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Wild Silkworms and Climate Resilience: Why Non-Mulberry Sericulture Matters Today

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Abstract

Non-mulberry sericulture, encompassing the cultivation of wild silkworm species collectively known as vanya silks, represents a critical yet underappreciated component of sustainable agriculture and climate adaptation strategies. This comprehensive review examines the ecological, economic and adaptive significance of wild silkworms including the tropical tasar silkworm (*Antheraea mylitta*), the muga silkworm (*Antheraea assamensis*), the eri silkworm (*Samia ricini*) and the oak tasar silkworm (*Antheraea paphia*) in the context of accelerating climate change. Unlike the domesticated mulberry silkworm (*Bombyx mori*) which requires intensive management and controlled environmental conditions, wild silkworm species demonstrate remarkable genetic diversity, host plant flexibility and natural resilience to environmental fluctuations. This review synthesizes recent evidence demonstrating that non-mulberry sericulture systems provide climate-resilient livelihood opportunities for tribal and rural communities while contributing to forest conservation and biodiversity maintenance. The analysis reveals that wild silkworm species possess inherent adaptive mechanisms including polyphagy, thermal tolerance and disease resistance that render them particularly suited to changing climatic conditions. Furthermore, sericulture-based agroforestry systems offer multifunctional landscapes that sequester carbon, preserve ecosystem services and provide sustainable income streams. However, significant challenges persist including habitat fragmentation, lack of systematic germplasm conservation and market access limitations. This review concludes that scaling non-mulberry sericulture through integrated policy support, technological innovation and community-based conservation represents a promising pathway for climate-resilient rural development. Future research priorities include genomic characterization of wild silkworm diversity, development of climate-smart breeding programs and establishment of inclusive value chains that benefit forest-dependent communities.

Keywords: Wild silkworms, non-mulberry sericulture, climate resilience, vanya silk, biodiversity conservation, sustainable livelihoods, agroforestry

1. Introduction

Sericulture, the practice of rearing silkworms for silk production, represents one of humanity's oldest agricultural enterprises with a history spanning over 5000 years (Xiang *et al.* 2018) [52]. The industry encompasses two distinct systems: mulberry sericulture based on the domesticated silkworm *Bombyx mori* and non-mulberry sericulture involving various wild silkworm species collectively termed vanya silks (Ahmed *et al.* 2015) [1]. While mulberry sericulture has achieved commercial dominance globally, producing approximately 95% of the world's silk, non-mulberry sericulture offers unique advantages that are increasingly relevant in the context of climate change and sustainable development (Dandin & Prabhu 2022) [11].

Non-mulberry sericulture encompasses several commercially important wild silkworm species. The tropical tasar silkworm (*Antheraea mylitta* Drury) produces the characteristic copper-coloured tasar silk and is distributed across the forest regions of central and eastern India (Vishaka *et al.* 2020) [49]. The muga silkworm (*Antheraea assamensis* Helfer) is endemic to north-eastern India and yields the prestigious golden muga silk renowned for its natural luster and durability (Devi *et al.* 2021) [14]. The eri silkworm (*Samia ricini* Donovan) demonstrates remarkable polyphagy and is cultivated across diverse agro-ecological zones (Singh *et al.* 2023) [42]. Additionally, the oak tasar silkworm (*Antheraea paphia*) thrives in the Himalayan foothills producing fine-quality oak tasar silk (Dandin & Prabhu 2022) [11].

Climate change poses unprecedented challenges to global sericulture. Rising temperatures, erratic rainfall patterns and increased frequency of extreme weather events compromise host plant productivity, disrupt silkworm life cycles and exacerbate disease incidence (Ram *et al.* 2016) ^[37]. Mulberry sericulture, being highly input-dependent and environmentally controlled, demonstrates particular vulnerability to these perturbations (Sujatha *et al.* 2024) ^[44]. Temperature fluctuations beyond the optimal range of 20-28 degrees Celsius severely affect silkworm growth, cocoon quality and silk yield (Manzoor & Qayoom 2024) ^[29]. Furthermore, climate-induced shifts in host plant phenology create temporal mismatches between silkworm rearing schedules and leaf availability (Kaushik *et al.* 2025) ^[25].

The objective of this review is to critically evaluate the ecological, economic and adaptive significance of wild silkworms in the context of climate change. By synthesizing recent peer-reviewed literature, this analysis demonstrates why non-mulberry sericulture deserves greater attention within climate-smart agriculture frameworks and sustainable development agendas. The review addresses the biodiversity and biology of wild silkworms, climate change impacts on sericulture systems, mechanisms underlying wild silkworm resilience, ecological significance, socio-economic dimensions, case studies from major producing regions, existing challenges, technological interventions and policy recommendations.

2. Diversity and Biology of Wild Silkworms

2.1 Taxonomy and Distribution

Wild silkworms belong to the family *Saturniidae* within the order *Lepidoptera* and exhibit remarkable taxonomic diversity across tropical and subtropical regions (Hamilton *et al.* 2019) ^[21]. The genus *Antheraea* comprises the majority of commercially exploited wild silkworm species including *A. mylitta*, *A. assamensis*, *A. paphia*, *A. roylei* and *A. proylei* (Dandin & Prabhu 2022) ^[11]. The genus *Samia* includes the eri silkworm *S. ricini* along with related species such as *S. cynthia* distributed across Southeast Asia (Seidel & Peigler 2018) ^[41]. Phylogenomic analyses have revealed significant diversification rate shifts during the evolution of silk moths, highlighting the evolutionary plasticity of this group (Hamilton *et al.* 2019).

