk fiber or yarn. The figure highlights the remarkable diversity among silk-producing insects in terms of morphology, cocoon structure, color, texture, and silk quality. Mulberry silk is characterized by fine white cocoons and lustrous filament silk; Tropical Tasar silk by robust cocoons yielding coarse copper-brown fibers; Eri silk by open-ended cocoons producing soft, wool-like spun silk; Muga silk by golden-yellow cocoons yielding naturally lustrous golden fibers; and Temperate Tasar silk by pale cocoons producing strong, durable filament silk. Together, these silk systems constitute the foundation of India's sericulture sector, supporting biodiversity conservation, rural livelihoods, traditional textile industries, and sustainable bioresource-based economic development.

3.3. CLIMATE CHANGE IMPACT ON THE DIVERSITY OF WILD SILK MOTHS IN INDIA

India harbours a remarkable diversity of wild silk moths (Vanya silkworms), including the tropical tasar silkworm *Antheraea mylitta*, muga silkworm *Antheraea assamensis*, and eri silkworm *Samia ricini*. These species represent valuable biological resources that contribute significantly to rural livelihoods, tribal economies, traditional knowledge systems, and the conservation of forest ecosystems (Jolly *et al.*, 1974; Sarkar, 1988; Bindroo and Sahu, 2014). However, the accelerating impacts of climate change are emerging as a serious threat to the diversity, distribution, productivity, and long-term survival of these economically and ecologically important insects (IPCC, 2023; Parmesan, 2006).

Wild silk moths are highly sensitive to climatic variability because, as ectothermic organisms, their physiological processes are strongly regulated by ambient temperature and relative humidity (Kingsolver *et al.*, 2011). Temperature influences growth rate, larval duration, pupal development,

adult emergence, mating behaviour, and fecundity in Lepidoptera (Bale *et al.*, 2002). Elevated temperatures can accelerate development beyond optimal thresholds, resulting in incomplete moulting, reduced cocoon quality, lower adult longevity, and increased mortality during vulnerable developmental stages (Deutsch *et al.*, 2008). Experimental studies on silkworms have demonstrated that thermal stress negatively affects egg hatchability, larval survival, reproductive performance, and silk productivity (Kumar *et al.*, 2019; Rahmathulla, 2012). Consequently, sustained warming may contribute to population declines and local extirpations of climate-sensitive wild silk moth populations.

Altered rainfall patterns constitute another major threat. Climate projections for India indicate increasing rainfall variability, delayed monsoon onset, prolonged drought periods, and a higher frequency of extreme precipitation events (Goswami *et al.*, 2006; Krishnan *et al.*, 2020). Such changes directly affect the growth, phenology, and nutritional quality of host plants essential for wild silk moth development. Tropical tasar silkworms primarily depend on *Terminalia arjuna*, *Terminalia tomentosa* and *Shorea robusta*, while muga silkworms utilize *Machilus bombycina* (Som) and *Litsea monopetala* (Soalu) as principal host plants (Benchamin and Jolly, 1986; Bindroo and Sahu, 2014). Drought stress can reduce leaf moisture content, protein concentration, and nutrient availability, thereby adversely affecting larval growth and cocoon characteristics (Mattson and Haack, 1987). In northeastern India, recurrent floods, erratic rainfall, and changing precipitation regimes have already been reported to disrupt muga culture and damage natural host plant habitats (Das *et al.*, 2010; Chakravorty *et al.*, 2015).

Climate change is also driving habitat fragmentation and shifts in species distributions. Rising temperatures and changing precipitation patterns are altering the geographical suitability of habitats for many insect species worldwide (Parmesan and Yohe, 2003; Chen *et al.*, 2011). Wild silk moth populations are particularly vulnerable because many occur in fragmented forest ecosystems already subjected to anthropogenic disturbances. Molecular studies on muga and eri silkworm populations have revealed substantial genetic structuring associated with geographical isolation and habitat fragmentation (Arunkumar *et al.*, 2006; Choudhury *et al.*, 2013). Reduced connectivity among populations can restrict gene flow, increase inbreeding, and diminish adaptive genetic diversity, thereby limiting the capacity of populations to respond to future environmental changes (Frankham *et al.*, 2017).

Species with narrow ecological amplitudes are expected to be especially vulnerable. The muga silkworm (*Antheraea assamensis*), endemic to the Brahmaputra Valley and adjoining regions of northeastern India, occupies a relatively restricted climatic niche (Singh and Benchamin, 2002). Species distribution modelling studies have demonstrated that climate change can substantially alter the future suitability of habitats for both insect herbivores and their host plants through shifts in temperature and precipitation regimes (Thuiller *et al.*, 2005; Bellard *et al.*, 2012). Such changes may result in habitat contraction, range shifts towards higher elevations or latitudes, and increased risk of local population extinction.

Climate warming can additionally disrupt ecological synchrony between silk moths and their host plants. The timing of larval emergence is often closely synchronized with the production of young, nutrient-rich leaves (Visser and Both, 2005). Climate-induced shifts in plant phenology may create temporal mismatches between larval feeding stages and optimal host plant availability. Such trophic mismatches are increasingly recognized as a major mechanism through which climate change affects insect populations, particularly Lepidoptera (Forrest, 2016; Renner and Zohner,

2018). Reduced synchrony can lead to poor larval nutrition, slower growth, increased mortality, and lower reproductive success.

Another emerging concern is the increased prevalence of pests, parasitoids, and pathogens under changing climatic conditions. Warmer temperatures and elevated humidity frequently favour the multiplication, survival, and geographic expansion of insect pests and microbial pathogens (Garrett *et al.*, 2006; Bebber *et al.*, 2013). Several diseases caused by fungi, bacteria, viruses, and protozoans are known to affect non-mulberry silkworms, often resulting in substantial crop losses (Samson *et al.*, 2018). Climate change may exacerbate these risks by creating environmental conditions more conducive to pathogen development and transmission. Furthermore, changes in temperature may influence the abundance and activity of natural enemies such as parasitoids and predators, thereby increasing mortality pressures on wild silk moth populations (Thomson *et al.*, 2010).

Beyond direct ecological effects, climate change may also erode the genetic diversity preserved within wild silk moth populations. Genetic diversity forms the foundation of adaptive resilience and evolutionary potential under environmental change (Hoffmann and Sgrò, 2011). Loss of populations due to habitat degradation or climatic stress can reduce the availability of unique genetic resources essential for future breeding and conservation programmes. Given the economic importance of wild silk production and the cultural heritage associated with muga, tasar, and eri sericulture, the conservation of these genetic resources is of strategic importance for India (Bindroo and Sahu, 2014). Climate change poses multifaceted threats to the diversity and sustainability of wild silk moths in India through habitat degradation, host plant stress, phenological mismatches, range shifts, genetic erosion, and increased biotic pressures. Strengthening conservation of host plant resources, restoring degraded forest habitats, establishing climate-resilient breeding programmes, conserving genetic diversity through both in situ and ex situ approaches, and implementing long-term ecological monitoring systems are critical measures for safeguarding India's unique wild silk biodiversity and sustaining the livelihoods of millions dependent on the Vanya silk sector (IPCC, 2023; Hoffmann and Sgrò, 2011; Bindroo and Sahu, 2014).

3.4. MAJOR CLIMATE-CHANGE-INDUCED THREATS TO WILD SILK MOTH DIVERSITY IN INDIA

Climate change is having a major impact on the diversity, distribution, and survival of wild silk moths, which belong mainly to the order Lepidoptera and include species such as tasar, muga, eri, luna, and giant silk moths. These moths are highly sensitive to environmental conditions because their life cycles depend on temperature, humidity, rainfall, and host plant availability.

3.4.1. Habitat Shift and Contraction Due to Rising Temperatures and Altered Precipitation Regimes

Climate change is significantly altering the distribution and quality of habitats supporting wild silk moths in India. Rising temperatures, irregular rainfall patterns, prolonged droughts, and extreme weather events are causing degradation of forests that serve as natural habitats for species such as the muga silkworm (*Antheraea assamensis*), tasar silkworm (*Antheraea mylitta*), oak tasar silkworm (*Antheraea proylei*), and eri silkworm (*Samia ricini*). In Northeast India and Himalayan ecosystems, shifts in temperature and moisture regimes are expected to reduce suitable habitat areas and alter vegetation composition. Sensitive silk moth populations inhabiting narrowly distributed ecological niches may experience habitat contraction, leading to local population declines and increased risk of extinction.

3.4.2. Phenological Mismatch Between Silk Moth Life Cycles and Host Plant Flushing

Wild silk moths have evolved synchronized life cycles with the seasonal growth patterns of their host plants. Climate-induced changes in temperature and rainfall can disrupt this synchronization. Earlier or delayed flushing of host plants may not coincide with egg hatching and larval emergence, resulting in a shortage of tender leaves required for larval feeding. Such phenological mismatches can reduce larval survival, prolong developmental periods, increase mortality, and ultimately decrease reproductive success. This threat is particularly severe for univoltine or bivoltine species whose life cycles are closely linked to seasonal environmental cues.

3.4.3. Increased Incidence of Pathogens and Parasitoids

Warmer temperatures and increased humidity create favorable conditions for the proliferation of fungal, bacterial, viral, and protozoan pathogens affecting silk moth populations. Climate change may also facilitate the expansion of parasitoid insects and predatory species into previously unsuitable regions. Increased disease pressure can lead to outbreaks causing substantial mortality in larvae, pupae, and adults. In natural forest ecosystems where disease monitoring is limited, emerging pathogens may remain undetected until severe population declines occur. Combined pathogen and parasitoid attacks can significantly reduce the resilience of already vulnerable wild silk moth populations.

3.4.4. Genetic Erosion of Wild Populations

Habitat fragmentation resulting from climate change, land-use change, and forest degradation reduces connectivity among silk moth populations. Small and isolated populations experience reduced gene flow, increased inbreeding, and loss of genetic diversity. Genetic erosion limits the adaptive capacity of species to respond to environmental stresses, diseases, and changing climatic conditions. Over time, unique eco-races and locally adapted populations may disappear, resulting in irreversible loss of valuable genetic resources important for future breeding and conservation programs.

3.4.5. Altitudinal and Geographical Range Shifts

As temperatures increase, many silk moth species are expected to shift their distribution toward higher altitudes and cooler regions. Himalayan silk moth populations are particularly vulnerable because suitable habitats become increasingly restricted with elevation. Species already occupying high-altitude zones may eventually encounter “mountaintop extinction” when no further suitable habitat remains. Geographical shifts may also disrupt ecological interactions with host plants, pollinators, natural enemies, and other components of the ecosystem, potentially reducing population stability and persistence.

3.4.6. Impact of Climate Change on Host Plants and Consequences for Wild Silk Moths in India

Host plants form the ecological foundation of wild silk moth survival, development, reproduction, and silk production. The persistence of wild silk ecosystems depends largely on the availability, quality, and phenological synchrony of host plants with the life cycles of silk-producing insects. However, climate change is increasingly disrupting these plant–insect interactions through rising temperatures, altered precipitation regimes, elevated atmospheric carbon dioxide concentrations, and increased frequency of extreme climatic events (IPCC, 2023; Parmesan, 2006).

One of the most significant impacts of climate change on wild silk moths is the alteration of host plant phenology. Temperature and rainfall are major determinants of leaf flushing, maturation,

and senescence in forest trees. Changes in these environmental cues can shift the timing of leaf emergence, creating phenological mismatches between larval hatching and the availability of tender, nutrient-rich foliage required for optimal growth (Visser and Both, 2005; Forrest, 2016). Such mismatches can reduce larval feeding efficiency, prolong developmental duration, increase mortality, and ultimately lower cocoon production and reproductive success.

Climate-induced stress also affects the physiological and nutritional quality of host plants. Elevated temperatures and prolonged drought conditions frequently reduce leaf water content and nitrogen concentration while increasing the accumulation of carbon-based defensive compounds such as phenolics and tannins (Coley *et al.*, 1985; Zvereva and Kozlov, 2006). Increased atmospheric carbon dioxide may further decrease foliar protein concentrations and alter carbon-to-nitrogen ratios, thereby reducing food quality for herbivorous insects (Lincoln *et al.*, 1986; Robinson *et al.*, 2012). Such nutritional deterioration negatively influences larval growth, digestion, cocoon weight, silk yield, fecundity, and overall fitness of silk moth populations (Mattson, 1980; Jamieson *et al.*, 2012).

