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Constraints and climate change impacts on sericulture farmers in west Bengal: Challenges and mitigation strategies

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Abstract
Sericulture serves as a vital socio-economic catalyst in West Bengal, providing sustainable livelihoods for rural communities and maintaining the state's status as a premier silk producer. However, the industry is increasingly compromised by climate-induced thermal shifts and erratic rainfall, which degrade mulberry quality and elevate silkworm mortality. Significant research gaps remain regarding micro-level sustainable adaptations and the socio-economic vulnerability of marginal farmers to these localized stressors. To address these challenges, a transition from traditional subsistence to a resilient, high-yield industry requires multidisciplinary interventions. This includes the deployment of climate-resilient mulberry varieties and thermo-tolerant bivoltine hybrids, alongside technological shifts such as microclimate-controlled rearing houses and AI-driven pest forecasting. By integrating sustainable agronomic practices with robust policy-backed insurance frameworks, West Bengal can mitigate environmental instability, ensuring the long-term viability of its sericulture sector and its continued contribution to the global silk economy.

Keywords: West Bengal, sericulture, mitigation, constraints, climate

1. Introduction
Sericulture, an agro-based and labor-intensive cottage industry, plays a vital role in rural economies by engaging communities in the rearing of sericigenous insects, including both mulberry and non-mulberry silkworms. Among more than 40 silk-producing countries, China remains the largest contributor, followed by India, which ranks second globally, producing 41, 121 MT of silk, with Mulberry (75.67%) and Eri (19.17%) leading. By November 2025, India had achieved 27, 560 MT of its 46, 500 MT target [1]. West Bengal stands as a cornerstone of India's sericulture industry, historically serving as one of the nation's premier zones for traditional silk production [2]. Climatic conditions play a crucial role in sericulture, contributing nearly 37.8% to the successful production of cocoon crops [3]. The environmental thresholds for larval rearing vary by age: early instars demand a warmer, highly humid environment (26-28°C, 80-90% RH), while late instars adapt better to marginally cooler temperatures (24-25°C) and reduced humidity (70-75%) [4]. In West Bengal, the silkworm rearing period is broadly divided into two seasons: the dry summer and the wet summer. The dry summer extends from November to April, excluding a brief winter period, and is characterized by temperatures that often exceed the optimum range while humidity remains below the required level. The wet summer, from May to October, experiences both higher temperatures and higher humidity than the ideal conditions for silkworm rearing [5]. The wet summer is generally regarded as an unfavorable season for silkworm cultivation in West Bengal because of the simultaneous occurrence of high temperature and high humidity. Under normal circumstances, an increase of 4% in humidity is typically accompanied by a decrease of approximately 1°C in temperature [6]. However, during the wet summer in West Bengal, both parameters remain elevated, creating conditions that are detrimental to silkworm growth and development. In addition, heavy rainfall during this period causes frequent temperature fluctuations, further affecting rearing performance. Despite these challenges, abundant rainfall promotes luxuriant growth of mulberry plants,

ensuring an ample supply of leaves for feeding silkworms. During the dry summer, humidity levels may occasionally fall below the optimum range, reducing the moisture content of mulberry leaves and thereby lowering their suitability as silkworm feed. However, in West Bengal, average temperatures during April, June-July, and August-September often exceed 30°C and may occasionally reach 40°C [7]. Conversely, average humidity levels during November, February, and April frequently fall below 70%, creating suboptimal conditions for successful silkworm rearing [8]. As an industry uniquely dependent on the delicate biological synchrony between the mulberry host plant (*Morus spp.*) and the silkworm (*Bombyx mori*), it is exceptionally vulnerable to shifting environmental parameters. Climate volatility severely impacts the economic viability of smallholder sericulturalists by causing erratic cocoon yields and driving up the operational costs of climate-control systems. Such disruptions threaten livelihood security, potentially forcing a transition toward climate-resilient alternatives and undermining the industry's role in rural poverty alleviation and sustainable development [9]. The sustainability of the global silk industry necessitates the urgent development of climate-resilient silkworm breeds and drought-tolerant mulberry varieties to mitigate these multifaceted risks. As silkworms are highly sensitive to environmental fluctuations, extreme heat, particularly during the unfavorable seasons (May to October), disrupts their physiological development, resulting in reduced cocoon quality and increased susceptibility to diseases like flacherie, grasserie, and muscardine [10]. Therefore, this review synthesizes the climatic challenges confronting West Bengal's sericulture farmers, evaluating key environmental constraints alongside crucial mitigation strategies to secure sustainable rural livelihoods.