The tropical tasar silkworm *Antheraea mylitta* exhibits extensive geographic distribution across the Indian subcontinent, inhabiting forest ecosystems from the central Indian plateau to the eastern ghats (Thakur *et al.* 2025) ^[46]. Multiple ecoraces have evolved in response to local environmental conditions, displaying adaptations to specific host plants and climatic regimes (Sivaprasad *et al.* 2024) ^[43]. The muga silkworm *A. assamensis* maintains a restricted distribution confined to the Brahmaputra valley and surrounding foothills of northeastern India, reflecting its narrow ecological niche and specific host plant requirements (Das 2021) ^[13]. Eri silkworm cultivation extends across tropical Asia including India, Thailand, Myanmar and Laos demonstrating the species' broader ecological amplitude (Park *et al.* 2022) ^[33].

2.2 Host Plant Diversity and Ecological Dependence

Wild silkworm species demonstrate varying degrees of host plant specificity that directly influence their ecological resilience. Tropical tasar silkworms feed primarily on *Terminalia* species including *T. arjuna*, *T. tomentosa* and *T. catappa* along with secondary hosts such as *Shorea robusta*

and *Lagerstroemia parviflora* (Kumara 2023) ^[27]. This polyphagous feeding habit provides ecological flexibility enabling tasar silkworms to persist despite fluctuations in individual host plant availability. Muga silkworms exhibit more specialized feeding behavior with *Litsea glutinosa* and *L. monopetala* serving as primary hosts supplemented by several secondary species including *Litsea nitida* and *L. salicifolia* (Devi *et al.* 2021) ^[14].

Eri silkworms display the broadest host plant range among commercial wild silkworm species, feeding on over 50 plant species across multiple families (Singh *et al.* 2023) ^[42]. Primary hosts include castor (*Ricinus communis*), kesseru (*Heteropanax fragrans*) and tapioca (*Manihot esculenta*) with numerous secondary hosts providing additional feeding options (Wongsorn *et al.* 2024) ^[51]. This extensive host range underpins the eri silkworm's reputation as the most adaptable wild silkworm species capable of thriving across diverse agro-ecological conditions. Research has demonstrated that host plant nutrition significantly influences eri silkworm life cycle parameters, economic traits and pupal nutritional value (Hussain & Rasid 2024) ^[24].

2.3 Life Cycle Adaptations in Natural Ecosystems

Wild silkworm species have evolved life cycle strategies that synchronize their development with seasonal environmental fluctuations. Tropical tasar silkworms typically complete two to three generations annually with diapause induction responding to photoperiod and temperature cues (Mazumdar *et al.* 2023) ^[30]. The non-diapausing voltine races enable year-round rearing in favourable climates while diapausing races provide genetic reservoirs for seasonal adaptation. Muga silkworms exhibit bivoltine or trivoltine life cycles synchronized with the flushing patterns of their primary host plants (Kumar *et al.* 2022) ^[26]. Eri silkworms demonstrate continuous breeding potential under suitable conditions with generation times of approximately 45-60 days enabling multiple annual crops (Singh *et al.* 2023) ^[42].

Comparative analysis reveals fundamental differences between wild and domesticated silkworm biology. While *Bombyx mori* has undergone extensive genetic modification through millennia of domestication resulting in reduced genetic diversity and increased environmental dependence, wild silkworms maintain broader genetic variation and natural hardiness (Fang *et al.* 2015) ^[15]. Domestication has selected for traits including high silk yield, uniform cocoon color and docile behavior but has concurrently reduced stress tolerance and disease resistance (Xiang *et al.* 2018) ^[52]. In contrast, wild silkworms retain adaptive mechanisms including thermal tolerance, pathogen resistance and behavioral plasticity that enhance their survival under variable environmental conditions.

3. Climate Change Impacts on Sericulture

3.1 Temperature and Extreme Events

Climate change manifests through rising mean temperatures, increased frequency of heat waves and altered precipitation patterns that collectively threaten sericulture sustainability. Research indicates that temperature increases beyond thermal optima severely impair silkworm physiological processes including digestion, growth and silk protein synthesis (Qayoom *et al.* 2023) ^[35]. Heat stress during critical developmental stages reduces cocoon weight, shell ratio and raw silk percentage with economic consequences for sericulture-dependent communities. Studies conducted across Indian sericulture belts demonstrate significant

correlations between temperature anomalies and silkworm disease incidence (Rabha *et al.* 2025) ^[36].

Extreme weather events including droughts, floods and unseasonal rainfall create additional challenges for sericulture systems. Drought conditions compromise host plant productivity reducing leaf availability and nutritional quality for silkworm rearing (Gani & Ghosh 2018) ^[17]. Conversely, excessive rainfall promotes fungal diseases affecting both host plants and silkworms while creating unfavourable rearing conditions. The increasing frequency of such extreme events under climate change scenarios necessitates adaptation strategies that enhance system resilience. Analysis of historical data reveals upward trends in silkworm disease incidence correlating with climatic variability particularly in traditional sericulture regions (Hossain *et al.* 2017) ^[23].

3.2 Host Plant Phenology and Availability

Climate-induced shifts in plant phenology disrupt the temporal synchrony between silkworm rearing schedules and host plant availability. Rising temperatures advance flushing periods in many tree species while altering leaf quality parameters including moisture content, nutritional composition and secondary metabolite concentrations (Sujatha *et al.* 2024) ^[44]. Such phenological mismatches create critical bottlenecks for silkworm rearing particularly for species with specialized host requirements. Research on mulberry host plants demonstrates that elevated atmospheric CO₂ concentrations affect leaf chemistry with cascading effects on silkworm growth and silk quality (Ram *et al.* 2016) ^[37].