The distribution and abundance of host plants are also increasingly affected by climate change. Forest ecosystems across India are experiencing greater incidence of droughts, heat waves, erratic rainfall, pest outbreaks, and disease epidemics, all of which can reduce host plant regeneration and survival (Allen *et al.*, 2010; IPCC, 2023). Species with narrow ecological tolerances may undergo range contractions or local extinction, resulting in habitat fragmentation and reduced food availability for host-specific silk moths (Thuiller *et al.*, 2005; Bellard *et al.*, 2012). Because many wild silk moth species exhibit high host specificity, declines in host plant populations directly translate into reductions in moth abundance and genetic diversity.

These impacts are particularly evident in tropical tasar ecosystems. The tropical tasar silkworm, Antheraea mylitta, depends primarily on host trees such as Terminalia arjuna, Terminalia tomentosa, and Terminalia bellirica. Variability in rainfall patterns, increasing temperatures, and recurrent drought conditions adversely affect the growth, leaf production, and physiological condition of these host species, thereby reducing the availability of suitable foliage for developing larvae (Suryanarayana and Srivastava, 2005; Datta and Nanavaty, 2007). Consequently, reductions in larval survival, cocoon weight, and silk productivity have been reported from several tasar-growing regions.

Similarly, the endemic muga silkworm, Antheraea assamensis, relies predominantly on Persea bombycina and Litsea monopetala in northeastern India. Rising temperatures, irregular precipitation patterns, floods, and prolonged dry spells are increasingly affecting the growth, distribution, and productivity of these host plants (Das *et al.*, 2010; Baruah *et al.*, 2019). Because muga sericulture is intrinsically linked to the health of these host species, climate-induced declines in host plant quality pose a significant threat to both the sustainability of muga silk production and the conservation of this unique endemic silk moth.

Extreme climatic events further intensify these challenges. Floods, cyclones, landslides, and forest fires can directly destroy host plant habitats and reduce vegetation cover over large areas (IPCC, 2023). Repeated disturbances limit natural regeneration, fragment habitats, and diminish the availability of feeding resources. Such habitat degradation contributes to reduced larval survival, lower cocoon yields, declining genetic diversity, and increased vulnerability of silk moth populations to local extinction (Thomas *et al.*, 2004; Bellard *et al.*, 2012).

Climate-change-induced alterations in host plant phenology, nutritional quality, abundance, and geographic distribution represent a major threat to the long-term persistence of India's wild silk moth diversity. Conservation of host plant genetic resources, restoration of degraded forest habitats, development of climate-resilient host plant plantations, and landscape-level ecosystem management will be essential to sustain wild silk production and enhance the resilience of these ecologically and culturally significant insect–plant systems.

3.4.7. Extreme Weather Events and Their Impacts on Indian Wild Silkworms

Extreme weather events associated with climate change, including floods, heat waves, droughts, wildfires, cyclonic storms, and unseasonal rainfall, have emerged as major threats to the survival and productivity of Indian wild silkworms such as tropical tasar (*Antheraea mylitta*), oak tasar (*Antheraea proylei*), muga (*Antheraea assamensis*), and eri (*Samia ricini*). These events directly damage vulnerable life stages of silkworms, including eggs, larvae, pupae, and cocoons, while simultaneously affecting the availability and quality of host plants and breeding habitats (Suryanarayana and Srivastava, 2005; Reddy *et al.*, 2014).

Heat waves can cause desiccation of eggs and larvae, reduce cocoon quality, and increase mortality rates, whereas floods and unseasonal heavy rainfall often wash away larvae and destroy cocoons attached to host plants. Cyclonic storms and strong winds lead to defoliation and breakage of host trees such as *Terminalia arjuna*, *T. tomentosa*, *Shorea robusta*, and *Persea bombycina*, thereby reducing food availability for wild silkworm populations (Singh *et al.*, 2013; Rahman *et al.*, 2021). In north-eastern India, erratic rainfall and prolonged droughts have been linked to declines in muga host plant vigour and cocoon productivity (Choudhury *et al.*, 2018).

Wildfires represent an additional emerging threat, particularly in the forested tasar-growing regions of Jharkhand, Chhattisgarh, Odisha, and Maharashtra. Forest fires destroy host vegetation, alter microclimatic conditions, and generate smoke that interferes with moth behaviour, dispersal, and reproduction. Repeated disturbances from wildfires, unusual winters, and ecological imbalance have been associated with reduced moth abundance and local population crashes in several forest ecosystems (FAO, 2020; IPCC, 2023). Such abrupt declines are particularly concerning for wild silkmoths because many populations already face habitat fragmentation and limited genetic connectivity. Consequently, increasing frequency and intensity of extreme weather events may significantly undermine the long-term resilience and conservation of India's unique wild silk biodiversity.

3.5. RECOMMENDED CLIMATE ADAPTATION STRATEGIES

3.5.1. Conservation of Wild Silk Moth Habitats and Host Plant Diversity

Protecting natural forests and maintaining diverse host plant populations are fundamental for conserving wild silk moth biodiversity. Conservation efforts should focus on safeguarding critical habitats, preventing deforestation, restoring degraded forests, and protecting ecological hotspots in Northeast India, Central India, and Himalayan regions. Preservation of host plant genetic diversity will enhance ecosystem resilience and ensure continuous food resources for silk moth populations under changing climatic conditions.

3.5.2. Creation of Climate-Resilient Host Plant Corridors

Ecological corridors connecting fragmented habitats can facilitate dispersal and gene flow among silk moth populations. Establishing climate-resilient corridors using native host plant species allows populations to migrate naturally in response to shifting climatic zones. Such corridors can reduce

isolation, enhance genetic exchange, and improve long-term survival prospects of vulnerable species and eco-races.

3.5.3. Establishment of Long-Term Climate and Disease Surveillance Networks

Integrated monitoring systems are essential for detecting climate-related changes in silk moth populations, host plants, pathogens, and forest ecosystems. Long-term surveillance networks combining meteorological observations, remote sensing, disease diagnostics, and biodiversity monitoring can provide early warning of emerging threats. Such systems support evidence-based decision-making and adaptive management strategies.

3.5.4. Development of Thermo-Tolerant and Disease-Resistant Breeds

Breeding programs should focus on identifying and developing silk moth strains possessing enhanced tolerance to heat stress, drought, and emerging diseases. Utilization of genetic diversity present in wild populations can facilitate the development of resilient breeds suitable for future climatic conditions. Molecular breeding and genomic tools can accelerate the identification of adaptive traits and improve breeding efficiency.

3.5.5. Assisted Migration and Conservation of Vulnerable Eco-Races

For highly vulnerable populations facing severe habitat loss, assisted migration may be considered as a conservation strategy. Carefully planned translocation of populations to climatically suitable habitats can help prevent local extinctions. Conservation programs should prioritize unique eco-races and geographically restricted populations possessing valuable adaptive traits and genetic diversity.

3.5.6. Genomic Characterization and Cryopreservation of Germplasm

Comprehensive genomic characterization of wild silk moth populations can identify adaptive genes, genetic diversity patterns, and conservation priorities. Establishing germplasm repositories through cryopreservation of eggs, embryos, tissues, DNA, and reproductive materials provides insurance against future biodiversity loss. Ex situ conservation complements in situ efforts and preserves genetic resources for breeding and research.

3.5.7. Community-Based Forest Restoration and Sustainable Sericulture Programs

Local communities play a crucial role in conserving silk moth habitats. Participatory forest restoration programs involving indigenous and tribal communities can improve habitat quality while generating livelihood opportunities. Sustainable sericulture practices, conservation incentives, and ecosystem-based management approaches can simultaneously support biodiversity conservation, climate resilience, and rural economic development. Integrating traditional ecological knowledge with modern conservation science can further strengthen long-term sustainability of wild silk moth ecosystems.

Table 1: Wild Silk Moths Under Climate Change: Major Drivers, Observed Responses, Production Consequences, and Management Interventions

Wild silk moth species	Region of investigation	Major climate change drivers	Important observations	Potential impact on diversity and production	Ameliorative measures	Key references
Antheraea assamensis (Muga)	Assam, Meghalaya, Arunachal Pradesh, Nagaland (Northeast India)	Rising temperature, erratic rainfall, extreme weather events, habitat fragmentation	Climate suitability models predict shifts in suitable habitats and changes in host plant distribution. Increased disease outbreaks (pebrine, flacherie, grasserie) and crop failures have been associated with climatic instability. Wild populations harbor significant genetic diversity essential for adaptation.	Contraction of suitable habitats, loss of local ecotypes, reduced cocoon yield, increased extinction risk of isolated populations.	Conservation of wild populations, climate-resilient host plantations (Soalu and Som), establishment of gene banks, habitat corridors, predictive climate-based monitoring systems.	Sarma *et al.* (2025); Singh *et al.* (2012); Arunkumar *et al.* (2012)
Antheraea mylitta (Tasar)	Jharkhand, Chhattisgarh, Odisha, Maharashtra, Telangana, Madhya Pradesh	Increasing temperature, drought frequency, irregular monsoon, forest degradation	Geographic races occur across diverse eco-climatic zones. Climate-induced stress on host plants (Terminalia spp., Shorea robusta) affects larval survival and cocoon quality. Fragmented populations show genetic differentiation.	Loss of eco-races, altered voltinism, reduced fecundity and survival, local population decline.	In situ conservation of eco-races, assisted migration, host-tree enrichment, climate-smart tasar forestry, community-based conservation.	Chakraborty *et al.* (2015); CSB and CTR&TI reports.
Samia ricini (Eri)	Assam, Meghalaya, Arunachal Pradesh and adjoining regions	Temperature fluctuations, altered humidity patterns, extreme rainfall events	Although relatively resilient because of indoor rearing, climatic changes influence host plant availability (castor, kesseru) and increase disease susceptibility. Outdoor seed crop production remains vulnerable.	Reduced genetic diversity of traditional strains, seasonal instability in seed production.	Development of thermo-tolerant strains, protected seed rearing, diversified host plant systems, disease surveillance.	Seidel & Peigler (2018).
Antheraea proylei	Himalayan regions of Uttarakhand, Himachal Pradesh and Jammu & Kashmir	Warming temperatures, changing snowfall patterns, altitudinal climate shifts	Climate warming is causing upward movement of many moth species in the Himalayas. Changes in oak forest phenology affect synchronization between larvae and host plants.	Range shifts to higher elevations, habitat compression, loss of lower-altitude populations.	Conservation of oak forests, assisted regeneration, altitudinal monitoring, ex situ germplasm conservation.	Himalayan biodiversity studies; Gogoi & Lahon (2021).

Wild silk moth species	Region of investigation	Major climate change drivers	Important observations	Potential impact on diversity and production	Ameliorative measures	Key references
Wild populations of muga and tasar moths collectively	Northeast India and Central Indian forests	Habitat loss combined with climate change	Wild populations possess unique alleles and adaptive genetic diversity that may be critical for future climate resilience. Fragmentation reduces gene flow among populations.	Genetic erosion and reduced adaptive capacity under future climate scenarios.	Landscape-level conservation, protected breeding refugia, genomic monitoring, conservation breeding programs.	Singh *et al.* (2012); Arunkumar *et al.* (2012).

3.6. CONSERVATION STATUS

Conservation and sustainable utilization of biodiversity-rich ecosystems underpin several rural and agro-based industries in India, particularly sericulture. The sericulture sector in North East India and other biodiversity hotspots plays a crucial role in livelihood security for tribal and marginal communities, where forest-based resources provide continuous income opportunities (CSB, 2020; Singh and Das, 2018). Among the silk-producing insects, **Muga silk (***Antheraea assamensis***)** is globally recognized as the costliest natural silk and is strictly endemic to the North Eastern region of India, particularly Assam, due to its unique ecological requirements and host plant dependency (Sarmah *et al.*, 2016; Central Silk Board, 2021).

Recognizing the ecological and economic significance of wild silk moths, the Central Silk Board (CSB) under the Ministry of Textiles has initiated structured in-situ conservation programmes across North East India, covering Assam, Arunachal Pradesh, Meghalaya, and Bodoland Territorial Region (BTR). In Assam, conservation efforts include establishment of protected wild silk moth habitats such as the Kuklung Reserve Forest Range, implemented jointly by the State Sericulture Department and Forest Department. Further strengthening this initiative, the Upper Doigrung Wildlife Area (approximately 5 km²) has been identified for conservation under a formal Memorandum of Understanding (MoU) between the Assam Forest Department and CSB–CMER&TI, Jorhat for in-situ conservation of muga and other wild silk moths (CMER&TI, 2022). Continuous ecological monitoring, including installation of Wi-Fi-enabled automatic weather stations, has been undertaken at both natural habitats and ex-situ sites such as the Bogidhola Muga Farm, enabling correlation of climatic variables with pest dynamics and supporting the development of predictive tools such as degree-day models for pest and disease forecasting (Barah *et al.*, 2019).

