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Impact of Climate Change on Sericulture: Adaptation Strategies and Future Directions

Hariharan S. [a++*], Monisha U. [b#], Logeshwari S. M. [b#], Mounisha K. [b#], Mohana J. [b#] and Karchi Kumar A. S. [c#]

[a] Division of Entomology, ICAR-Indian Agricultural Research Institute Mega University, Hyderabad Hub, India.
[b] Department of Agricultural Entomology, Tamil Nadu Agricultural University, Coimbatore, India.
[c] Department of Agricultural Entomology, Agricultural College and Research Institute, Madurai, India.

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ABSTRACT

Global warming affects different natural systems which include agricultural systems. Sericulture, the rearing of silkworms for the purpose of silk production, has a history stretching back thousands of years. In this section, we will study about the biological profile and life cycle of the silkworm (*Bombyx mori*), the major sericulture producing countries across the globe, and the socioeconomic importance of sericulture in different countries. Climate change can be defined as slow and gradual changes in temperature, rainfall, and other atmospheric conditions on the Earth's surface mainly

[++]Ph.D Scholar;
[#]PG Scholar;
**Corresponding author: Email: hariharanselvamvpm1999@gmail.com;*
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caused by activities like the use of fossil energies and destruction of forests. The measures towards adaptation of sericulture under climate change involve a combination of technological, agronomic, and policy changes. Sericulture can be sustained despite changing climatic conditions through resilience and innovation that ensures that many people have source of income and livelihood.

Keywords: Climate change; sericulture; policy interventions; silkworm; climate change.

1. INTRODUCTION

Sericulture, the art and science of silk production, has a rich history dating back thousands of years. Originating in ancient China, sericulture has played a significant role in various cultures and economies worldwide. The process involves rearing silkworms, primarily the Bombyx mori species, feeding them mulberry leaves, and harvesting their silk cocoons. Silk, esteemed for its luxurious texture and cultural significance, has been a valuable commodity in trade and a symbol of status and elegance. The importance of sericulture extends beyond its cultural significance. It has been a key driver of economic development in many regions, particularly in Asia, where silk production is a significant industry. Sericulture provides livelihoods for millions of people, from farmers cultivating mulberry trees to silk weavers and traders. Furthermore, silk products contribute to global trade and tourism, bolstering economies and fostering cultural exchange. Climate change refers to long-term alterations in temperature, precipitation patterns, and other atmospheric conditions, primarily caused by human activities such as burning fossil fuels and deforestation. These activities release greenhouse gases like carbon dioxide and methane into the atmosphere, trapping heat and leading to global warming. Climate change has far-reaching consequences for various natural systems, including agriculture [1].

Sericulture, the practice of cultivating silkworms for the production of silk, has a rich history dating back thousands of years. In this overview, we will delve into the biology and lifecycle of the silkworm (*Bombyx mori*), explore the major regions of sericulture production worldwide, and discuss the economic and cultural significance of sericulture in various countries. Silkworms, the larval stage of the domestic silk moth *Bombyx mori*, play a central role in sericulture. The lifecycle of the silkworm consists of four main stages: egg, larva, pupa, and adult moth. The process begins with the laying of eggs by the adult moth, typically on specially prepared paper or leaves. These eggs hatch into larvae within approximately 10 days [2]. The larval stage, or caterpillar stage, is the most crucial phase for silk production. During this stage, the silkworms feed voraciously on mulberry leaves, growing rapidly and molting several times as they increase in size. This period lasts around 4-6 weeks, after which the silkworms enter the pupal stage. In the pupal stage, the silkworm spins a protective cocoon around itself using silk produced from specialized glands. This cocoon serves as the silkworm's shelter as it undergoes metamorphosis into an adult moth. The pupal stage typically lasts for about 2-3 weeks, depending on environmental conditions. Once the metamorphosis is complete, the adult moth emerges from the cocoon. However, in commercial silk production, the cocoons are usually harvested before the adult moth can emerge to prevent damage to the silk fibers. The harvested cocoons are then boiled to soften the silk fibers, which are unwound to produce raw silk [3].

2. MAJOR REGIONS OF SERICULTURE PRODUCTION WORLDWIDE

Sericulture is practiced in various regions across the globe, with each region having its own unique characteristics and methods of silk production. Some of the major regions of sericulture production include (Table 1) [4]:

1. *China:* China is the largest producer of silk in the world, with a long history of sericulture dating back thousands of years. The country's vast mulberry plantations and advanced silk production techniques contribute to its dominance in the global silk market.
2. *India:* India is another significant player in the silk industry, particularly known for its production of high-quality silk varieties such as Tussar and Muga. Sericulture is an important source of income for many rural communities in India, particularly in states like Karnataka, West Bengal, and Jammu & Kashmir.