The phenological sensitivity of host plants varies among species influencing their suitability for sericulture under changing climates. Deciduous host species including *Terminalia* and *Litsea* show pronounced seasonal leafing patterns that may become desynchronized with traditional rearing calendars (Devi *et al.* 2021) ^[14]. Evergreen alternatives including castor for eri silkworm rearing offer more stable leaf availability but may still experience quality fluctuations under environmental stress. Understanding these phenological dynamics is essential for developing climate-responsive sericulture management practices.

3.3 Disease and Pest Dynamics

Climate change exacerbates disease and pest pressures in sericulture through multiple mechanisms. Elevated temperatures accelerate pathogen replication rates while humidity fluctuations influence fungal disease epidemiology (Tayal & Chauhan 2017) ^[45]. Major silkworm diseases including grasserie caused by nucleopolyhedrovirus, flacherie due to bacterial infections, muscardine from fungal pathogens and pebrine caused by *Nosema bombycis* demonstrate increased incidence under climatic stress conditions (Mandal *et al.* 2025) ^[28]. Research in Indonesia has documented correlations between pebrine disease prevalence and climate anomalies highlighting the disease-climate nexus (Nuraeni *et al.* 2023) ^[32].

Mulberry sericulture systems exhibit particular vulnerability to disease outbreaks due to high silkworm densities and controlled rearing environments that facilitate pathogen transmission (Kaushik *et al.* 2025) ^[25]. In contrast, wild silkworm species reared under more natural conditions demonstrate greater disease resistance potentially reflecting evolutionary adaptation to pathogen pressure in forest ecosystems. However, climate-induced stress can compromise even wild silkworm immunity necessitating integrated disease management approaches. Temporal

analysis of disease trends in West Bengal reveals increasing grasserie and flacherie incidence correlating with warming trends (Rabha *et al.* 2025) ^[36].

3.4 Vulnerability of Monoculture Systems

The monoculture-based mulberry sericulture system exhibits structural vulnerabilities that amplify climate risks. Dependence on a single silkworm species (*B. mori*) and limited host plant varieties creates genetic uniformity that reduces adaptive capacity (Ruiz & Almanza 2018) ^[40]. Intensive management requirements including controlled temperature, humidity and hygiene conditions increase system sensitivity to environmental perturbations. Furthermore, the high input demands of mulberry cultivation including irrigation, fertilization and pesticide applications create economic and environmental sustainability challenges (Gangopadhyay 2024) ^[18].

Evidence from sericulture regions worldwide demonstrates the vulnerability of monoculture systems to climate shocks. Crop failures due to heat waves, disease outbreaks and host plant failures have caused significant economic losses for mulberry sericulture farmers (Sujatha *et al.* 2024) ^[44]. In contrast, diversified sericulture systems incorporating multiple silkworm species and host plants demonstrate greater stability under variable conditions. This comparative resilience highlights the adaptive value of biodiversity in agricultural systems facing climate uncertainty.

4. Why Wild Silkworms Are Climate-Resilient

4.1 Genetic Diversity and Adaptive Plasticity

Wild silkworm populations maintain substantially higher genetic diversity than their domesticated counterparts providing raw material for adaptive evolution. Population genetic studies reveal that domestication has reduced genetic variation in *B. mori* by approximately 30-40% compared to its wild progenitor *Bombyx mandarina* (Chen *et al.* 2019) ^[9]. In contrast, wild silkworm species retain extensive genetic polymorphism distributed across their geographic ranges enabling local adaptation to diverse environmental conditions. This genetic reservoir provides critical capacity for responding to selection pressures including climate change.

The ecorace system in tropical tasar silkworms exemplifies adaptive genetic diversity in wild silkworms. Distinct ecoraces including Daba, Sukinda, Raily and Andhra Local have evolved in response to local environmental conditions displaying variation in voltinism, host plant preference and thermal tolerance (Sivaprasad *et al.* 2024) ^[43]. Conservation of this genetic diversity through in situ and ex situ approaches provides essential resources for breeding climate-resilient strains. Genomic studies are increasingly characterizing the genetic basis of adaptive traits enabling marker-assisted selection for climate resilience (Venkatesh Kumar *et al.* 2025) ^[48].

4.2 Polyphagy and Host Plant Flexibility

The polyphagous feeding habits of many wild silkworm species confer significant adaptive advantages under changing environmental conditions. Ability to utilize multiple host plant species enables silkworms to switch feeding substrates when primary hosts become unavailable due to drought, disease or phenological mismatches (Kumara 2023) ^[27]. Research demonstrates that eri silkworms successfully complete development on diverse host plants albeit with variation in growth parameters and silk yield (Wongsorn *et al.* 2024) ^[51]. This dietary flexibility

buffers silkworm populations against host plant failures providing stability under climate variability. Comparative studies of host plant suitability reveal that wild silkworms can exploit secondary hosts with reasonable efficiency when primary hosts are unavailable. Muga silkworms have been successfully reared on alternative *Litsea* species when primary hosts were scarce (Kumar *et al.* 2022) ^[26]. Similarly, tasar silkworms demonstrate adaptability to different *Terminalia* species and can utilize mixed host plantings to ensure continuous leaf availability. Such feeding plasticity represents a key resilience mechanism that reduces dependence on any single host species.

4.3 Natural Selection in Forest Ecosystems

Wild silkworm populations in forest ecosystems experience continuous natural selection for stress tolerance, disease resistance and environmental adaptability. Unlike domesticated silkworms protected in controlled rearing environments, wild silkworms face natural mortality pressures that maintain robustness in population gene pools (Dandin & Prabhu 2022) ^[11]. Exposure to variable temperatures, humidity fluctuations, natural enemies and pathogens selects for individuals possessing superior stress-coping mechanisms. This ongoing selection process maintains adaptive traits that enhance climate resilience. Forest ecosystems provide additional buffering against climate extremes through microclimate regulation. Canopy cover moderate's temperature fluctuations while maintaining higher humidity levels than open environments (Ahmed *et al.* 2015) ^[1]. These moderated conditions enable wild silkworms to persist through periods of climatic stress that would severely impact silkworms in exposed rearing environments. Furthermore, forest biodiversity supports natural enemy communities that regulate pest populations reducing the need for chemical interventions.