In addition, conservation sites have been identified in Arunachal Pradesh (Mebo Reserve Forest, Pasighat) and Meghalaya (Tura Peak, Garo Hills), strengthening the regional conservation network for wild silk biodiversity. For tropical tasar, *Antheraea mylitta* exhibits extensive eco-racial diversity and is being conserved in in-situ conditions, particularly in Jharkhand and Odisha (Similipal Biosphere Reserve), which are recognized hotspots for tasar genetic diversity (CSB, 2020; Nayak *et al.*, 2017).

Similarly**,** oak tasar silkworms **(***Antheraea frithi* and *A. pernyi***)** are naturally distributed in Manipur's oak-dominated forests and adjoining hilly regions of Nagaland, where conservation potential remains high. Arunachal Pradesh also supports extensive oak forests ranging from Tawang to Pasighat, dominated by species such as *Quercus incana*, *Q. himalayana*, *Q. serrata*, *Q. semiserrata*, and *Castanopsis indica*, which form critical host plant resources for oak tasar silkworms (Singh *et*

al., 2015; Sharma and Raina, 2019). These forest ecosystems represent important reservoirs of wild sericultural biodiversity across the Himalayan and sub-Himalayan belts.

In the future, these integrated conservation initiatives are expected to address the demand for quality seed stock of muga, eri, tasar, and oak tasar silkworms while simultaneously safeguarding wild silk moth germplasm. The conserved genetic resources will also provide a foundation for selective breeding programmes aimed at improving silk yield, disease resistance, and climate resilience in sericulture systems (CSB, 2021; Thangavelu *et al.*, 2018).

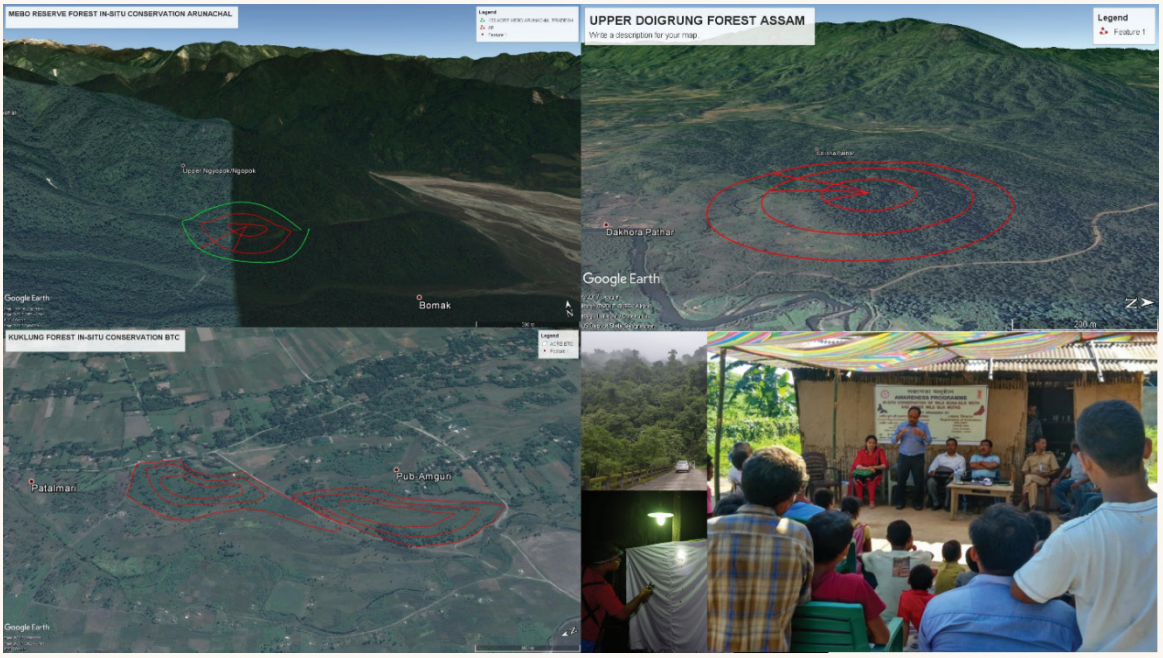


Figure 5: *In-situ* conservation by Central Silk Board

3.7. CONCLUSION

India is globally recognized as a major Centre of wild silk moth diversity and as a unique repository of all four commercially important silk types, reflecting an exceptional convergence of biological richness, ecological complexity, and cultural heritage. The Vanya silk systems—tasar, muga, and eri, alongside mulberry sericulture, together form a dynamic interface linking forest biodiversity with rural livelihoods. This remarkable diversity of silk moths, especially in biodiversity-rich regions such as the North-East and Central Indian forests, is sustained by diverse climatic conditions, abundant host plant resources, and long-evolved insect–plant interactions. This finely balanced ecological system not only supports sericulture productivity but also contributes to the stability and functioning of forest ecosystems.

However, this fragile equilibrium is increasingly threatened by rapid environmental change. Climate-induced stresses such as rising temperatures, shifting rainfall patterns, habitat fragmentation, phenological mismatches, and increasing biotic pressures are emerging as serious risks to the survival and productivity of wild silk moths. These challenges are further intensified by genetic erosion and the gradual loss of locally adapted eco-races, thereby reducing the adaptive capacity of these species. The impacts extend beyond biodiversity loss, adversely affecting rural economies, traditional knowledge systems, and the long-term resilience of India's sericulture sector.

Despite these concerns, India retains strong institutional capacity and conservation momentum through ongoing in-situ and ex-situ initiatives led by the Central Silk Board and allied organizations. Approaches integrating habitat conservation, host plant restoration, genomic tools, climate-resilient breeding, and community participation provide a practical pathway for safeguarding this valuable resource base.

The conservation of India's wild silk moth diversity requires a coordinated strategy that integrates ecological protection, scientific innovation, and socio-economic inclusion. Protecting these species is essential not only for sustaining silk production but also for conserving a globally significant component of biodiversity and ecological heritage. Climate change continues to pose a major threat by disrupting habitats, life cycles, host plant availability, and increasing disease incidence and extreme weather events, with sensitive species such as muga and tasar being particularly vulnerable.

3.8. FUTURE PROSPECTS

Understanding the future trajectory of climate change impacts on India's wild silk moth diversity is critical for anticipating ecological risks, safeguarding adaptive genetic resources, and ensuring the long-term sustainability of sericulture-based livelihoods.

- **Strengthening Climate-Resilient Sericulture Systems:** Development and adoption of climate-resilient rearing practices, including adaptive management of temperature and humidity, will be essential to sustain wild silk moth populations under changing environmental conditions.
- **Conservation of Genetic Diversity and Eco-races:** Systematic conservation of locally adapted eco-races of tasar, muga, and eri silk moths will become increasingly important to maintain adaptive potential against climate variability and environmental stress.
- **Habitat Restoration and Host Plant Enrichment:** Large-scale restoration of degraded forest habitats and enrichment of primary host plants will help mitigate the effects of habitat loss, fragmentation, and shifting phenological cycles.
- **Integration of Climate-Smart Monitoring Tools:** Use of remote sensing, AI-based forecasting, and phenology tracking systems will improve early warning capabilities for climate-induced stress, pest outbreaks, and host plant mismatches.
- **Expansion of In-situ and Ex-situ Conservation Programs:** Strengthening both natural habitat conservation and germplasm repositories will safeguard wild silk moth species from extreme climatic events and irreversible population decline.
- **Socio-economic Adaptation and Livelihood Diversification:** Enhancing livelihood resilience of tribal and rural communities dependent on sericulture through diversification, value addition, and alternative income sources will reduce vulnerability to climate shocks.
- **Policy Integration and Multi-institutional Collaboration:** Coordinated action among research institutions, forest departments, and the Central Silk Board will be crucial for integrating climate adaptation strategies into national biodiversity and sericulture policies.

3.9. REFERENCES

Allen, C.D., Macalady, A.K., Chenchouni, H. *et al.* (2010) 'A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests', *Forest Ecology and Management*, 259(4), pp. 660–684.

Arora, G.S. and Gupta, I.J. (1979) *Taxonomic studies of some of the Indian non-mulberry silkmoths (Lepidoptera: Saturniidae)*. Memoirs of the Zoological Survey of India, 16(1), pp. 1–63.

Arunkumar, K.P., Metta, M. and Nagaraju, J. (2006) 'Molecular phylogeny of silkmoths reveals the origin of domesticated silkworms and their relationships with wild relatives', *BMC Evolutionary Biology*, 6, 71.

Arunkumar, K.P., Sahu, A.K., Mohanty, A.R. *et al.* (2012) 'Genetic diversity and population structure of Indian golden silkmoth (*Antheraea assama*)', *PLOS ONE*, 7(8), e43716. https://doi.org/10.1371/journal.pone.0043716

Bale, J.S. *et al.* (2002) 'Herbivory in global climate change research', *Global Change Biology*, 8, pp. 1–16.

Baruah, K.K., Sarma, D. and Gogoi, B. (2019) 'Climate change and its impact on muga host plant productivity in Northeast India', *Journal of Environmental Biology*, 40(5), pp. 875–882.

Beccaloni, G.W., Scoble, M.J., Robinson, G.S. and Pitkin, B. (2017) *LepIndex: The Global Lepidoptera Names Index*. Natural History Museum, London.

Bebber, D.P., Ramotowski, M.A.T. and Gurr, S.J. (2013) 'Crop pests and pathogens move polewards in a warming world', *Nature Climate Change*, 3, pp. 985–988.

Benchamin, K.V. and Jolly, M.S. (1986) *Principles of eri and muga silkworm rearing*. Proceedings of National Seminar on Non-Mulberry Sericulture. Ranchi: Central Silk Board, pp. 63–106.

Benchamin, K.V. and Jolly, M.S. (1986) *Principles of tropical tasar culture*. Ranchi: Central Tasar Research Institute.

Bindroo, B.B. and Sahu, A.K. (2014) *Prospects and strategies for development of vanya silks*. New Delhi: Central Silk Board.

Central Silk Board (2023) *Annual Report 2022–23*. Bengaluru: Ministry of Textiles, Government of India.

Central Silk Board (CSB) (2023) *Sericulture in India: Statistics and development programmes*. Bengaluru: Ministry of Textiles, Government of India.

CEPF (2023) *Biodiversity hotspots*. Critical Ecosystem Partnership Fund. Available at: https://www.cepf.net (Accessed: 30 May 2026).

Chakraborti, S., Kundu, S., Ghosh, S.K. and Das, P. (2019) 'Molecular characterization and genetic diversity assessment of Indian wild silkmoths using DNA markers', *Journal of Genetics*, 98, pp. 1–12.

Chakravorty, R., Neog, K. and Das, R. (2015) 'Biodiversity and conservation of muga silkworm and its host plants in North-East India', *International Journal of Wild Silkmoth and Silk*, 20, pp. 1–12.

Chakravorty, R., Neog, K. and Das, P.K. (2011) *Eri silkworm and eri culture*. Jorhat: Central Muga Eri Research and Training Institute.

Chakraborty, S., Muthulakshmi, M., Vardhini, D. *et al.* (2015) 'Genetic analysis of Indian tasar silkmoth (*Antheraea mylitta*) populations', *Scientific Reports*, 5, 15728.

Choudhury, S.N., Choudhury, B.N. and Das, P.K. (2018) *Muga culture*. Guwahati: Directorate of Sericulture and Weaving, Government of Assam.

Coley, P.D., Bryant, J.P. and Chapin, F.S. III (1985) 'Resource availability and plant antiherbivore defense', *Science*, 230(4728), pp. 895–899.

Das, P., Sarma, K. and Phukan, J.C. (2010) 'Host plant management in muga culture under changing climatic conditions', *Indian Silk*, 49(5), pp. 10–14.

Das, R. and Rajkhowa, G. (2019) 'Diversity and conservation status of wild sericigenous insects in North-East India', *Journal of Entomology and Zoology Studies*, 7(2), pp. 1201–1208.

Datta, R.K. and Nanavaty, M. (2007) *Global silk industry: A complete source book*. New Delhi: APH Publishing Corporation.

FAO (2010) *The state of the world's forest genetic resources*. Rome: Food and Agriculture Organization of the United Nations.

FAO (2020) *Global forest resources assessment 2020: Main report*. Rome: FAO.

Forrest, J.R.K. (2016) 'Complex responses of insect phenology to climate change', *Current Opinion in Insect Science*, 17, pp. 49–54.

Frankham, R., Ballou, J.D. and Briscoe, D.A. (2017) *Introduction to conservation genetics*. 2nd edn. Cambridge: Cambridge University Press.

Garrett, K.A. *et al.* (2006) 'Climate change effects on plant disease', *Annual Review of Phytopathology*, 44, pp. 489–509.