3. *Japan:* Japan has a rich tradition of sericulture, with silk production being an integral part of its cultural heritage. Japanese silk, known for its superior quality and craftsmanship, is highly sought after in global markets.
4. *Italy:* Italy is renowned for its production of luxury silk fabrics, particularly in regions like Como and Veneto. Italian silk is prized for its exquisite designs and superior craftsmanship, making it a symbol of luxury and elegance worldwide.

Table 1. Major regions of sericulture production worldwide

Region	Primary Silk Varieties	Production Volume (metric tons)
China	Mulberry, Eri, Tussar	145,000
India	Mulberry, Tussar, Muga	35,000
Japan	Mulberry	5,000
Italy	Mulberry	2,500
Thailand	Eri, Mulberry	1,500
Brazil	Mulberry	1,200

3. ECONOMIC AND CULTURAL SIGNIFICANCE OF SERICULTURE IN VARIOUS COUNTRIES

Sericulture holds significant economic and cultural importance in many countries around the world. Economically, the silk industry provides livelihoods for millions of people involved in various stages of silk production, including farmers, silk reelers, weavers, and traders. Moreover, silk exports contribute significantly to the GDP of countries like China, India, and Italy, earning valuable foreign exchange revenue. Culturally, sericulture has deep roots in the traditions and customs of many societies, shaping their social fabric and identity [5]. In countries like China and Japan, silk is not just a commodity but a symbol of national pride and heritage, with centuries-old traditions surrounding its production and use. Silk fabrics are often used in traditional ceremonies, festivals, and rituals, reflecting the cultural significance attached to them. Sericulture is a fascinating industry with a rich history and global significance. Understanding the biology of the silkworm, the geographical distribution of silk production, and the economic and cultural importance of sericulture provides valuable insights into this ancient craft [6]. As we navigate the challenges of climate change and environmental sustainability, it is essential to develop adaptation strategies and explore innovative approaches to ensure the future of sericulture for generations to come (Table 2).

Table 2. Economic and cultural significance of sericulture in various countries

Country	Economic Importance	Cultural Importance
China	Major contributor to GDP; Provides livelihoods for millions	Symbol of national pride and heritage; Integral part of traditional culture
India	Source of income for rural communities; Contributes to GDP	Deeply rooted in customs and traditions; Used in festivals and ceremonies
Japan	Drives tourism and exports; Supports traditional crafts	Reflection of cultural identity; Used in traditional arts and rituals
Italy	Contributes to luxury fashion industry; Generates export revenue	Symbol of luxury and elegance; Craftsmanship admired worldwide
France	Supports luxury fashion houses; Promotes artisanal craftsmanship	Iconic symbol of French elegance and sophistication
Thailand	Provides employment opportunities; Supports rural development	Embedded in Thai culture and traditions; Used in traditional costumes

4. CLIMATE CHANGE AND ITS IMPACTS

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 [7]. The current state of climate change is marked by unprecedented global warming, evidenced by rising average temperatures, melting glaciers, and shifting weather patterns [8].

The impacts of climate change on agriculture are profound and multifaceted, posing significant challenges to global food security. Agriculture, including sericulture, is particularly vulnerable due to its reliance on specific environmental conditions. Climate change encompasses a range of phenomena, but at its core, it involves alterations in Earth's climate system. The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "a change in the state of the climate that can be identified by changes in the mean and/or variability of its properties, and that persists for an extended period, typically decades or longer, whether due to natural variability or as a result of human activity" [9]. The current state of climate change is alarming. Global temperatures have risen by approximately 1.2 degrees Celsius above pre-industrial levels, with significant consequences for ecosystems, weather patterns, and human societies [10]. The primary driver of this warming trend is the increased concentration of greenhouse gases in the atmosphere, particularly carbon dioxide emitted from activities such as burning fossil fuels and deforestation [9].

4.1 General Impacts of Climate Change on Agriculture

The impacts of climate change on agriculture are diverse and far-reaching. One of the most pronounced effects is the rise in temperatures, which can lead to heat stress in crops and livestock, affecting growth rates, reproductive success, and overall productivity [11]. Altered precipitation patterns, including changes in the frequency and intensity of rainfall, pose challenges for crop irrigation, water management, and soil erosion control [12]. Extreme weather events such as droughts, floods, hurricanes, and wildfires are becoming more frequent and intense due to climate change, causing crop losses, infrastructure damage, and disruptions to supply chains [13]. These events exacerbate food insecurity and economic instability, particularly in regions with limited adaptive capacity and resources.