4.4 Reduced Dependence on Controlled Environments

Wild silkworm rearing requires minimal environmental control compared to mulberry sericulture reducing vulnerability to climate-induced infrastructure failures. Tropical tasar silkworms are typically reared on host trees in forest environments or simple outdoor structures that require no artificial climate control (Vishaka *et al.* 2020) ^[49]. Eri silkworms can be reared in low-cost thatched houses or even outdoor conditions in suitable climates (Singh *et al.* 2023) ^[42]. This reduced infrastructure dependence lowers both capital requirements and operational vulnerabilities.

The lower input requirements of non-mulberry sericulture translate to reduced economic risks for farmers when climatic conditions are unfavourable. Unlike mulberry sericulture where substantial investments in rearing houses, equipment and inputs create high sunk costs, wild silkworm rearing can be adjusted seasonally based on environmental conditions (Gangopadhyay *et al.* 2019) ^[19]. This flexibility enables farmers to avoid catastrophic losses during extreme weather events by temporarily suspending rearing operations.

4.5 Lower Susceptibility to Anthropogenic Stressors

Wild silkworm species demonstrate greater tolerance of suboptimal conditions including temperature fluctuations, humidity variations and reduced food quality compared to domesticated silkworms. Research comparing thermal tolerance ranges reveals that wild silkworm species maintain physiological function across broader temperature ranges than *B. mori* (Mazumdar *et al.* 2024) ^[31]. This physiological

robustness reflects evolutionary adaptation to variable forest environments and provides inherent climate resilience.

Additionally, wild silkworms possess more effective immune responses to pathogens than domesticated silkworms. Comparative transcriptomic analysis has identified differential expression of immunity-related genes between wild and domesticated silkworms (Fang *et al.* 2015) ^[15]. Wild silkworms maintain more diverse gut microbiota that contribute to pathogen resistance and nutritional adaptation (Chen *et al.* 2018) ^[8]. These biological attributes reduce disease risks and enhance survival under stressful conditions.

5. Ecological and Environmental Significance

5.1 Role in Forest Ecosystems

Wild silkworms play important ecological roles in forest ecosystems beyond their economic value. As herbivores, silkworm larvae contribute to nutrient cycling through leaf consumption and frass deposition (Ahmed *et al.* 2015) ^[1]. Adult silkworms serve as pollinators for various forest plant species while also providing food resources for insectivorous birds, bats and other predators. These ecological functions integrate silkworms into forest food webs supporting broader biodiversity conservation objectives.

Sericulture-based forest management practices can enhance habitat quality for diverse flora and fauna. Traditional tasar sericulture in central Indian forests maintains mixed tree stands that provide resources for wildlife including ungulates, primates and birds (Vishaka *et al.* 2020) ^[49]. The retention of diverse host plant species creates structural complexity that benefits forest-dependent species. Thus, sustainable wild silkworm harvesting aligns with biodiversity conservation goals when managed appropriately.

5.2 Contribution to Ecosystem Services

Non-mulberry sericulture systems provide multiple ecosystem services that extend beyond silk production. Forest-based sericulture contributes to carbon sequestration through tree biomass accumulation while maintaining forest cover that would otherwise be cleared for alternative land uses (Gangopadhyay 2024) ^[18]. Watershed protection, soil conservation and microclimate regulation represent additional regulating services provided by sericulturesupporting forests. These ecosystem services have economic value that should be incorporated into assessments of sericulture sustainability.

Agroforestry systems incorporating sericulture host plants enhance agricultural landscape multifunctionality. Integration of tasar host trees with agricultural crops creates shade, improves soil fertility through leaf litter and provides additional income streams (Chakraborti *et al.* 2024) ^[6]. Such diversified systems demonstrate greater resilience to climate variability than monoculture agriculture while supporting rural livelihoods. The ecosystem service benefits of sericulture-based agroforestry warrant greater recognition in agricultural policy frameworks.

5.3 Reduced Chemical Input Requirements

Non-mulberry sericulture typically requires minimal chemical inputs compared to intensive mulberry sericulture reducing environmental impacts and production costs. Wild silkworm rearing in forest environments relies on natural host plants requiring no fertilization, irrigation or pesticide applications (Attri *et al.* 2024) ^[2]. Even cultivated eri silkworm host plants such as castor and tapioca are

relatively low-input crops tolerant of marginal soil conditions. This reduced chemical dependence minimizes production costs while decreasing environmental contamination risks.

The ecological sustainability of low-input sericulture aligns with organic and sustainable agriculture certification schemes. Eri silk produced without chemical inputs can command premium prices in environmentally conscious markets (Seidel & Peigler 2018) ^[41]. Furthermore, reduced chemical exposure benefits silkworm health and product safety for consumers. These advantages position non-mulberry sericulture favourably within sustainable agriculture development agendas.

5.4 Linkages with Sustainable Agriculture

Sericulture-based agroforestry represents a sustainable agricultural model that integrates tree cultivation with livestock and crop production. The innovative agroforestry systems developed in India demonstrate how sericulture can enhance livelihood security while maintaining ecological integrity (Handa *et al.* 2016) ^[22]. Multi-strata agroforestry incorporating sericulture host trees at different canopy levels maximizes land productivity while creating favourable microclimates for associated crops.