Goswami, B.N. *et al.* (2006) 'Increasing trend of extreme rain events over India', *Science*, 314, pp. 1442–1445.

Hoffmann, A.A. and Sgrò, C.M. (2011) 'Climate change and evolutionary adaptation', *Nature*, 470, pp. 479–485.

IPCC (2023) *Climate change 2023: Synthesis report*. Geneva: Intergovernmental Panel on Climate Change.

Jamieson, M.A. *et al.* (2012) 'Consequences of climate warming and altered precipitation patterns for plant–insect interactions', *Plant Physiology*, 160(4), pp. 1719–1727.

Jolly, M.S., Sen, S.K., Sonwalkar, T.N. and Prasad, G.K. (1979) *Non-mulberry sericulture*. FAO Agricultural Services Bulletin No. 29. Rome: FAO.

Jolly, M.S., Chatterjee, S.N. and Sen, S.K. (1974) *Non-mulberry silks*. Bombay: Central Silk Board.

Jolly, M.S., Sen, S.K., Ahsan, M.M. and Sonwalkar, T.N. (1974) *Non-mulberry sericulture in India*. Bombay: Central Silk Board.

Kingsolver, J.G. *et al.* (2011) 'Complex life cycles and responses to climate change', *Integrative and Comparative Biology*, 51, pp. 719–732.

Krishnan, R. *et al.* (2020) *Assessment of climate change over the Indian region*. Singapore: Springer.

Mattson, W.J. Jr. (1980) 'Herbivory in relation to plant nitrogen content', *Annual Review of Ecology and Systematics*, 11, pp. 119–161.

Myers, N., Mittermeier, R.A., Mittermeier, C.G. *et al.* (2000) 'Biodiversity hotspots for conservation priorities', *Nature*, 403, pp. 853–858.

Nässig, W.A., Treadaway, C.G. and Peigler, R.S. (1996) 'The wild silkmoths of the Oriental region: taxonomy and distribution', *Nachrichten des Entomologischen Vereins Apollo*, Supplement 17, pp. 1–230.

Parmesan, C. (2006) 'Ecological and evolutionary responses to recent climate change', *Annual Review of Ecology, Evolution, and Systematics*, 37, pp. 637–669.

Rahman, M.L., Das, K.K. and Bhattacharyya, P.R. (2021) 'Climate variability and its implications for muga silk production in North-East India', *Indian Journal of Sericulture*, 60(1), pp. 1–10.

Rahmathulla, V.K. (2012) 'Management of climatic factors for successful silkworm crop', *Psyche*, 2012, 121234.

Rajesh Kumar (2017) *Wild silk moths diversity and conservation in India*. *Indian Silk*, 56, pp. 38–43.

Rajesh Kumar, Goswami, D. and Singh, B.K. (2017) *Illustrated male genitalic identification guide: North East Indian wild silk moths*. ISBN 9788193269725.

Rajkhowa, G. (2013) *Muga silkworm and golden silk of Assam*. Jorhat: Central Muga Eri Research and Training Institute.

Reddy, R.M., Suryanarayana, N. and Srivastava, P.P. (2010) 'Eco-racial diversity and conservation of tropical tasar silkworm, *Antheraea mylitta*', *Indian Journal of Sericulture*, 49(1), pp. 1–10.

Reddy, R.M., Rao, P.V. and Rao, D.M. (2014) 'Impact of climate change on sericulture and adaptation strategies', *International Journal of Industrial Entomology*, 29(1), pp. 1–10.

Robinson, E.A., Ryan, G.D. and Newman, J.A. (2012) 'Effects of elevated CO_2 on plant–arthropod interactions', *New Phytologist*, 194(2), pp. 321–336.

Sarkar, D.C., Das, P.K. and Choudhury, B.N. (2018) 'Eri culture in North-East India: status, challenges and opportunities', *Indian Silk*, 57(5), pp. 20–25.

Sarma, K. *et al.* (2025) 'Ensemble distribution model of muga silkworm (*Antheraea assamensis*) and its host plant *Litsea monopetala*', *Scientific Reports*, 15, 22080.

Scoble, M.J. (1995) *The Lepidoptera: form, function and diversity*. 2nd edn. Oxford: Oxford University Press.

Seidel, C.L. and Peigler, R.S. (2018) 'Entomological aspects of sericulture based on *Antheraea assamensis* and *Samia ricini*', *Tropical Lepidoptera Research*, 28(1), pp. 1–15.

Singh, K.C. and Benchamin, K.V. (2002) *Tribal vanya sericulture in India*. Ranchi: Central Tasar Research and Training Institute.

Singh, K.C. and Benchamin, K.V. (2002) 'Biology and ecology of wild silkmoths of India', *International Journal of Wild Silkmoth and Silk*, 7, pp. 87–99.

Singh, K.C., Sinha, A.K. and Suryanarayana, N. (2013) *Tasar culture*. New Delhi: Central Silk Board.

Singh, Y.T., Mazumdar-Leighton, S., Saikia, M. *et al.* (2012) 'Genetic variation within native populations of *Antheraea assamensis* indicates need for in situ conservation', *PLOS ONE*, 7(11), e49972.

Suryanarayana, N. and Srivastava, A.K. (2005) *Monograph on tropical tasar silkworm, Antheraea mylitta Drury*. Ranchi: Central Tasar Research and Training Institute.

Thangavelu, K. (2002) *Fascinating world of silkworms*. Bangalore: Central Silk Board.

Thomas, C.D. *et al.* (2004) 'Extinction risk from climate change', *Nature*, 427, pp. 145–148.

Thomas, J.A. *et al.* (2004) 'Comparative losses of British butterflies, birds and plants and the global extinction crisis', *Science*, 303, pp. 1879–1881.

Thuiller, W. *et al.* (2005) 'Climate change threats to plant diversity in Europe', *PNAS*, 102(23), pp. 8245–8250.

Vinakumar, K., Mohanraj, P. and Peigler, R.S. (1992) 'Life history of *Attacus mcmulleni*', *Journal of Research on Lepidoptera*, 31(3–4), pp. 169–179.

Venkumari, K., Peigler, R.S. and Naumann, S. (1992) 'An inventory of silk moths of the Indian subcontinent', *Wild Silkmoth and Silk*, 1, pp. 45–60.

Visser, M.E. and Both, C. (2005) 'Shifts in phenology due to global climate change', *Proceedings of the Royal Society B*, 272, pp. 2561–2569.

Zvereva, E.L. and Kozlov, M.V. (2006) 'Consequences of elevated CO_2 and temperature for plant–herbivore interactions', *Global Change Biology*, 12(1), pp. 27–41.

CHAPTER 4: CLIMATE VARIABILITY AND RESILIENCE OF THE ERI SERI-ECOSYSTEM

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4.1. INTRODUCTION

Eri silkworm, *Samia ricini* (Donovan), is a multivoltine, polyphagous, and fully domesticated sericigenous insect belonging to the family Saturniidae. The silk produced by this species is popularly known as "Ahimsa Silk" because the pupae are not killed during silk extraction, making it one of the most eco-friendly and ethically produced natural fibres. Among the non-mulberry silks, eri silk occupies a prominent position and ranks second only to mulberry silk in terms of production, contributing more than 7,886 metric tonnes annually in India (CSB, 2026). The expanding production and market demand highlight its growing importance in the sericulture sector and rural economy.

Eri culture is an integral component of the farming systems of North-Eastern India, where it has traditionally been practised for generations. Unlike other commercially exploited vanya silkworms, eri silkworms can be reared entirely under indoor conditions, offering greater protection against predators, parasitoids, diseases, and adverse weather conditions. This unique feature facilitates year-round rearing and provides a reliable source of income for rural households.

The species exhibits remarkable genetic diversity expressed through variations in larval colouration, cocoon morphology, silk characteristics, and adaptation to different agro-climatic conditions. Twenty-six eco-races have been reported from the North-Eastern region of India, representing valuable genetic resources for conservation, breeding, and climate adaptation programmes. Such diversity plays a critical role in enhancing resilience against environmental stresses and improving productivity under changing climatic conditions.



Figure 1: Diversity of eri silkworms and its cocoons

Eri silkworms are primarily reared on castor (*Ricinus communis*), which serves as the principal host plant, although alternative hosts such as kesseru (*Heteropanax fragrans*), borpat (*Ailanthus grandis*), payam (*Evodia flaxinifolia*), and tapioca (*Manihot esculenta*) are also utilized depending on local availability (Jigyasu *et al.*, 2025). The nutritional quality and seasonal abundance of these host plants directly influence larval growth, cocoon quality, and silk yield.

Apart from silk production, eri culture contributes significantly to nutritional security and livelihood diversification. The pre-pupae and pupae are rich sources of protein and are consumed as traditional food in many parts of North-Eastern India and Southeast Asia. Consequently, eri culture provides dual benefits in the form of fibre production and edible insect protein, thereby enhancing household income and food security.

The life cycle of *S. ricini* is strongly regulated by environmental factors, particularly temperature and humidity. Under favourable conditions, the life cycle is completed within 52–60 days. However, during winter, lower temperatures reduce metabolic activity and feeding efficiency, extending the life cycle to 75–90 days. Seasonal variations therefore have a direct impact on developmental rate, crop duration, and annual cocoon productivity.

Although spring and autumn are considered the most favourable seasons for eri cocoon production, summer conditions often present considerable challenges. Temperatures frequently exceed 35°C and are accompanied by substantial fluctuations in humidity, adversely affecting both seed and cocoon production. Such conditions may lead to the emergence of deformed moths, reduced mating success, poor fecundity, unfertilized eggs, impaired embryonic development, egg desiccation, and reduced hatchability.

The eri silkworm is generally regarded as more tolerant to biotic and abiotic stresses than many other commercially exploited silkworm species. Nevertheless, climatic extremes can increase susceptibility to diseases, particularly flacherie, which is capable of causing severe crop losses during hot and humid seasons. Recent investigations have identified bacterial pathogens such as *Bacillus cereus* and *Bacillus thuringiensis* as important contributors to flacherie outbreaks in eri silkworms. Understanding pathogen dynamics under changing climatic conditions is therefore essential for developing effective disease management strategies.

In recent decades, climate change has emerged as a major threat to sustainable sericulture worldwide. Rising temperatures, irregular rainfall patterns, prolonged droughts, increased frequency of extreme weather events, and fluctuations in relative humidity have significantly altered agricultural ecosystems. Since silkworms are highly sensitive to environmental conditions, climate variability directly influences host plant productivity, silkworm physiology, cocoon quality, and overall economic returns from ericulture.

Given the ecological, economic, and social importance of eri culture, understanding the impacts of climate variability on the entire eri sericulture ecosystem including host plants, silkworm biology, disease incidence, cocoon production, and farmer livelihoods is essential for developing effective adaptation and mitigation strategies. This chapter examines the influence of climate variability on eri host plants and silkworm performance and discusses potential approaches for enhancing the resilience and sustainability of eri sericulture under future climate scenarios.

4.2. IMPACT ON PRIMARY FOOD PLANT (CASTOR)

Castor (*Ricinus communis* L.) is the principal host plant of the eri silkworm and plays a pivotal role in determining the productivity and sustainability of eri sericulture. Although castor is recognized

as a hardy and drought-tolerant species capable of growing under a wide range of environmental conditions, increasing climatic variability and environmental pollution pose significant challenges to its growth, physiology, leaf production, and seed yield.

Climate change-associated factors, including rising temperatures, irregular precipitation patterns, prolonged droughts, flooding events, and elevated atmospheric carbon dioxide concentrations, directly influence castor productivity. Temperature is one of the most critical environmental determinants regulating seed germination, vegetative growth, photosynthetic efficiency, and reproductive development. Under optimum conditions (20–31°C), castor exhibits vigorous growth, rapid canopy development, and maximum leaf and seed production. However, exposure to temperatures beyond the optimum range induces physiological and biochemical stress responses that adversely affect plant performance.

Elevated temperatures reduce photosynthetic efficiency through increased photorespiration and stomatal closure, thereby limiting carbon dioxide assimilation and biomass accumulation. Prolonged heat stress suppresses cell division and elongation, resulting in reduced plant height, smaller leaf area, and diminished canopy development. Concurrently, drought stress exacerbates these effects by restricting water availability, impairing nutrient uptake, and reducing chlorophyll synthesis. Consequently, vegetative growth, branching pattern, and overall biomass production decline substantially under prolonged moisture-deficit conditions.

Extreme climatic events such as intense rainfall and flooding further threaten castor cultivation. Waterlogging damages root systems, disrupts nutrient acquisition, and increases plant susceptibility to diseases and insect pests. During reproductive stages, elevated temperatures adversely affect pollen viability, fertilization success, and capsule development, ultimately reducing seed yield and quality. Climate-induced stress may also alter seed biochemical composition by decreasing oil content and modifying fatty acid profiles, thereby affecting its industrial and commercial value.