2. Climate Change and Its Impact on Sericulture

2.1. Thermal Dynamics in Sericulture: As a delicate, domesticated insect, *Bombyx mori* L. exhibits suboptimal phenotypic expression and crop vulnerability when nutritional and climatic conditions deviate from physiological optima [11]. Among the different types of abiotic factors, temperature significantly influences the growth, survival, and productivity of *Bombyx mori*. Optimal silkworm productivity occurs within 23°C-28°C, temperatures exceeding 30°C impair silkworm health, while drops below 20°C retard early-instar physiology, elevating disease susceptibility. Temperature fluctuations in West Bengal severely disrupt silkworm rearing due to hot, humid summers exceeding 30°C, which stress larvae, shorten cycles, and drastically reduce larval weight, cocoon yield, and fiber quality, underscoring the necessity of precise thermal regulation. Temperature shifts directly constrain silkworm development: lower temperatures prolong larval duration and increase cocoon weight, while higher temperatures hasten development but degrade larval feeding quality [12]. On the other hand, *Morus alba* L., the main food of domesticated silkworm, thrives in optimal tropical conditions, yet climate change-induced multi-stressors (frost, drought) threaten genetic productivity, potentially reducing crop yields by 50-70%. During dry seasons, humidity drops below 70%, slowing growth and drying mulberry leaves. With enough heat, light, air, humidity, and soil rich in humus, the growing season can be extended [13].

2.2. Impact of Humidity Dynamics on Pests, Larval Physiology, and Cocoon Yield: Atmospheric humidity, the measure of moisture content in the air, serves as a critical determinant of insect metabolic rates, behavioral kinetics, and lifecycle transitions, including post-diapause eclosion, ecdysis, and copulation [14]. While xeric conditions induce diapause, hydric environments accelerate larval development and pupation. Pathogen kinetics exhibit distinct humidity thresholds; intermediate relative humidity (50-56%) optimizes lesion expansion and spore germination within favorable thermal ranges, whereas extremely low humidity arrests sporulation and hastens host tissue necrosis. Conversely, prolonged saturation (more than 96%) maximizes the virulence and infectivity of entomopathogenic agents. Paradoxically, xeric conditions enhance mite fertility and longevity, while high humidity levels reduce the viability of neonate populations [15]. Furthermore, soil moisture directly governs the virulence, population dynamics, and dispersal vectors of phytopathogenic nematodes. Consequently, fluctuations in ambient humidity dictate the microclimatic thresholds driving pest epidemics and subsequent chemical mitigation strategies. Fluctuating humidity induces rapid leaf desiccation, causing larval consumption loss, stunted growth, and disease susceptibility. While 90% relative humidity stabilizes vital water balance and larval weight, reducing it to 70% ensures uniform molting. High relative humidity (90%) during wet seasons facilitates pathogen proliferation, notably Grasserie and Flacherie, while hindering rearing bed evaporation, leading to elevated larval mortality [16]. Additionally, excessive humidity during the spinning stage prevents proper sericin drying, resulting in fused cocoons and higher renditta [17].

2.3. Impact of Rainfall Variability: West Bengal's annual rainfall averages 1, 900 mm, with 80% concentrated in the monsoon. Precipitation significantly increased in Gangetic West Bengal (GWB) at 1.8-2.9 mm/year during monsoon and post-monsoon periods, whereas Dakshin Dinajpur in sub-Himalayan West Bengal (SHWB) exhibited a significant monsoon decline of 3.2 mm/year [18]. Excessive precipitation promotes fungal and bacterial infections, whereas prolonged dry spells reduce leaf quality and yield [19]. Thereby constraining cocoon production and threatening the sustainability of the regional sericulture industry in West Bengal under ongoing climate change. Monsoon-driven waterlogging and drought-induced moisture stress reduce mulberry biomass and nutritional quality, necessitating costly irrigation. Conversely, pre-monsoon dry spells accelerate foliar desiccation, impairing larval ingestion and growth [20].