Integration of sericulture with other agricultural enterprises creates diversified income streams that reduce economic vulnerability. Farmers practicing sericulture-based agroforestry can derive income from silk, host plant products, intercrops and livestock within integrated systems (Gangopadhyay 2024) ^[18]. This diversification buffers against commodity price fluctuations and production risks enhancing rural economic resilience. The sustainable agriculture attributes of non-mulberry sericulture warrant greater integration into climate-smart agriculture initiatives.

6. Socio-Economic and Livelihood Dimensions

6.1 Importance in Tribal and Rural Economies

Non-mulberry sericulture provides critical livelihood support for tribal and rural communities across major producing regions. In India, vanya sericulture engages approximately 2.5 million people primarily from marginalized tribal communities in forest-dependent areas (Dandin & Prabhu 2022) ^[11]. The low capital requirements and flexible labor demands of wild silkworm rearing make it accessible to resource-poor households lacking alternative income opportunities. Sericulture income supplements subsistence agriculture enabling improved food security and household welfare.

Tribal communities in central India including the *Gonds*, *Baigas* and *Oraons* have practiced tasar sericulture for generations integrating it into traditional livelihood portfolios (Bawaskar *et al.* 2022) ^[3]. Similarly, indigenous communities in northeastern India maintain muga sericulture as a cultural heritage practice that provides economic returns (Chakravorty *et al.* 2015) ^[7]. These traditional knowledge systems embody sustainable resource management practices developed through generations of experience. Recognition and support for indigenous sericulture knowledge contributes to both cultural preservation and livelihood enhancement.

6.2 Employment Generation and Gender Roles

Sericulture generates employment across the value chain from host plant cultivation through reeling and weaving

providing income opportunities for diverse household members. Wild silkworm rearing involves tasks suitable for women, elderly and children including leaf collection, larval care and cocoon harvesting (Das 2021) ^[13]. This inclusive employment profile enables whole-household participation in income generation unlike labor activities requiring physical strength or mobility. Gender analysis reveals significant female participation in sericulture particularly in rearing and reeling activities.

The decentralized nature of wild silkworm rearing enables home-based income generation reducing barriers to women's economic participation. Women can combine sericulture activities with domestic responsibilities enabling productive engagement without compromising household duties (Wani *et al.* 2018) ^[50]. Furthermore, women's groups organized around sericulture activities gain collective bargaining power and access to extension services. These gender dimensions of sericulture livelihoods warrant consideration in development programming.

6.3 Climate-Resilient Livelihood Systems

Non-mulberry sericulture contributes to climate-resilient livelihood portfolios by providing income sources less vulnerable to climate shocks than rainfed agriculture. While crop failures due to drought or floods cause catastrophic agricultural losses, wild silkworm populations in forest ecosystems often persist through such events enabling continued income generation (Vishaka *et al.* 2020) ^[49]. The complementary risk profiles of sericulture and agriculture create diversified livelihood systems that enhance household resilience.

Climate adaptation planning increasingly recognizes the value of biodiversity-based livelihoods including non-mulberry sericulture. National adaptation programs in India have identified sericulture as a priority sector for climate-resilient rural development (Kaushik *et al.* 2025) ^[25]. Integration of sericulture into watershed development, forest restoration and rural employment schemes creates synergies between climate adaptation and livelihood enhancement objectives. Scaling these integrated approaches requires coordinated policy support and investment.

7. Case Studies

7.1 Climate Adaptation in Muga Silk Systems in Northeast India

The muga silk production systems of Assam demonstrate both the vulnerabilities and adaptation potential of non-mulberry sericulture under climate change. Muga sericulture in the Brahmaputra valley faces increasing challenges from temperature extremes, erratic rainfall and host plant phenology shifts (Das 2021) ^[13]. Research documented that summer temperatures exceeding 35°C cause larval mortality while unseasonal rainfall during rearing periods increases disease incidence. These climate impacts have contributed to declining muga silk production in recent decades threatening the livelihoods of approximately 30,000 farming families.

Adaptive responses by muga sericulture communities include host plant diversification, rearing calendar adjustments and improved hygiene practices. Farmers have increasingly cultivated secondary host species including *Litsea nitida* and *L. salicifolia* alongside primary hosts to ensure leaf availability (Devi *et al.* 2021) ^[14]. Community-based organizations have promoted scientific rearing

practices including disinfection protocols and proper mounting techniques that reduce disease losses. Government support through the Central Silk Board has provided improved seed, training and marketing assistance. These integrated adaptation measures demonstrate pathways for climate-resilient sericulture development.

7.2 Tasar Sericulture in Central Indian Plateau Under Drought Conditions

Tasar sericulture in the drought-prone central Indian plateau illustrates the climate resilience of wild silkworm systems under water scarcity conditions. The tropical tasar belt spanning Jharkhand, Chhattisgarh, Odisha and Maharashtra experiences frequent droughts that severely impact agricultural productivity (Thakur *et al.* 2025) ^[46]. However, tasar host trees including *Terminalia arjuna* and *T. tomentosa* demonstrate drought tolerance enabling continued silkworm rearing when agricultural crops fail. This ecological resilience translates to livelihood stability for tribal communities dependent on forest resources.

Recent research in the Similipal Biosphere Reserve documented habitat suitability for *A. mylitta* across diverse forest types indicating potential for range expansion under changing climates (Thakur *et al.* 2025) ^[46]. Modeling studies identified optimal habitat zones where conservation interventions could enhance tasar silkworm populations. Community-based tasar cultivation initiatives have successfully engaged tribal villages in sustainable forest management while generating supplementary income. The Vana Samrakshana Samiti (VSS) model in Odisha demonstrates how institutional arrangements can support both conservation and livelihood objectives (Dansana *et al.* 2024) ^[12]. These experiences provide lessons for scaling climate-resilient sericulture across similar agro-ecological contexts.