Environmental pollution represents an additional constraint to castor productivity. Heavy metals such as cadmium (Cd), lead (Pb), chromium (Cr), nickel (Ni), zinc (Zn), and copper (Cu), originating from industrial effluents, sewage discharge, and contaminated agricultural lands, accumulate in soils and are absorbed by castor roots. Owing to its extensive root system and high biomass production, castor possesses considerable phytoremediation potential and can tolerate moderate levels of contamination. Nevertheless, excessive accumulation of heavy metals induces oxidative stress, disrupts enzymatic activities, inhibits chlorophyll biosynthesis, and interferes with nutrient homeostasis (Jigyasu *et al.*, 2022).

Heavy metal toxicity frequently manifests as leaf chlorosis, reduced leaf expansion, premature senescence, impaired root growth, and decreased water-use efficiency. Studies have demonstrated substantial accumulation of toxic metals in castor roots, shoots, and leaves, accompanied by reductions in aerial biomass and physiological efficiency. Such changes not only decrease plant productivity but may also influence the nutritional quality of leaves used for eri silkworm feeding.

4.2.1. Effect of Climate Variability on Leaf Yield

Leaf production is the most important economic trait of castor in relation to eri sericulture, as leaves constitute the primary food source for eri silkworm larvae. Climatic stresses, particularly elevated temperature and drought, significantly influence leaf biomass, quality, and nutritional composition.

Temperatures exceeding 35°C initiate physiological stress responses that reduce leaf initiation, expansion, and biomass accumulation. Under severe heat stress (>40°C), photosynthetic activity

declines sharply due to enhanced photorespiration and degradation of chlorophyll pigments. The resulting imbalance between photosynthesis and respiration depletes carbohydrate reserves, limiting vegetative growth and foliage production. Furthermore, excessive heat accelerates leaf senescence, causing leaf scorching, marginal necrosis, and premature abscission (Koutroubas *et al.*, 1999; Witt *et al.*, 2023; Susan Mahr, 2026).

High temperature also suppresses node formation and leaf emergence, thereby reducing the total number of harvestable leaves per plant. Simultaneously, increased evapotranspiration promotes stomatal closure as a water-conservation mechanism, restricting carbon dioxide uptake and further reducing photosynthetic productivity. Drought stress compounds these effects by lowering leaf moisture content, chlorophyll concentration, and nutrient accumulation, resulting in poor-quality foliage (Koutroubas *et al.*, 1999; Witt *et al.*, 2023; Susan Mahr, 2026).

Environmental pollution similarly affects leaf productivity. Heavy metal accumulation in leaf tissues reduces leaf area, succulence, moisture content, and protein concentration while increasing oxidative damage. Although castor exhibits moderate tolerance to contaminated environments, prolonged exposure to heavy metal stress substantially reduces foliage production and nutritional quality. Such reductions directly affect eri silkworm growth and cocoon productivity by limiting the availability of nutritious host plant material.

4.2.2. Effect of Climate Variability on Seed Yield

Seed production in castor is highly sensitive to environmental conditions, particularly temperature and water availability during flowering, fertilization, and seed-filling stages. The crop requires a minimum temperature of approximately 15.6°C for germination, while optimum growth and reproductive performance occur between 25°C and 31°C (Torsoni *et al.*, 2025).

Exposure to temperatures above 30–35°C during flowering disrupts reproductive development by reducing the proportion of female flowers and increasing the prevalence of male flowers within racemes. This phenomenon, often referred to as sex reversion, significantly decreases the number of seed-bearing structures and ultimately lowers seed yield. Short-term exposure to temperatures exceeding 40°C may cause flower blasting, impaired pollination, and abortion of developing capsules (Koutroubas *et al.*, 1999; Witt *et al.*, 2023; Susan Mahr, 2026).

Heat stress during seed filling and oil biosynthesis alters carbon partitioning and lipid metabolism, resulting in reduced seed weight and lower oil content. Elevated temperatures can also modify the fatty acid composition of castor oil, affecting its industrial utility. Furthermore, prolonged exposure of mature capsules to high field temperatures accelerates seed deterioration, increases free fatty acid content, and promotes oxidative degradation of oil quality.

Moisture stress during reproductive development further aggravates yield losses by reducing raceme formation, capsule number, and seed size. Similarly, heavy metal contamination interferes with metabolic pathways involved in reproductive growth, nutrient translocation, and seed development. Consequently, seed germination, viability, and oil content may decline under prolonged environmental stress.

Despite its remarkable adaptability and phytoremediation capacity, sustained exposure to climatic extremes and environmental pollution can substantially reduce castor productivity. Since castor constitutes the principal host plant of the eri silkworm, climate-induced reductions in leaf and seed production have direct implications for the sustainability and profitability of eri sericulture systems.

Table 1: Summary of temperature thresholds for castor plant (Severino and Auld, 2014; Koutroubas *et al.*, 1999; Goneli *et al.*, 2018; Witt *et al.*, 2023).

Impact on				
Temperature Range	**Propagation**	**Foliage**	**Seed Production**	**Leaf Yield**
Below 15 °C	Below base growth temperature; slow/ delayed germination.	Inhibits vegetative growth; induces chilling stress.	Incomplete ripening and reduced yields.	Stunted, slow-developing canopy.
20 °C – 31 °C	Optimum range for cultivation, germination, and fertilization.	Optimum range for rapid vegetative growth and canopy establishment.	Maximum seed yield and ideal seed weight.	Maximum leaf area, high biomass, and lush foliage.
Above 35 °C	Restricts female flower development; disrupts oil formation.	Triggers high transpiration and minor metabolic stress.	Declining oil content; lower seed quality.	Reduced leaf size; slight decline in overall yield.
Above 40 °C	Reaches maximum ceiling threshold; causes flower blasting.	Shuts down plant growth; accelerates chlorophyll breakdown and leaf drop.	Severe seed abortion and drastic yield failure.	Severe loss of leaf biomass; scorched and wilted foliage.

4.3. IMPACT ON ERI SILKWORM AND COCOON PRODUCTION

The eri silkworm exhibits greater tolerance to climatic fluctuations than the mulberry silkworm (*Bombyx mori*), extreme variations in temperature and relative humidity can adversely affect physiological processes, feeding behaviour, survival, and cocoon productivity. The impacts of climate variability are further compounded by climate-induced changes in host plant quality, resulting in nutritional deficiencies that directly influence larval growth and silk production.

4.3.1. Influence of Temperature and Humidity on Larval Growth and Development

Temperature and relative humidity are the principal environmental factors regulating the metabolic activity of eri silkworms. Optimum larval growth is generally achieved under temperatures ranging from 24–28°C and relative humidity between 75–85%. However, exposure to temperatures exceeding 32°C, particularly when coupled with relative humidity above 80%, imposes significant physiological stress on larvae (Das *et al.*, 2021).

Elevated temperatures increase metabolic rates and accelerate larval development, thereby shortening the feeding period and reducing the duration available for nutrient assimilation. Consequently, larvae attain lower body weight and exhibit reduced growth efficiency. Excessive humidity further aggravates these effects by decreasing feeding activity and impairing digestion, resulting in poor food conversion efficiency and reduced accumulation of body reserves required for cocoon formation (Das *et al.*, 2021).

Climate-induced deterioration in host plant quality also contributes to reduced larval performance. Heat and moisture stress can decrease leaf moisture, protein content, and nutrient availability in castor and other host plants. Moreover, under hot and humid rearing conditions, harvested leaves deteriorate rapidly due to increased microbial activity and fermentation. Such leaves are often rejected by larvae, leading to inadequate nutrient intake and impaired growth.

4.3.2. Physiological Responses to Heat Stress

Heat stress affects several physiological and biochemical processes in eri silkworms. Exposure to elevated temperatures disrupts enzyme activity, protein metabolism, and cellular homeostasis. At the cellular level, thermal stress may induce oxidative damage through the excessive generation of reactive oxygen species (ROS), resulting in membrane instability and impaired physiological functioning.

Prolonged exposure to temperatures above the optimal range can alter endocrine regulation, disturb moulting processes, and reduce larval vigour. In severe cases, heat stress affects the synthesis and structural stability of essential proteins and nucleic acids, ultimately reducing survival and increasing susceptibility to diseases. Similar observations have been reported in several lepidopteran insects, where elevated temperatures adversely affect growth, immunity, and reproductive fitness.

4.3.3. Impact on Cocoon Formation and Silk Quality

The spinning stage represents one of the most climate-sensitive phases of the eri silkworm life cycle. Successful cocoon formation requires a favourable microclimate to ensure proper secretion, extrusion, and solidification of silk proteins. Exposure to temperatures above 32°C in combination with high relative humidity can significantly impair cocoon formation and silk quality.

High temperatures affect the biosynthesis and secretion of fibroin and sericin within the silk glands, leading to reduced silk deposition during spinning. Simultaneously, excessive humidity interferes with the drying and hardening of extruded silk filaments, resulting in loosely woven, thin-shelled, or malformed cocoons. Such conditions frequently produce cocoons with reduced shell weight, lower shell ratio, and inferior fibre characteristics.

Adverse climatic conditions during spinning also increase larval mortality and susceptibility to microbial infections. Dead or diseased larvae may fail to complete cocoon formation, producing stained or defective cocoons of little commercial value. Consequently, elevated temperature and humidity substantially reduce cocoon yield, pupal weight, shell weight, and overall silk recovery.

Table 2: Critical microclimate thresholds for Eri Silkworm

Rearing Phase	Optimum Temperature	Optimum RH	Combined Impact of High Temp (>35 °C) + High Humidity (> 85%)
Egg Incubation	24°C – 26°C	75% – 85%	Desiccation of egg masses; dead-in-shell embryos.
Young Age (Chawki: I – II Instar)	26°C – 28°C	85% – 90%	High initial mortality; uneven growth across the batch.
Late Age (III - V Instar)	24°C – 26°C	70% – 80%	Severe Flacherie outbreaks; reduced food intake; light larval weight.
Spinning (Cocoon Stage)	24°C – 27°C	70% – 75%	Thin-layered, flimsy shells; dead pupae; stained silk.

4.3.4. Effects on Reproductive Performance and Seed Production

Climate variability also exerts profound effects on the reproductive biology of eri silkworms. Exposure to temperatures above 35°C during pupal development and adult emergence often results in developmental abnormalities and reduced reproductive fitness. High-temperature stress may impair spermatogenesis and reduce mating success, leading to partial or complete male sterility.

Female moths emerging under thermal stress generally exhibit reduced fecundity, lower egg-laying capacity, and poor egg adhesion. Furthermore, elevated temperatures adversely affect embryonic development, resulting in decreased egg viability and hatchability. The combined effects of reduced mating efficiency, lower fertility, and poor egg hatch significantly compromise seed production and the availability of quality disease-free layings (DFLs) for subsequent rearing cycles.

4.3.5. Consequences for Eri Sericulture

The cumulative effects of climate-induced stress on larval growth, cocoon formation, and reproductive performance translate into substantial reductions in productivity and profitability. Reduced larval survival, lower cocoon weight, decreased shell ratio, poor silk quality, and diminished seed production collectively threaten the sustainability of eri sericulture. As climate change continues to intensify, the development of thermo-tolerant eri silkworm strains, improved rearing technologies, and climate-resilient host plant management practices will be critical for maintaining stable cocoon production and ensuring the long-term sustainability of the eri silk industry.

4.4. CONCLUSIONS

Climate variability and climate change have emerged as major challenges to the sustainability and productivity of the eri sericulture ecosystem. Rising temperatures, irregular rainfall patterns, prolonged droughts, humidity fluctuations, and the increasing frequency of extreme weather events affect all components of the eri production system, including host plants, silkworm growth and development, cocoon production, silk quality, and seed generation. As a poikilothermic insect, the eri silkworm (*Samia ricini*) is highly sensitive to environmental conditions, and even moderate deviations from optimal temperature and humidity ranges can adversely influence larval survival, feeding efficiency, reproductive performance, and cocoon productivity.

Climate-induced stress on major host plants, particularly castor (*Ricinus communis*), results in reduced leaf yield, altered nutritional composition, impaired physiological processes, and lower seed production. Such changes directly affect larval nutrition and subsequently reduce cocoon weight, shell ratio, and silk yield. Furthermore, elevated temperature and humidity create favourable conditions for disease outbreaks, especially flacherie and other microbial infections, leading to increased crop losses and economic instability among farming communities.