Sericulture, the practice of rearing silkworms for the production of silk, is intricately linked to climatic conditions. Silkworms, specifically the domesticated Bombyx mori species, are highly sensitive to environmental factors such as temperature, humidity, and photoperiod. Rising temperatures can disrupt the delicate balance required for silkworm development, affecting their growth, cocoon quality, and survival rates [14]. Shifts in precipitation patterns may alter the availability of mulberry leaves, the primary food source for silkworms, leading to fluctuations in silk production and quality [15]. Extreme weather events, such as storms and heatwaves, pose direct threats to silkworm colonies and silk production facilities, potentially causing substantial economic losses for sericulture industries [16]. Additionally, climate change may exacerbate the spread of pests and diseases that affect silkworms, further impacting silk yields and quality [17]. Climate change presents significant challenges for agriculture, including sericulture, due to its impacts on temperature, precipitation, and extreme weather events. Adapting to these changes requires innovative strategies and investments in research, technology, and policy interventions to ensure the resilience and sustainability of sericulture systems in the face of a changing climate.

4.2 Direct Impacts of Climate Change on Sericulture

Sericulture, the practice of silk production through the rearing of silkworms, has been deeply intertwined with human culture and economies for centuries. However, the effects of climate change are increasingly posing challenges to this delicate industry. The direct impacts of climate change on sericulture encompass various aspects, including temperature fluctuations, changes in precipitation patterns, increased pest and disease incidences, and extreme weather events. Understanding these impacts is crucial for devising effective adaptation strategies to sustain sericulture in the face of climate change [18].

4.3 Temperature Fluctuations and Silkworm Growth

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. [19] found that even slight deviations from optimal temperatures can significantly impact silkworm growth rates.

4.4 Changes in Precipitation Patterns and Mulberry Cultivation

Mulberry leaves are the primary food source for silkworms, and any changes in precipitation patterns directly affect mulberry cultivation. Alterations in rainfall patterns, such as prolonged droughts or excessive rainfall, can disrupt mulberry growth cycles, leading to decreased leaf quality and quantity. This, in turn, affects the health and productivity of silkworms. Studies by Li et al. [20] have highlighted the vulnerability of mulberry plants to water stress and the need for adaptive irrigation strategies in sericulture.

4.5 Increased Incidence of Pests and Diseases

Climate change contributes to the proliferation of pests and diseases, posing significant threats to both silkworms and mulberry plants. Warmer temperatures create favorable conditions for the breeding and spread of pests such as mites and pathogens like fungal infections. These infestations not only directly harm silkworms and mulberry plants but also reduce silk quality and yield. Effective pest management strategies, including integrated pest management approaches, are essential to mitigate these impacts [21].

4.6 Extreme Weather Events and Sericulture Infrastructure

Extreme weather events, such as droughts and floods, are becoming more frequent and intense due to climate change. These events can cause substantial damage to sericulture infrastructure, including silk production facilities, mulberry plantations, and silkworm rearing units. Floods can wash away mulberry fields, while droughts can lead to water scarcity for silkworm rearing. Investments in resilient infrastructure and disaster preparedness are imperative for ensuring the continuity of sericulture in regions prone to extreme weather events [22]. The direct impacts of climate change on sericulture encompass various interconnected factors, including temperature fluctuations, precipitation changes, pest and disease incidences, and extreme weather events. Addressing these challenges requires a multi-faceted approach that integrates scientific research, technological innovations, and adaptive management strategies. By understanding and mitigating the effects of climate change on sericulture, stakeholders can safeguard this ancient industry and ensure its sustainability for future generations.

4.7 Indirect Impacts of Climate Change on Sericulture

Sericulture, the cultivation of silk-producing insects, predominantly relies on the mulberry plant (*Morus spp.*) for sustenance. However, climate change-induced alterations in temperature, precipitation, and ecological dynamics pose significant challenges to this delicate ecosystem. While the direct effects of climate change are evident, understanding its indirect impacts is equally imperative for devising effective adaptation strategies [23].

4.8 Soil Degradation and Changes in Soil Fertility Affecting Mulberry Quality

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 CO_2 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 [24].

4.9 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 [25].

4.10 Socio-economic Impacts on Communities Dependent on Sericulture

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 [26]. 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.