7.3 Eri Silk as a Sustainable and Ethical Silk System

Eri sericulture has emerged as a model for sustainable and ethical silk production with significant climate adaptation potential. Unlike other silk systems requiring pupal killing for cocoon processing, eri silk can be harvested after adult emergence earning it the designation of peace silk or *ahimsa silk* (Seidel & Peigler 2018) ^[41]. This ethical attribute appeals to environmentally conscious consumers creating market opportunities for premium pricing. Eri silkworm polyphagy enables utilization of diverse host plants including agricultural byproducts reducing competition with food production.

Research in Thailand demonstrated that eri silkworms successfully develop on various host plants with significant effects on life cycle parameters and economic traits (Wongsorn *et al.* 2024) ^[51]. Silkworms fed castor leaves showed superior growth performance and silk yield compared to those fed tapioca or other alternatives. Nutritional analysis revealed that pupae from different host plant treatments varied in protein and fat content affecting their value as food and feed. These findings inform host plant selection for optimizing both silk production and pupal utilization in integrated systems.

7.4 Wild Silk-Based Resilience Models in Southeast Asia

Southeast Asian countries including Thailand, Myanmar, Laos and Vietnam maintain diverse wild silk production systems that contribute to rural livelihoods and cultural

heritage. Thailand has developed commercial eri sericulture producing silk for domestic and export markets (Park *et al.* 2022) ^[33]. Research institutions have evaluated host plant suitability, improved rearing techniques and developed silk processing technologies. The integration of eri sericulture with agricultural systems demonstrates how wild silk production can enhance farm diversification and income stability.

In Vietnam, wild silkworm species including *Antheraea pernyi* and *Samia cynthia* are cultivated in forest-based systems that provide ecosystem services alongside silk production (Thu *et al.* 2021) ^[47]. However, forest plantation pests and diseases pose increasing challenges requiring integrated management approaches. Cross-border collaboration in germplasm exchange, technology transfer and market development could enhance the sustainability of Southeast Asian sericulture. Regional research networks have facilitated knowledge sharing but greater coordination is needed to address common challenges.

7.5 Ecological Restoration Through Sericulture in Degraded Mining Areas

An innovative case study from Odisha demonstrates how sericulture can contribute to ecological restoration while generating livelihood benefits. The Purnapani limestone mining area degraded by decades of extractive operations has been targeted for rehabilitation through tasar host tree plantation and vanya silkworm conservation (Choudhary *et al.* 2023) ^[10]. Ecological restoration involving native tree species including *Terminalia arjuna* and *Shorea robusta* has created habitat suitable for tropical tasar silkworm rearing. Tribal communities displaced by mining operations have been engaged as tasar cultivators providing sustainable income while supporting restoration objectives. The five-storeyed tropical rainforest ecosystem established on restored sites now supports diverse flora and fauna including wild silkworm populations. This win-win approach demonstrates how sericulture can be integrated into mine closure and rehabilitation programs. Similar opportunities exist across India's extensive mining landscapes where ecological restoration could simultaneously address environmental and livelihood objectives.

8. Challenges in Non-Mulberry Sericulture

8.1 Dependence on Forest Ecosystems and Deforestation Risks

The dependence of wild silkworm species on forest ecosystems creates vulnerability to habitat loss from deforestation and degradation. India's forest cover has declined significantly over recent decades with consequent impacts on wild silkworm habitats (Roy *et al.* 2025) ^[39]. Mining, infrastructure development and agricultural expansion have fragmented forest landscapes reducing connectivity between silkworm populations. Habitat loss threatens not only current production but also the genetic diversity essential for future adaptation (Ahmed *et al.* 2015) ^[1].

The paradox of sericulture-driven deforestation merits attention. While sustainable sericulture can support forest conservation, unsustainable harvesting practices including host tree lopping and forest fires degrade silkworm habitats (Remadevi, 2022) ^[38]. Overexploitation of wild silkworm populations without adequate conservation measures threatens long-term sustainability. Balancing production

intensification with conservation requires clear tenure arrangements, sustainable harvesting protocols and community-based resource management institutions.

8.2 Lack of Systematic Host Plant Cultivation

Unlike mulberry sericulture where systematic cultivation ensures reliable leaf supply, wild silkworm rearing often depends on naturally occurring host trees with unpredictable productivity. The lack of organized host plant cultivation creates supply bottlenecks particularly during peak rearing seasons (Kumara 2023) ^[27]. Seasonal leaf availability constraints limit rearing scale and create competition among farmers for limited resources. This unorganized supply chain reduces production efficiency and farmer incomes.

Efforts to promote host plant cultivation have achieved limited success due to long gestation periods, land tenure constraints and market uncertainties. Tropical tasar host trees require 5-7 years to reach productive size discouraging farmer investment (Vishaka *et al.* 2020) ^[49]. Tenure insecurity on forest lands discourages long-term tree planting while unclear market arrangements reduce incentives for cultivation. Addressing these constraints requires coordinated policy support including land allocation, technical assistance and market linkages.

8.3 Low Productivity and Technological Gaps

Non-mulberry sericulture generally exhibits lower productivity compared to mulberry sericulture due to technological limitations and genetic constraints. Wild silkworm races have not undergone intensive selection for yield traits resulting in lower cocoon weights and silk percentages (Sivaprasad *et al.* 2024) ^[43]. Rearing practices often follow traditional methods without scientific optimization of temperature, humidity and hygiene conditions. Disease incidence causes significant crop losses that could be reduced through improved management practices.