The impacts of climate change extend beyond biological productivity and threaten the socio-economic foundation of eri culture, which serves as an important source of livelihood, nutritional security, and women-centric rural employment in many regions of India. The vulnerability of smallholder farmers to climate-induced production fluctuations underscores the need for climate-resilient interventions and sustainable management practices.

To ensure the long-term sustainability of ericulture, integrated adaptation strategies are essential. These include the development of thermo-tolerant and disease-resistant eri silkworm strains, conservation and utilization of diverse eri eco-races, improvement of climate-resilient host plant varieties, adoption of climate-smart rearing technologies, and strengthening of disease surveillance systems. Improved microclimate management within rearing houses, efficient water-use practices, agroforestry-based host plant cultivation, and capacity-building programmes for farmers can further enhance resilience against climatic stress.

Future research should focus on understanding the physiological, molecular, and genetic mechanisms underlying climate adaptation in both host plants and eri silkworms. Advances in genomics, breeding technologies, climate modelling, and precision sericulture have the potential to provide innovative solutions for mitigating climate-related risks. A multidisciplinary approach integrating

research, extension, policy support, and farmer participation will be critical for safeguarding the eri sericulture ecosystem under changing climatic conditions.

In conclusion, while climate variability poses significant threats to eri sericulture, the rich genetic diversity of eri silkworms, combined with scientific innovations and adaptive management strategies, offers considerable opportunities for developing a resilient and sustainable eri silk industry capable of supporting rural livelihoods and contributing to environmentally sustainable textile production in the future.

4.5. REFERENCES

Das Sudipta Kumar, Dutta Lohit Chandra, Deka Rajib Lochan (2021). Phenology and cocoon characters of eri silkworm (*Samia ricini* Boisduvial) affected by temperature and humidity at Jorhat, Assam. Journal of Agrometeorology 23 (2) : 256-259

Goneli, A. L. D., Corrêa, P. C., Oliveira, A. P. L. R., Hartmann Filho, C. P., & Oba, G. C. (2018). Castor beans quality subjected to different storage temperatures and periods. Engenharia Agrícola, 38(3), 361–368. https://doi.org/10.1590/1809-4430-Eng.Agric.v38n3p361-368/2018

Jigyasu DK**,** Kumar A, Pal S, Shabnam A A, Barua P, Sahu P, Kumari KMV, (2022). Assessment of remediation potential of naturally grown castor in the polluted river catchments and its suitability for Ericulture. Plant Archives, 22, Special Issue (VSOG), 103-107. e-ISSN:2581-6063

Jigyasu, D.K., Patidar, O.P., Shabnam, A.A., Kumar, A. (2025). Castor Plant in Ericulture: Opportunities and Challenges. In: Bauddh, K., Singh, R.P. (eds) Ricinus Communis: A Climate Resilient Commercial Crop for Sustainable Environment. Springer, Singapore. https://doi.org/10.1007/978-981-96-3224-4_7

Koutroubas S.D., Papakosta D.K., Doitsinis A., (1999). Adaptation and yielding ability of castor plant (*Ricinus communis* L.) genotypes in a Mediterranean climate. European Journal of Agronomy,11(3–4), 227-237, https://doi.org/10.1016/S1161-0301(99)00034-9.

Mahesh DS, Jigyasu DK, Shabnam AA, (2024). Handbook of eri culture (1st ed.). CSB-Central Muga Eri Research and Training Institute, Lahdoigarh, Jorhat, Assam, India, Book no. 2, pp-290. ISBN: 978-81-972337-4-6

Severino L.S., Auld D.L. (2014). Study on the effect of air temperature on seed development and determination of the base temperature for seed growth in castor (*Ricinus communis* L.) Aust. J. Cro. Sci., 8(2):290–295.

Shabnam AA, Kumar A, Jigyasu DK, Sahu P, Patidar OP, Kumari Vijaya KM, (2022). Descriptor-cum-Catalogue: Characterisation of Eri silkworm major host plant Castor (*Ricinus communis* L.) Germplasm. Central Muga Eri Research and Training Institute, Central Silk Board, Lahoigarh, Jorhat, Assam, India, Book no. 1, pp-94.B

Shabnam Aftab A., Kumar Amit, Sahu Priyanka, Jigyasu D.K. and Vijaya Kumari K.M. (2022). Entrapment of the Genetic Diversity of Perennial Castor (*Ricinus Communis* L.) in Northeast India. Plant Archives, 22, Special Issue (VSOG), 240-246. e-ISSN:2581-6063 (online), ISSN:0972-5210.

Singh S, Jigyasu DK, Patidar OP, Kumar A and Shabnam AA. (2024). Eri Silk Insect (*Samia ricini*, Donovan). In: Omkar (Ed.), Commercial Insects. CRC press, Taylor & Francis Group, pp 103-124, DOI: 10.1201/9781003454960

Susan Mahr (2026). Castor Bean, *Ricinus communis*. In: Allen Pyle, Horticulture Outreach Specialist, Bruce Spangenberg, Horticulture Outreach Specialist, UW—Madison Extension, University of Wisconsin—Madison.

Torsoni, G.B., Aparecido, L.E.d.O., Lorençone, J.A. *et al.* (2025). Climate challenges in castor bean production: agroclimatic zoning and future prospects for sustainable biofuel. *Theor Appl Climatol* 156, 398. https://doi.org/10.1007/s00704-025-05626-5

Witt TW, Flynn KC, Zoz T, Lee TO, Monteiro JEBA. (2023). A site suitability analysis for castor (*Ricinus communis* L.) production during Brazil's second harvest incorporating disease prediction. Heliyon. 6;9(8): e18981. https://doi.org/10.1016/j.heliyon.2023.e18981.

CHAPTER 5: CLIMATE CHANGE-INCIDENCE AND DYNAMICS OF DISEASES AND PESTS IN ERI AND MUGA SILKWORM ECOSYSTEMS

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5.1. INTRODUCTION

The North Eastern Region (NER) of India, comprising Assam, Arunachal Pradesh, Meghalaya, Mizoram, Nagaland, Tripura, Manipur, and Sikkim holds a unique position in global sericulture as the exclusive production zone for Muga and a primary hub for Eri silk cultivation. These two Vanya (wild) silks represent indigenous sericultural traditions deeply embedded in the region's cultural fabric and rural economy. The muga silkworm, *Antheraea assamensis* Helfer, is endemic to this region and is renowned for producing the naturally lustrous, golden-yellow "Muga silk," a fiber of high aesthetic and commercial value. Unlike other silks, muga silk is exclusive to the North-Eastern states, especially Assam and parts of Manipur, making it an important geographical indication product and a source of livelihood for thousands of rural households.

5.1.1. Role of Eri and Muga culture in Rural Economy Development

Production and Economic Contribution: Assam dominates production, contributing 78% of India›s Muga and 77% of Eri silk, with the state producing 6,305 MT of raw silk in 2024–25 and supporting 30.93 lakh livelihoods across 10,380 villages. Nationally, Eri silk production reached 7,886 MT in 2024–25, while Muga produced 232 MT, both showing steady growth despite climate challenges. Muga silk is geographically restricted to NER, with 95% produced exclusively in Assam, making it a GI-protected unique product with no global equivalent.

Employment and Women's Empowerment: The sericulture sector is highly labour-intensive and gender-inclusive, with women comprising approximately 65% of the workforce and 54.4% from weaker socioeconomic sections. In Meghalaya, Eri silk (Ryndia) provides community-based household income, particularly for women engaged in cocoon rearing, spinning and weaving, with GI recognition in 2025 enhancing market visibility and pricing. The broader sericulture workforce in India expanded by 24% from 78 lakh (2013–14) to 98 lakh (2024–25), with NER playing a pivotal role.

5.1.2. Climate change-Threat to Eri and Mugaculture

Climate change directly impacts the population dynamics and seasonal occurrence of insect pests such as stem borers, defoliators, and sap-sucking insects, which damage host plants and reduce leaf quality. Simultaneously, fluctuating temperature and humidity create favourable conditions for the proliferation of pathogens causing diseases such as pebrine, flacherie, grasserie, and muscardine in silkworms. The combined effect of these biotic stresses leads to substantial economic losses and threatens the sustainability of muga culture.

Despite its importance, systematic studies on the interaction between climate variability, pest incidence, and disease occurrence in the muga ecosystem remain limited. Understanding these interactions is essential for developing effective management strategies and ensuring resilience in muga production systems. Therefore, the present study aims to examine the influence of climate variability on insect pest dynamics and disease occurrence in the muga ecosystem, with special

emphasis on vulnerable pre-seed crops. The findings are expected to contribute to the development of climate-resilient sericulture practices and improved pest and disease management strategies in the region.

5.2. GLOBAL SCENARIO OF CLIMATE CHANGE

Global mean temperatures have risen by approximately 1.1°C above pre-industrial levels, with projections under SSP2–4.5 scenarios indicating an additional 1.5–2.0°C increase by 2050 in the Indo-Gangetic and northeastern sub-Himalayan regions (IPCC, 2021). Concurrently, the region has experienced intensification of pre-monsoon heat events, erratic precipitation patterns, elevated atmospheric humidity during the kharif season and increased frequency of unseasonable cold spells. These changes directly perturb the microclimatic conditions under which silkworm pathogens proliferate and arthropod pest populations establish. Comprehensive scientific understanding of these climate–disease–pest interactions is a prerequisite for designing adaptation strategies in non-mulberry sericulture.

5.2.1. Climate change in North-eastern India

Northeastern India (NER) is experiencing overwhelming climate change impacts, with minimum temperatures increasing consistently across all states. The region shows particularly significant warming:

Parameter	Observed Trend
Post-monsoon temperature increase	0.1–0.4°C per decade in northeast India
Warm days frequency	Increasing by 1.2 per decade in Hindu Kush-Himalayan (HKH) region
Warm nights frequency	Increasing by 1.7 per decade in HKH region
Cold nights lost	1 per decade; cold days lost: 0.5 per decade
Himalayan warming (1950–1999)	Maximum 2.5°C

Projections to 2100: Under moderate emission scenarios (RCP 4.5), India's average temperature may rise 1.2–2°C by 2100, while high-emission scenarios (RCP 8.5/SSP5-8.5) project 3.5–5.1°C increase. The Hindu Kush-Himalayan region, including Northeast India, faces even more severe warming up to 5.2°C, with some projections indicating 9°C rise by 2100.

Extreme Weather Events and Disasters

NER faces multifaceted climate-induced risks with increasing frequency and severity:

Event Type	Observed Changes
Floods	States affected increased from 8 (2017) to 15 (2021); frequency increasing in northeast
Flash floods	Exacerbated by extreme rainfall events; common in Assam, Arunachal Pradesh
Landslides	Frequent due to hilly terrain, intense rainfall, and ecological changes
Lightning/thunderstorms	Major climate-induced risks in NE India
Droughts	Extremely dry/severely dry conditions observed in 2021 across Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura

Northeastern India faces a dual climate crisis- overall rainfall decline coupled with intensifying extreme rainfall events that trigger devastating floods and landslides. With temperatures projected to rise 2–5°C by 2100 and extreme events quadrupling, the region requires urgent long-term adaptation planning, improved early warning systems and climate-resilient development strategies to protect vulnerable communities, agricultural and sericultural systems.

5.3. INFLUENCE OF CLIMATE CHANGE IN PESTS AND DISEASE OCCURRENCE IN MUGA ECOSYSTEM

In sericulture industry, the host plant plays a vital role in silkworm rearing. The quality of host plant leaves influenced the quality and quantity production of silk. Som (*Persea bombycina*), and Soalu (*Litsea monopetala*) are the primary host plants of muga silkworm (Thangavelu *et al.*, 1988). These plants are infected by various diseases and attacked by insects which affects the rate of cocoon yield by affecting the quality and quantity of leaves of the plants (Das *et al.*, 2003). Some of the important pathogen and insect pests of Muga and Eri food plants are given as follows.

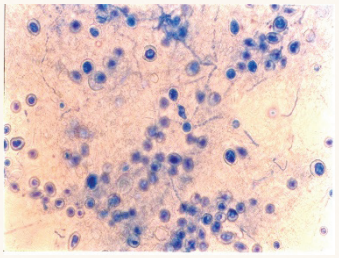
5.3.1. Leaf Spot



Symptoms: Leaf spot is characterized by circular or irregular brown spots surrounded by yellow margin appear on both surfaces of the young and mature leaves. The symptoms are more prominent on the upper surface. As the disease progresses, the minute spots spread irregularly, become brown in colour.

Causal organism

The causal organism is *Phyllosticta perseae* Ell. & Mart. Mycelia are brunched, septet and light green in colour. Conidia are hyaline, 3.4 - 4.6 x 1.4 - 4. 4 microns in size.