2.4. Increased Incidence of Silkworm Diseases and Pests: The domesticated silkworm, *Bombyx mori* L., is highly vulnerable to four major pathologies: Grasserie, Flacherie, Muscardine, and Pebrine. In the autumn rearing season, disease incidence spikes due to an elevated environmental pathogen load, sharp diurnal temperature fluctuations, high late-stage relative humidity, and the poor nutritional quality of autumn mulberry foliage [21]. Pathogenic threats, including bacteria and viruses (Grasserie), induce high larval mortality (20-30%) in West Bengal's summer silkworm crops, severely curtailing cocoon yields by up to 30 kg/100 dfls. [22]. Longitudinal data over the past six years

(2018-25) indicate that Grasserie represents the most prevalent disease, with an incidence rate ranging from 2.99% to 8.37%. This was followed by Flacherie (1.03% to 5.08%) and Muscardine, which exhibited the lowest baseline occurrence (0% to 3.84%) [23]. Because no *B. mori* strain possesses absolute immunity or complete genetic resistance to these pests and pathogens, disease management relies entirely on rigorous prophylaxis. Crop loss due to uzi infestation was reported to be 0.008%-11.6% in West Bengal [24].

2.5. Increased Incidence of Mulberry Pests and Diseases: Sustainable productivity is severely constrained by biotic stressors; among the various factors degrading mulberry leaf yield and quality, pest and disease infestations represent the primary threat, with approximately 300 insect and non-insect pest species documented to feed on *Morus* crops [25]. More recently, instances of root rot disease have emerged across various districts of West Bengal. Persistent soil-borne root rot poses a severe threat, potentially causing 100% crop failure. Consequently, accurate diagnosis and targeted management strategies are critical [26]. The perennial nature of mulberry crops, combined with intensive monoculture practices, facilitates the continuous presence of diverse pest complexes and escalates infestation risks throughout the year [27]. The primary insect pests driving significant defoliation and economic damage in mulberry cultivation include mealybugs, hairy caterpillars, thrips, cutworms, and leaf Webbers [28]. Among these, the pink mealybug (*Maconellicoccus hirsutus*) represents a major threat, inducing "tukra" disease in mulberry plants. This infestation accounts for severe biomass depletion, with estimated leaf yield losses reaching up to 34.24%, equivalent to approximately 4, 500 kg/ha/year [29].

2.6. Soil Quality: West Bengal's soil fertility varies significantly; fertile Terai and alluvial zones contrast with lateritic, red, and coastal regions constrained by low nutrient levels, acidity, or high salinity [30]. Climate-driven temperature rises accelerate soil chemical reactions and organic matter decomposition. While this degrades soil structure and releases CO_2, enhanced plant biomass from elevated atmospheric carbon may partially offset these losses. Soil fertility is foundational to mulberry production across West Bengal's 15, 734 hectares of sericultural land. However, the intensive practice of conducting five rearing cycles annually causes rapid nutrient depletion through frequent foliage harvests. If left uncompensated, soil quality deteriorates, yet indiscriminate chemical fertilization conversely triggers severe soil degradation and sub-optimal cocoon yields. In West Bengal, the majority of mulberry soils are acidic (67.5%) and highly deficient in both sulfur (67.2%) and potassium (53.4%). To mitigate this constraint under shifting climatic conditions, transitioning toward the Government of India's Soil Health Card (SHC) framework is imperative. By systematically evaluating 12 key parameters, i.e., encompassing macronutrients (N, P, K), secondary nutrients (S), micronutrients (Zn, Fe, Cu, Mn, B), and physico-chemical indicators (pH, Electrical Conductivity, Organic Carbon), farmers can implement soil-test-recommended, site-specific fertilizer doses to prevent soil degradation and sustainably secure high-quality leaf production [33].