Technological gaps extend across the value chain from breeding through processing to product development. Limited availability of quality silkworm seed forces farmers to rely on wild collection or informal exchange networks (Dandin & Prabhu 2022) ^[11]. Basic rearing infrastructure including mounting frames and rearing houses remains inadequate in many producing areas. Post-harvest processing including stifling, reeling and weaving employs outdated technologies that reduce silk quality and recovery rates. Addressing these technological constraints requires targeted research and extension investments.

8.4 Market and Policy Constraints

Non-mulberry sericulture faces significant market challenges including price volatility, limited market access and weak value chain integration. Vanya silk commands premium prices in niche markets but overall demand remains limited compared to mulberry silk (Halagundegowda *et al.* 2023) ^[20]. Farmers often sell cocoons to intermediaries at unfavourable prices due to lack of organized marketing channels. Value addition through reeling and weaving remains underdeveloped limiting income capture by primary producers.

Policy support for non-mulberry sericulture has historically lagged behind mulberry sericulture despite its livelihood importance. Research and development investments have focused predominantly on *B. mori* improvement with limited attention to wild silkworm species (Bhat 2024) ^[4]. Extension services for vanya sericulture remain inadequate

particularly in remote tribal areas. Market development initiatives including branding, certification and export promotion require scaling up. Addressing these policy gaps is essential for realizing the potential of non-mulberry sericulture in climate-resilient development.

9. Technological and Biotechnological Interventions

9.1 Genetic Improvement of Wild Silkworms

Genetic improvement programs for wild silkworms aim to enhance productivity while maintaining genetic diversity and adaptive traits. Conventional breeding approaches have achieved yield improvements in selected tasar and eri silkworm races through hybridization and selection (Sivaprasad *et al.* 2024) ^[43]. Crossbreeding between ecoraces has combined desirable traits including disease resistance, temperature tolerance and silk quality. However, breeding progress remains slower than in mulberry silkworms due to longer generation times and limited genetic characterization.

Molecular approaches including marker-assisted selection and genomic selection offer opportunities to accelerate genetic improvement. Genome sequencing of wild silkworm species has identified genetic markers associated with economically important traits (Venkatesh Kumar *et al.* 2025) ^[48]. Comparative genomic analysis between wild and domesticated silkworms has revealed candidate genes underlying domestication syndrome providing insights for breeding. Integration of genomic tools with conventional breeding programs could enhance selection efficiency while maintaining genetic diversity.

9.2 Habitat Restoration and Agroforestry Integration

Habitat restoration initiatives aim to expand wild silkworm habitat while enhancing ecosystem services and livelihood opportunities. Plantation programs establishing tasar and muga host trees on degraded lands, community lands and farm boundaries have created new silkworm rearing areas (Choudhary *et al.* 2023) ^[10]. Agroforestry systems integrating sericulture host trees with agricultural crops demonstrate synergies between production and conservation objectives. Research on optimal planting configurations, management practices and economic returns informs scaling of these approaches.

Ecological restoration of degraded forests for sericulture requires attention to biodiversity conservation alongside productivity objectives. Mixed-species plantations supporting diverse flora and fauna provide better ecosystem services than monoculture stands (Attri *et al.* 2024) ^[2]. Natural regeneration of native species alongside planted host trees enhances habitat quality for wild silkworms and associated biodiversity. Monitoring and adaptive management ensure that restoration achieves intended ecological and socioeconomic outcomes.

9.3 Climate-Smart Sericulture Practices

Climate-smart sericulture practices aim to reduce vulnerability to climate change while maintaining productivity and sustainability. Modified rearing technologies including low-cost temperature regulation, improved ventilation and humidity management reduce climate risks (Kaushik *et al.* 2025) ^[25]. Seasonal rearing calendars adjusted to projected climate scenarios optimize timing to match host plant availability and avoid extreme weather periods. Early warning systems for disease outbreaks based on weather monitoring enable preventive management.

Host plant management practices including irrigation, fertilization and pruning can buffer climate impacts on leaf availability and quality. Drought-tolerant host varieties identified through screening programs provide planting material for water-limited environments (Kumara 2023) ^[27]. Mixed host plantings combining species with different phenologies and drought tolerances reduce climate risks. These climate-smart practices require validation across diverse agro-ecological contexts before large-scale promotion.

9.4 Role of Biotechnology

Biotechnological approaches offer powerful tools for wild silkworm conservation, characterization and improvement. Cryopreservation of silkworm germplasm including eggs, larvae and pupae provides insurance against genetic erosion (Zabelina *et al.* 2015) ^[53]. Sperm cryopreservation and artificial insemination techniques enable conservation of male genetic lines and facilitate controlled breeding (Fukumori *et al.* 2022) ^[16]. These biobanking approaches complement in situ conservation of wild silkworm populations.

Genomic and transcriptomic analyses illuminate the genetic basis of adaptive traits in wild silkworms. Comparative gene expression studies have identified candidate genes involved in thermal tolerance, disease resistance and silk synthesis (Fang *et al.* 2015) ^[15]. Genome editing technologies including CRISPR-Cas9 offer potential for precise genetic modification although regulatory and ethical considerations require careful attention. Integration of biotechnological approaches with conventional conservation and breeding programs enhances capacity for maintaining and utilizing wild silkworm genetic resources.

10. Policy and Future Directions

10.1 Need for Climate-Resilient Sericulture Policies

Climate-resilient sericulture development requires policy frameworks that recognize the unique attributes and challenges of non-mulberry systems. National sericulture policies should prioritize genetic conservation, habitat restoration and community-based management of wild silkworm resources (Kaushik *et al.* 2025) ^[25]. Integration of sericulture into national climate adaptation plans ensures access to climate finance and technical support. Research and development investments should address the specific needs of vanya sericulture including breeding, pest management and processing technologies.