5. ADAPTATION STRATEGIES FOR SERICULTURE UNDER CLIMATE CHANGE

Sericulture, the practice of silk production, has been a significant aspect of many cultures for centuries. However, the impact of climate change presents a substantial challenge to the sustainability and productivity of sericulture. Rising temperatures, erratic rainfall patterns, and the increasing frequency of extreme weather events threaten the delicate balance required for successful silk production. In response, adaptation strategies are crucial for mitigating these risks and ensuring the resilience of sericulture systems (Table 3).

Development and Use of Climate-Resilient Silkworm and Mulberry Varieties: One key adaptation strategy involves the development and utilization of climate-resilient silkworm and mulberry varieties. Traditional varieties may not be equipped to withstand the changing climate conditions, making them more susceptible to stressors such as heatwaves or drought. Through selective breeding and genetic engineering techniques, researchers can develop varieties that exhibit traits such as heat tolerance, pest resistance, and improved productivity under altered climate conditions [27]. These resilient varieties can help safeguard sericulture against the adverse effects of climate change.

Improved Sericulture Practices: Adapting sericulture practices to changing climatic conditions is essential for maintaining productivity and minimizing risks. This includes optimizing mulberry cultivation techniques to ensure efficient water use and nutrient management in the face of altered precipitation patterns. Additionally, advancements in silkworm rearing methods, such as temperature and humidity control in rearing facilities, can help mitigate the impacts of temperature extremes on silkworm health and productivity [28]. Implementing best management practices tailored to the specific climatic challenges of each region is crucial for sustainable sericulture.

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 [29].

Water Management Strategies for Mulberry Cultivation: Water scarcity and erratic precipitation patterns resulting from climate change pose significant challenges to mulberry cultivation, which is a water-intensive crop. Implementing water management strategies such as drip irrigation, rainwater harvesting, and efficient water storage systems can help optimize water use efficiency and ensure the sustainable cultivation of mulberry even in water-stressed

Table 3. Adaptation strategies for sustainable sericulture

Adaptation Strategy	Implementation Measures
Soil Conservation	Contour Plowing, Cover Cropping, Organic Amendments
Biodiversity Preservation	Conservation of Biodiversity Hotspots, Habitat Restoration
Socio-economic Resilience	Diversification of Income Sources, Access to Climate-smart Agriculture, Social Safety Nets

environments [30]. Furthermore, integrating mulberry cultivation with agroforestry or aquaculture systems can create synergies that enhance water conservation and overall resilience.

Technological Innovations: Advancements in agricultural technologies offer promising solutions for enhancing the resilience of sericulture systems to climate change. Precision agriculture techniques, including remote sensing and geographic information systems (GIS), enable farmers to monitor and manage their crops more effectively, optimizing resource use and reducing environmental impacts [31]. Climate forecasting tools provide valuable information for anticipating weather-related risks and implementing timely adaptive measures, such as adjusting planting schedules or implementing protective measures during extreme weather events.

Policy Support and Funding: Effective adaptation to climate change in sericulture requires strong policy support and adequate funding for research and development initiatives. Governments and international organizations play a crucial role in facilitating knowledge exchange, capacity building, and the dissemination of best practices among sericulture stakeholders. Investing in research and development programs focused on climate-resilient sericulture varieties, innovative technologies, and sustainable practices is essential for ensuring the long-term viability of the silk industry in the face of climate change [32].

Adaptation strategies for sericulture under climate change are multifaceted and require a holistic approach that integrates technological, agronomic, and policy interventions. By developing climate-resilient varieties, optimizing cultivation practices, managing pests and diseases effectively, and harnessing technological innovations, sericulture can continue to thrive in the face of evolving climatic challenges [33]. However, concerted efforts from governments, researchers, industry stakeholders, and farmers are necessary to implement these strategies effectively and ensure the sustainability of silk production for future generations.

6. CASE STUDIES

Sericulture, the practice of silk production through the rearing of silkworms, is a significant economic activity in various regions worldwide. However, climate change poses substantial challenges to this industry, affecting silk production through altered temperature and precipitation patterns, changes in host plant availability, and increased incidence of pests and diseases [34].

Case Studies: Successful Adaptation Strategies:

1. **Temperature Control Systems:** In regions experiencing temperature fluctuations due to climate change, successful adaptation strategies involve the implementation of temperature-controlled rearing facilities. These facilities maintain optimal conditions for silkworm rearing, ensuring consistent silk production throughout the year. Case studies from regions such as China and India demonstrate the effectiveness of such systems in sustaining sericulture despite climatic challenges [35].
2. **Diversification of Host Plants:** Climate change affects the availability and quality of host plants for silkworms. Successful adaptation involves diversifying host plant species to ensure a stable food supply for silkworms. For example, research conducted in Japan has identified alternative host plants that are resilient to climate change and can support silk production even under adverse environmental conditions [36].