Control

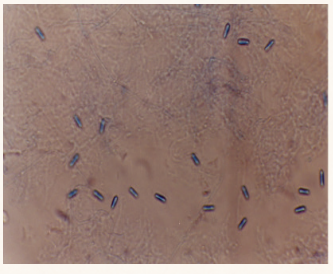
1. Application of 1% Indofil M-45 twice at 15 days interval before the peak season of incidence significantly control the disease.

5.3.2. Leaf Blight



Symptoms- The symptom appears on young and mature leaves in the form of 'ash' colour, round to oval spots irregularly spread to the entire leaf. As the intensity of disease increases, the spots got collapsed and malformed. These spots usually appear nearer to the leaf edges. The infected areas dry up and become brown to black in colour.

Causal organism:



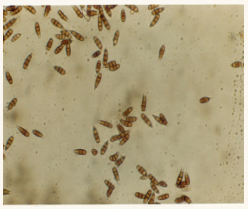
The Causal organism is ***Colletotrichum gloeosporioides*** **Penz.** The mycelium consist of septet, inter and intracellular hyphae. Acervuli are formed abundantly on the infected host surface.

Control

Plucking and burning of infected leaves at the initial stage can minimize the pathogen. As the pathogen is soil born, deep hoeing is an effective means to destroy the pathogen inoculums.

5.3.3. Grey Blight





Symptoms

The disease first shows its appearance as small, oval, discoloured lessons, which are irregularly scattered on the leaves. The brown or grey spots grow irregularly with increasing infection. Symptom appears on both young and mature leaves. As the disease development progresses, the spots get collapsed, malformed and ultimately the entire leaf dries up.

Causal organism: ***Pestalotiopsis desiminata*** **(Thuem.)** Stey is the causal organism of grey blight disease. Generally the disease occurs during April to October. The fructification takes place in acervuli, which are epidermal or sub epidermal, formed of brown thin-walled polyhedral cells.

Control: Timely cultural operation, pruning and pollarding can prevent the disease. Foliar spray of 0.1% Bavistin twice in 15 days interval can check the disease up to 85.2%.

5.4. INSECT PESTS OF MUGA HOST PLANTS

5.4.1. Stem borer (*Zeuzera indica*)

The stem borer infestation is a major problem for muga grower. The caterpillar of stem borer bores the main trunk and also the side shoots and feeds upon the internal tissue. It forms extracting silky thread and thereafter starts feeding on the tissue and form tunnel in the main stem. In case of severe infestation the plant utility dries up. The number of holes per plant is ranges between 1 - 5 and size of holes are 0.5 – 2.0 cm. Infestation is prevalent throughout year but the peak period of infestation was recorded during April to June in Lower Assam and August to November in Upper Assam with causing a damage of 51% in som and 80 % in soalu.

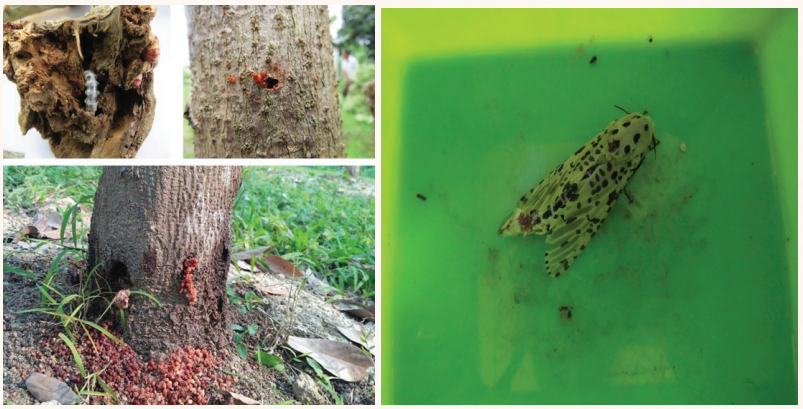


Figure. Larva of *Zeuzera indica* inside the trunk of Som tree and its adult stage

Management Practices

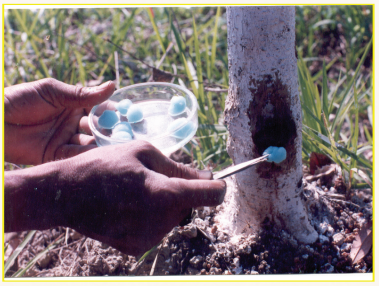
Mechanical control

Mechanical control through plastic wrapping on the main trunk of som and soalu prevent the egg laying of the stem borer by which incidence can be reduced. By using mud plastering on the main stem also prevent the egg laying and minimized the stem borer infestation up to 68%.

By using phyto-chemicals

Plant extract of Neem (*Azadirechta indica*), Posotia (*Budelia asciatica*) Dotura (*Dotura metal*), Titabahak (*Adhatoda vasica*) and Castor (*Ricinus communis*) were found effective in controlling the stem borer up to 95%.

5.4.2. Leaf gall - *Pauropsylla beesoni* and *Asphondylia sp*





Somleaf gall



Soalu leaf gall

Gall infestation is prevalent during winter. Gall is tumour like growth induced by toxic saliva secreted by gall insect. The soalu galls are oval, spherical and globular in shape while the galls of som are spherical in the lower surface and tapering in the terminal region. The infested leaves become unsuitable for silkworm feeding. In case of severe infestation, 60-90 galls per leaf in soalu and 20-40 galls / leaf in som have been reported. *Pauropsylla beesoni* (Homoptera: Psyllidae) cause soalu leaf gall. This pest seriously damaged (49%) soalu leaves during April affecting both sides of the leaves. *Asphondylia sp* infests som plant during June- July up to the extent of 19-.50%.

Control: Severely gall infested plants should be pollarded and all the gall infested leaves and branches should be destroyed through burning. The low infested leaves should be plucked and burned to minimize further multiplication. The pest can be controlled effectively up to the tune of 94% by spraying systemic insecticide like 0.03% Dimecron.

5.4.3. *Cricula trifenestra* (lepidoptera : Saturniidae)

Locally known as 'Amphutukani' in Assam. The larvae of the pest voraciously feed on leaves of som plant causing loss of foliage. Infestation is reported throughout the year, but intensity is high during June to September.

Control: The pest can be control mechanically by collection and killing of caterpillar and eggs. Cocoons should be collected and burnt to stop further multiplication. Spraying of 0.05% phosphomidon can effectively control the pest.



Figure. *Cricula trifenestrata* **infesting Som muga host plant**

5.4.4. Red tree ant (*Oecophylla* spp) Hymenoptera: Formicidae

The red tree ant is a minor pest of som plant. It is unique among the other ants that the species construct nests largely made up of silk produced by the larvae. The nests contain numerous eggs as well as adult insect along with larvae and pupae. The damage by this insect is negligible (Cole *et al.,* 1948).

Different insect pests become a major threat for Muga silk industry because of severity of damage to the host plant. Detailed study of such pest device effective pest forecasting as well as pest management schedule. Again study of natural enemies of these pests in combination with other methods would lead to find out an effective eco-friendly pest management techniques.



Red ants attacking muga silkworm at rearing farm

5.5. INFLUENCE OF CLIMATE CHANGE IN PESTS OCCURRENCE IN ERI SERICULTURE

The primary host plant of Eri silkworm viz. castor is attacked by a multitude of insect pests. This plant is preferred by many insects; therefore it is termed as a storehouse of insect pests. Some of the important insect pests whose population is alarmingly increased in castor farms are given below.

5.5.1 Red hairy caterpillar (*Amsacta albistriga*)

Nature of damage: Defoliation.

More destruction to young crops. This insect is active during June – August.



A. albistriga

Cultural Control

- Setting of light traps (250 watts mercury lamps) on a community basis with the first monsoon rains to attract the moths and kill them.
- Sowing cucumber along with castor.
- Placing the twigs of *Ipomoea*, *Jatropha* and *Calotropis* to attract the migrating caterpillars and kill them mechanically.

Biological control

One scelionid egg parasite, *Aholcus euproctiscidis* and two braconid larval parasites, *Apanteles enproctisiphagus* and *Glyptomorpha deesae* have been recorded.

Chemical control

- Spray 0.05% Monocrotophos or Chloropyriphos (0.07%).
- Trenching around the field and dusting with endosulphan 4% to control migrating larvae.

5.5.1. Castor Semilooper (Achaea janata)

Nature of damage: Defoliation. The peak period of incidence is during July-September.



Achaea janata

Cultural control

- Hand-picking of older larvae during early stages.
- Manipulate parasitic activity by avoiding chemical spray, when 1–2 larval parasites are observed on castor plants.

Biological control

The eggs are parasitized by releasing *Trichogramma minutum* @ 50000/acre.

Chemical/Botanical control

- Spray 0.05%Monocrotophos or 0.07%Endosulphan if 4–5 semi-loopers per plant are observed on 30 and 40 days old seedlings.
- Spray neem seed kernel extract (NSKE) 4% synchronising with egg /early larval stage.

Others

Providing bird perches (10/acre) helps in reducing the incidence.

5.5.2. Tobacco caterpillar (*Spodoptera litura*)

Nature of damage: Defoliation. The peak period of incidence is during August-October.



Spodoptera litura

Cultural control

- If the area to be treated is small, collect and destroy the egg masses and caterpillars in the early stages of infestation.
- Plough up the soil to expose the pupae

Biological control

- The braconid parasites, one larval and another egg-larval, *Apantelesprodeniae* and *Chelonus* sp. have also been recorded.

Chemical control

- To control early-stage larvae, spray neem seed kernel extract (NSKE) 4% or Spray Chloropyrifos 2.5 ml or neem oil 5 ml in one litre of water.

- As the grown-up larvae are nocturnal, poison bait (1 litre of monocrotophos in 10 kg of bran, 1 kg jaggery, and little water to make the bait into pellets for one hectare) placement at the base of the plant helps in killing the larvae.

5.5.3. Jassid (*Empoasca flavescens* Fabricius)

Sucks the sap from plants and hopper burn symptoms on severe infestation. Peak period of incidence during November-January.




Empoasca flavescens (adults)

Chemical control

- Spraying with any systemic insecticide.
- Seed treatment with Imidacloprid or Carbosulfan or stem application with Monocrotophos protects the crop from all sucking pests including Jassids for about a month.

5.6. CASTOR PLANT DISEASES AND MANAGEMENT PRACTICES

5.6.1. *Alternaria* leaf blight

Symptoms: Premature defoliation. Light brown spots on cotyledons turn angular with age. Inflorescence and capsules develop sooty growth. The immature capsule turns brown and falls. Affected capsules have small seeds without oil.

Control: Seeds should be treated with Thiram @ 3 g / kg, Spray 0.2% Mancozeb.

5.6.2. *Fusarium Wilt*

Symptoms: Wilting of plants, root degeneration, dropping of leaves, necrosis of affected tissue and finally leading to death of plants

Control: Seeds should be treated with 3g / kg of Thiram or 2g / kg of Carbendazim.

5.6.3. *Cercospora leaf spot*

Symptoms: Both surfaces of the leaf bear black or brown spots with pale green margins.

Finally turns brown and falls

Control: Spray 0.3% Copper oxychloride or 0.25% Mancozeb two to three times.

5.6.4. *Powdery Mildew*

Symptom: White powdery growth under the surface of the leaves



Altermaria leaf blight Cercospora leaf spot

Control: Spray of 0.2% Sulphur at 15-day intervals during dry weather.

5.7. THERMAL OPTIMA AND CLIMATIC SENSITIVITY

5.7.1. Muga Silkworm *(Antheraea assamensis)*

The optimal rearing temperature for *A. assamensis* lies between 25°C and 27°C, with a permissive range of 15–33°C and a relative humidity (RH) requirement of 75–85% (Mongabay, 2018). Even marginal departures from these ranges particularly temperatures exceeding 33°C during the Bhadrua (August–September) and Kotia (October–November) crops precipitate heat stress, larval lethargy and immunosuppression, which collectively predispose worms to secondary infection. Farmers in Jorhat district reported shifting rearing sessions by 10–15 days to avoid peak summer temperatures, a behavioural adaptation that fundamentally alters pest and pathogen exposure windows (IJECC, 2026). Climate modelling using CMCC-ESM2 and HadGEM3 scenarios predicts significant contraction of climatically suitable habitat for both *A. assamensis* and its primary host plant *Litsea monopetala* under future warming scenarios, with implications for disease-resistant wild ecotype conservation.