Institutional arrangements for sericulture governance require strengthening to support sustainable development. Coordination among forestry, agriculture and rural development agencies reduces policy conflicts and creates synergies (Gangopadhyay 2024) ^[18]. Community-based organizations including cooperatives and self-help groups enhance farmer bargaining power and access to services. Public-private partnerships can mobilize investment for value chain development while ensuring equitable benefit sharing. These institutional innovations require policy support and capacity building for effective implementation.

10.2 Integration into Climate-Smart Agriculture Frameworks

Non-mulberry sericulture merits explicit inclusion in climate-smart agriculture initiatives given its adaptation and mitigation co-benefits. Carbon sequestration through sericulture-based agroforestry could qualify for climate finance mechanisms including carbon credits (Chakraborti *et al.* 2024) ^[6]. Biodiversity conservation outcomes from

sustainable sericulture align with payment for ecosystem service schemes. Climate-resilient livelihood benefits support inclusion of sericulture in adaptation programs targeting vulnerable communities.

Technical guidelines for climate-smart sericulture practices require development and dissemination through extension systems. Training programs for farmers, extension workers and NGO staff build capacity for implementing adaptation measures (Sujatha *et al.* 2024) ^[44]. Demonstration plots and farmer field schools facilitate experiential learning and technology adoption. Monitoring and evaluation systems track adaptation outcomes informing adaptive management. These implementation mechanisms require sustained investment and institutional commitment.

10.3 Conservation of Wild Silkworm Germplasm

Systematic conservation of wild silkworm genetic resources is essential for maintaining adaptive capacity and breeding progress. Ex situ conservation through germplasm banks maintains representative samples of ecoraces diversity providing material for research and breeding (Dandin & Prabhu 2022) ^[11]. In situ conservation in protected areas and community forests maintains evolutionary processes and local adaptation. Integrated conservation strategies combining ex situ and in situ approaches provide comprehensive genetic resource security.

Germplasm characterization using molecular markers and phenotypic evaluation informs conservation prioritization and utilization. Core collections representing maximum diversity in minimum accessions facilitate efficient management and use (Venkatesh Kumar *et al.* 2025) ^[48]. Genome resource banks combining cryopreserved material with genomic information provide next-generation conservation tools. International collaboration in germplasm exchange and information sharing enhances global conservation capacity. These advances require sustained funding and coordination among conservation stakeholders.

10.4 Scaling Non-Mulberry Systems

Scaling non-mulberry sericulture for sustainable silk production requires coordinated action across research, policy and market domains. Technology packages combining improved seed, best management practices and processing equipment enhance productivity and quality (Sivaprasad *et al.* 2024) ^[43]. Market development including branding, certification and value chain integration improves farmer incomes and investment incentives. Policy support including credit, insurance and extension services reduces risks and enables adoption.

International cooperation can accelerate sericulture development through technology transfer, investment and market access. South-South collaboration among sericulture-producing countries facilitates exchange of germplasm, expertise and experiences (Park *et al.* 2022) ^[33]. Regional research networks address common challenges while avoiding duplication. Fair trade and ethical sourcing initiatives create market opportunities for sustainably produced wild silk. These collaborative approaches enhance the contribution of non-mulberry sericulture to sustainable development globally.

Conclusion

This comprehensive review demonstrates that non-mulberry sericulture represents a critical yet underappreciated

resource for climate-resilient rural development. Wild silkworm species including *A. mylitta*, *A. assamensis*, *S. ricini* and *A. paphia* possess inherent attributes that render them particularly suited to changing climatic conditions. Their genetic diversity, host plant flexibility, natural hardiness and low input requirements provide adaptive mechanisms lacking in domesticated mulberry sericulture. The ecological integration of wild silkworms within forest and agroforestry systems creates multifunctional landscapes that provide ecosystem services alongside livelihood benefits.

The socio-economic importance of non-mulberry sericulture for tribal and rural communities across major producing regions underscores the development significance of this sector. Climate-resilient livelihood opportunities provided by wild silkworm rearing buffer vulnerable households against climate shocks while supporting biodiversity conservation. Case studies from India and Southeast Asia demonstrate both the challenges facing wild silkworm systems and the potential for adaptive management to enhance resilience. Technological innovations including genetic improvement, habitat restoration and biotechnology provide tools for addressing production constraints.

However, significant challenges persist including habitat loss, technological gaps, market constraints and inadequate policy support. Addressing these challenges requires integrated approaches combining conservation, research, extension and market development. Climate-smart sericulture policies that recognize the unique attributes of wild silkworm systems are essential for scaling sustainable production. Conservation of genetic resources through integrated ex situ and in situ approaches maintains adaptive capacity for future challenges. International cooperation in research, technology transfer and market development can accelerate progress toward sustainable sericulture globally.

Future research priorities include comprehensive genomic characterization of wild silkworm diversity, development of climate-resilient breeding programs, optimization of agroforestry integration and establishment of inclusive value chains. Interdisciplinary research combining genetics, ecology, social science and economics can inform integrated sericulture development. Participatory research approaches engaging farming communities ensure that innovations address local needs and constraints. Long-term monitoring of sericulture systems under climate change provides empirical evidence for adaptive management.

In conclusion, non-mulberry sericulture offers a compelling model for climate-resilient agriculture that integrates biodiversity conservation, livelihood enhancement and ecosystem service provision. As climate change accelerates and agricultural systems face increasing uncertainty, the adaptive attributes of wild silkworms become ever more valuable. Realizing the full potential of non-mulberry sericulture requires sustained commitment from researchers, policymakers, development practitioners and farming communities. The future of sustainable silk production depends in significant measure on our collective ability to conserve, understand and wisely utilize the remarkable biodiversity of wild silkworms.

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