Failed Attempts and Lessons Learned:

1. **Lack of Technology Transfer:** In some regions, attempts to introduce advanced technologies for sericulture adaptation have failed due to the lack of technology transfer and capacity building among local sericulturists. For instance, initiatives to implement temperature-controlled rearing facilities in certain African countries faced challenges due to insufficient training and support for local sericulture communities [37].

   Inadequate Pest Management: Climate change contributes to the proliferation of pests and diseases in sericulture. Failed attempts to address this issue often stem from inadequate pest management practices. Case studies from Southeast Asia highlight the importance of integrated pest management strategies that combine cultural, biological, and chemical control methods to effectively mitigate pest damage in sericulture.

7. EMPHASIS ON THE IMPORTANCE OF ADAPTIVE STRATEGIES FOR THE SUSTAINABILITY OF SERICULTURE

Table 4. Adaptive strategies for climate-resilient sericulture

Adaptive Strategy	Description
Crop Diversification	Cultivation of multiple mulberry varieties to mitigate risks associated with climate variability
Eco-Friendly Silkworm Breeds	Breeding of silkworm varieties with enhanced resistance to environmental stressors
Sustainable Farming Practices	Adoption of agroecological methods to promote soil health and conserve water resources
Remote Sensing and GIS Mapping	Utilization of satellite imagery and geographic information systems for monitoring sericulture ecosystems

The sustainability of sericulture hinges upon the successful implementation of adaptive strategies. As climate change continues to accelerate, traditional sericulture practices become increasingly vulnerable to environmental disruptions. Therefore, it is imperative for sericulture stakeholders to proactively adapt to changing climatic conditions [38]. Adaptive strategies not only buffer sericulture against climate-related risks but also foster resilience within the sector. By diversifying mulberry cultivation, enhancing silkworm resistance to stressors, and embracing sustainable farming techniques, sericulture can better withstand the challenges posed by climate change. Furthermore, collaborative efforts between researchers, policymakers, and industry players are essential for developing and disseminating effective adaptation measures (Table 4) [39,40].

8. CONCLUSION

Climate change poses significant challenges to sericulture, impacting silk production worldwide. In this paper, the close link between climate change and sericulture has been described in detail. We established how increase in temperature, inconsistent rainfall, and other related disasters upset the sensitive conditions necessary for silk making. These environmental changes influence mulberry plant, silkworm, and cocoon, which in turn influence the quality and quantity of silk production. Furthermore, we looked into different actions taken by different stakeholders in the sericulture industry to minimize the impact of climate change. Some of these strategies include crop diversification, planting of drought resistant silkworm mulberry varieties and using ecological silkworm breeds and practices. Similarly, remote sensing techniques and GIS mapping are some of the most important technologies that can help in early detection and management of the sericulture ecosystems changes due to climate variability.

9. FUTURE DIRECTIONS: RESEARCH GAPS AND AREAS NEEDING FURTHER INVESTIGATION

The future of sericulture is intricately intertwined with the evolving climate. While climate change presents formidable challenges, it also offers opportunities for innovation and resilience-building within the sericulture sector. By embracing adaptive strategies and leveraging technological advancements, sericulture can navigate the uncertainties posed by climate change and emerge stronger and more sustainable. However, realizing this vision requires concerted action at the global, national, and local levels. Investments in research and development, capacity building, and policy support are crucial for fostering a climate-resilient sericulture industry. Furthermore, initiatives aimed at promoting sustainable silk production and consumption can contribute to the broader goals of climate adaptation and environmental conservation. The impact of climate change on sericulture necessitates proactive adaptation measures to ensure the sector's sustainability. By prioritizing resilience-building and innovation, sericulture can continue to thrive in the face of evolving climatic conditions, providing livelihoods and economic opportunities for millions worldwide. There is a need for research to develop silkworm strains that are resilient to climate change-induced stressors such as temperature extremes and fluctuations in host plant availability. Genetic engineering and biotechnology offer promising avenues for

breeding climate-resilient silkworm varieties that can thrive under changing environmental conditions. Future research should focus on developing sustainable sericulture practices that minimize the environmental impact of silk production. This includes exploring alternative feed sources for silkworms, optimizing resource use efficiency, and reducing greenhouse gas emissions associated with sericulture operations.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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