5.7.2. Eri Silkworm *(Samia ricini)*

Samia ricini is a multivoltine, completely domesticated silkworm completing 5–6 broods annually. Its rearing efficiency is influenced by climatic conditions at a weight of 37%, second only to food quality (38.2%), underscoring the primacy of thermal and hygric environments (Rahmathulla, 2012). The optimal range for larval development is 28 ± 3°C with 70% RH (Vaidya *et al.*, 2014). At temperatures above 30°C combined with low humidity below 30% RH, complete failure of egg hatching has been reported (Gomaa, 1973). During summer in Northeast India, temperatures routinely reach 35–39°C, with co-occurring humidity fluctuations that severely compromise grainage characters, including moth emergence rate, fecundity and hatching percentage (Sarkar *et al.*, 2010). The domesticated nature of Eri theoretically allows some degree of microclimate management; however, most smallholder rearing operations lack infrastructure for temperature regulation.

Parameter	*A. assamensis* (Muga)	*S. ricini* (Eri)	Climate Projection (NE India, 2050)
Optimal temperature	25–27°C	25–31°C	+1.5–2.0°C above baseline
Permissive max. temp.	33°C	~35°C	Pre-monsoon maxima: 38–42°C (projected)

Parameter	*A. assamensis* (Muga)	*S. ricini* (Eri)	Climate Projection (NE India, 2050)
Optimal RH	75–85%	65–75%	Increased humidity variability; erratic monsoon onset
Rearing environment	Fully outdoor	Indoor (smallholder)	Outdoor crops maximally exposed to climate forcing
Disease susceptibility trigger	T >33°C or sudden fluctuation	T >35°C or RH <50%	Increasing frequency of threshold-breach events

5.8. CLIMATE CHANGE AND DISEASE DYNAMICS IN ERI AND MUGA SILKWORMS

5.8.1. Flacherie *(Bacterial Disease Complex)*

Flacherie is the most prevalent disease of both Muga and Eri silkworms, caused primarily by opportunistic bacteria including *Serratia marcescens*, *Streptococcus* spp., *Pseudomonas* and *Bacillus* spp. acting under conditions of compromised host immunity. In *A. assamensis*, the disease is highly associated with sudden temperature fluctuations combined with high humidity and nutritionally poor host plant foliage conditions that are increasingly frequent under current climate trajectories (NESDR, 2020). Correlation analyses for mulberry sericulture in West Bengal demonstrated a strong positive relationship between Flacherie incidence and both minimum temperature and maximum RH (Springer Nature, 2025), a pattern presumed to extend to non-mulberry species given the shared pathophysiology. Infection peaks during the rainy and summer seasons (June–August), precisely when climatic anomalies are most pronounced. Individual crop losses attributable to flacherie can reach 40% in muga rearing operations (Mongabay, 2018).

5.8.2. Pebrine *(Protozoan Disease)*

Pebrine, caused by the microsporidian *Nosema* spp., is the most serious disease of muga silkworm and is unique in its capacity for transovarial (vertical) and transovum (Horizontal) transmission to offspring through infected moths. Primary infection can result in >50% larval mortality before the third moult, while secondary infections during the fourth larval instar produce flimsy, commercially unusable cocoons (CSB, Ribhoi). Elevated temperatures accelerate the germination and proliferation of *Nosema* spores, while increased humidity promotes spore viability in outdoor rearing environments. The combination of warmer springs and erratic pre-monsoon rains characteristic of the post-2010 climate regime in Assam has extended the seasonal window of pebrine transmission risk, demanding more intensive disease-free laying (DFL) screening protocols at grainage centres.

5.8.3. Muscardine *(Fungal Diseases)*

White muscardine (*Beauveria bassiana*) and green muscardine (*Metarrhizium anisopliae*) are climatically the most sensitive of the major silkworm diseases, exhibiting peak incidence under conditions of low temperature (below 23°C) and high RH (above 80%) (KSSRDI, 2021). Research at CSB-CMER&TI, Lahdoigarh, identified an optimum spore germination temperature of ~25°C at 70% RH for the pathogen affecting Som and Soalu plantations. White muscardine alone accounts for 10–40% of Eri crop losses, with peak incidence during the rainy and winter seasons. As climate change simultaneously extends the duration of high-humidity post-monsoon conditions and creates unseasonal cold episodes, the epidemiological windows for muscardine are becoming prolonged and temporally unpredictable. In Muga rearing, the outdoor exposure of larvae to wind-dispersed

conidia from infected lepidopteran alternate hosts further amplifies risk under increased rainfall variability.

5.8.4. Grasserie / *Nuclear Polyhedrosis Virus (NPV)*

Grasserie is a baculovirus-mediated disease caused by Nuclear Polyhedrosis Virus (NPV), producing characteristic haemolymph liquefaction, inter-segmental swelling and translucency in fifth-instar larvae. The disease peaks during high-temperature, low-humidity periods precisely the conditions that climate change is amplifying in pre-monsoon and post-monsoon phases. In Eri silkworm, NPV-caused grasserie enters the host through contaminated castor and alternative host plant leaves; viral dispersal through milky exudate from infected larvae contaminates rearing appliances and accelerates lateral spread. Temperature-driven weakening of larval cellular immunity is the proximate mechanism enabling NPV proliferation. The incidence of grasserie during the Shravani (June–July) crop in West Bengal reached 8.37% in recent surveillance (Springer Nature, 2025), with comparable patterns expected in Assam's Eri and Muga sectors.

Climate change modelling (CMCC-ESM2 and HadGEM3) projects significant habitat contraction for wild *Antheraea assamensis* and Litsea *monopetala* in Northeastern India under 2050 warming scenarios, with cascading implications for wild disease-resistant germplasm conservation and future strain improvement programmes.

Disease/Pest	Causal Agent	Host	Crop Loss (%)	Climate Sensitivity
Flacherie	*Serratia marcescens* , Bacillus spp.	Muga, Eri	Up to 40%	↑ with T fluctuation + high RH
Pebrine	*Nosema* spp. (Microsporidia)	Muga, Eri	>50% (primary)	↑ with warm springs, erratic rain
White Muscardine	*Beauveria bassiana*	Muga, Eri	10–40%	↑ with low T + high RH; extended windows
Grasserie (NPV)	Nuclear Polyhedrosis Virus	Muga, Eri	Variable; up to 30%	↑ during high T, low RH periods
Uzi fly	*Exorista sorbillans*	Muga, Eri	15–86% (seasonal)	↑ generations; extended activity season
Wasp predation	*Vespa orientalis*	Muga	~20% (Aherua/ Bhodia)	↑ foraging with warming spring temps
Grey Blight (host plant)	*Pestalotiopsis disseminata*	Som (P. bombycina)	40% leaf infection	↑ in Aug–Sep under high humidity

5.9. ADAPTIVE STRATEGIES AND RESEARCH PRIORITIES

Several adaptation measures have been identified or are under active development. Seasonal calendar shifts of 10–15 days, already practised by farmers in Jorhat, reduce thermal stress and partially decouple rearing from peak Uzi fly infestation windows, but impose logistical and economic constraints (Mongabay, 2018). Indoor rearing of early-instar Muga larvae using the integrated leaf freshness technology (Barman & Rajan, 2012) offers protection from pathogen inoculum loads during the most susceptible developmental stages. Biological control of uzi fly using the ecto-pupal parasitoid *Nesolynx thymus*, which achieves 40–60 parasitoids per Uzi pupa, represents the most environmentally compatible management strategy, particularly given the prohibition on chemical

insecticides in Muga fields (CSB/MESSO,2020). Genomic approaches to strain improvement developing thermo-tolerant and disease-resistant silkworm varieties constitute a long-term priority. Selection programmes for Eri silkworm under continuously elevated temperature (42 ± 1°C) and reduced RH (50 ± 5%) have demonstrated heritable tolerance across 12 successive generations (Wongsorn *et al.*, cited in Academia.edu, 2020), establishing proof-of-concept for climate-adaptive strain development. Species Distribution Modelling using ensemble climate projections (CMCC-ESM2, HadGEM3) should be integrated into conservation planning for wild *A. assamensis* populations to safeguard disease-resistant germplasm. Standardised climate-sensitive disease early warning systems, exemplified by the Muga Disease Early Warning System (MDEWS) of NESDR/CMER&TI, require expanded deployment and real-time calibration with meteorological datasets.

5.10. CONCLUSION

Climate change constitutes an escalating, multidimensional threat to the sericulture systems supporting Muga and Eri production in Northeast India. The convergence of thermal stress, altered humidity regimes and unpredictable precipitation is amplifying the virulence and seasonal extent of flacherie, pebrine, muscardine and grasserie, while simultaneously enhancing the reproductive capacity and geographic spread of key pests particularly *E. sorbillans*. Indirect pathways through host plant diseases and agrichemical drift further compound crop vulnerability. Quantitative crop losses from individual diseases already reach 40–50% and the synergistic interaction of climate-mediated immune suppression with pathogen and pest pressure threatens to push losses beyond economically viable thresholds without targeted adaptation. An integrated response combining climate-resilient strain development, phenologically adaptive rearing calendars, biological pest control, host plant disease management and data-driven early warning infrastructure is essential for the long-term sustainability of non-mulberry sericulture in a warming climate.

5.11. REFERENCES

Barman, H., & Rajan, R. K. (2012). Muga silkworm (Antheraea assamensis Helfer) indoor rearing by integrated 'leaf freshness technology'. African Journal of Agricultural Research, 7, 3490–3497.

Baruah, J. P. (2021). Muga silkworm, Antheraea assamensis Helfer (Lepidoptera: Saturniidae)—An overview of distribution, life cycle, disease and control measure. Munis Entomology and Zoology Journal, 16(1), 214–220.

Baruah, J. P., & Kalita, C. (2020). Integrated pest management of uzi fly (Exorista sorbillans) in Muga silkworm Antheraea assamensis Helfer (Lepidoptera: Saturniidae): A review. Journal of Entomology and Zoology Studies, 8(4), 341–343.

Central Silk Board (CSB). (2021). Diseases and Pests of Silkworms. CSB Ribhoi Station, Meghalaya. https://silks.csb.gov.in/ribhoi/diseases-and-pests-of-silkworms/

Das, K., Borgohain, A., & Mahanta, S. (2023). Effect of climate change on eri and muga cultivation and the resultant impact on rural income and employment in Assam. Journal of Livestock Science, 14, 135–147.

Gomaa, E. A. (1973). Biological studies on the Eri silkworm Attacus ricini Boisd. (Lepidoptera: Saturniidae). Zeitschrift für Angewandte Entomologie, 73(1–4), 113–121. https://doi.org/10.1111/j.1439-0418.1973.tb01788.x

Haloi, K., Kalita, M. K., Nath, R., & Devi, D. (2016). Characterization and pathogenicity assessment of gut-associated microbes of muga silkworm Antheraea assamensis Helfer (Lepidoptera: Saturniidae). Journal of Invertebrate Pathology, 138, 73–85.

IPCC. (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report. Cambridge University Press.

Karnataka State Sericulture Research and Development Institute (KSSRDI). (2021). Diseases of Silkworm and Control Measures. https://kssrdi.karnataka.gov.in/

Mongabay-India. (2018). Assam's muga silkworm battles climate change. https://india.mongabay.com/2018/02/assams-muga-silkworm-battles-climate-change/

Nath, I., Dutta, P. L., & Narzary, P. R. (2023). Muga silkworm (Antheraea assamensis Helfer) production and sustainability: Implications of tea gardening in the region. AgriGate—An International Multidisciplinary e-Magazine.

NESDR/CMER&TI. (2020). Muga Disease Early Warning System (MDEWS). https://apps.nesdr.gov.in/MDEWS/

Rahmathulla, V. K. (2012). Management of climatic factors for successful silkworm (Bombyx mori L.) crop and higher silk production: A review. Psyche: A Journal of Entomology, 2012, Article 121234.

Sarkar, B. N., Sarmah, M. C., & Chakravorty, R. (2010). Seasonal variation of grainage characters in seed production of eri silkworm, Samia ricini. International Journal of Entomology, 2010.

Singh, B. Saratchandra, & Reddy, S. G. Eswara. (2014). Push–Pull Strategies for Pest Management in Sericulture. Central Silk Board, Bangalore.

Subharani, S., & Jayaprakash, P. (2015). Insect pests of muga silkworm, Antheraea assamensis (Lepidoptera: Saturniidae). Global Journal of Bio-Science and Biotechnology, 4(2), 130–134.

Vaidya, S., Yadav, U., & Bhouraskar, J. (2014). Effects of temperature and relative humidity on rearing performances of eri silkworm (Philosamia ricini). Environment Conservation Journal, 15(3), 189–196. https://doi.org/10.36953/ECJ.2014.15330

Wongsorn, D., Sirimungkararat, S., & Saksirirat, W. (2020). Improvement of eri silkworm (Samia ricini D.) tolerant to high temperature and low humidity conditions by continuous rearing regime. Khon Kaen University, Thailand.


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