2.7. Pesticide toxicity: While pesticides are standard agricultural interventions, they are paradoxically detrimental to silkworms, often suppressing stress-responsive genes and fostering pest resistance. Intensive farming and nitrogenous fertilizer overuse have augmented mulberry vulnerability to pests. Climate change exacerbates this by disrupting host-pest synchronization and expanding thermal windows for pathogen reproduction, particularly fungal rusts. These shifts, driven by rising temperatures and CO2 levels, extend infection cycles and threaten foliar productivity in West Bengal [34]. In *Bombyx mori*, multi-class pesticides induce a "multi-hit" effect by inhibiting mitochondrial oxidative phosphorylation, triggering ROS-dependent antioxidant (CncC/Keap1) and apoptotic pathways, and dysregulating gut microbiota, which suppresses immunity and thereby exacerbates susceptibility to infectious agents, most notably BmNPV [35]. Sub-lethal imidacloprid and thiamethoxam exposure prolongs *Bombyx mori* larval duration while significantly depressing biomass accumulation, pupation rates, and economic traits like cocoon shell weight and silk yield [36]. Ingestion of neonicotinoid, organophosphate, and pyrethroid residues even at sublethal concentrations, precipitates significant physiological disruptions, including developmental retardation and "non-spinning syndrome" [37].

3. Key Constraints Faced by Sericulture Farmers in West Bengal

3.1. Unpredictable Climate Events: Unpredictable climate shifts bottleneck sericultural output by causing environmental stress, erratic rainfall, and humidity imbalances, alongside surging pest pressures, soil depletion, and highly volatile mulberry and silkworm yields. Adverse weather patterns disrupt rearing cycles, impair egg viability, and post-cocoon parameters like reelability and denier consistency. To sustain silk production, it is imperative to develop climate-resilient breeds, optimize cultivation techniques, and implement precise environmental controls in West Bengal [38]. During 2018-2024, Grasserie peaked in Shravani (8.37%) and Bhaduri (7.18%) crops, while Flacherie peaked in Shravani (3.4%) and Bhaduri (5.08%), both favoring rainy and summer seasons. Muscardine prevailed during Falgooni (3.84%) and Agrahayani (2.22%) crops. West Bengal's sericulture productivity fluctuates across rearing cycles, including the profitable Agrahayani and Falgooni winter crops. Conversely, the Baisakhi summer and Shravani and bhaduri monsoon crops impose severe thermic stress and pathological risks, significantly undermining cocoon quality and yield. Thermal stress during Baisakhi and high humidity during Bhaduri crops facilitate pathological outbreaks and poor silk development, causing significant yield losses and perpetual farmer debt. Seasonal leaf quality variations create nutritional gaps, causing economic instability [23].

3.2. Inadequate Infrastructure: West Bengal's sericulture relies on fragmented, small-scale cultivation (intercropping and perimeter planting), leading to low yields and limited industrialization [39]. The continued use of bamboo trays (dala) without special cleaning nets makes it difficult to remove waste properly, creating environments where harmful microbes can thrive. This weakness in biosecurity is made worse by insufficient cleaning of rearing areas, improper care of infected larvae, and storing leftover mulberry twigs indoors for use as firewood, which helps spread disease-causing organisms. Additionally, because there are no specific structures for rearing silkworms, many small-scale farmers use their homes for this activity. This mixing of living and rearing spaces makes it hard to manage the right climate conditions for healthy larvae and also puts farming families at risk of serious health problems from long-term exposure to allergens and disinfectants. Traditional mud-and-thatch rearing houses lack essential thermal insulation and ventilation, preventing necessary microclimate regulation. This deficiency, coupled with a lack of standardized disinfection and segregated rearing spaces, compromises biosecurity and exacerbates climate-induced larval mortality, significantly undermining productivity [40].

3.3. Competition with other cash crops: Mulberry sericulture generates more employment opportunities than jute, mango, and paddy crops because silkworms can be raised 5 to 6 times from a mulberry garden round the year. Escalating agrochemical dependency in adjacent cropping systems has intensified foliar contamination through spray drift and systemic persistence. Due to depressed potato markets, agricultural frameworks in the Gangetic plains are shifting toward intensive cultivation. The comparative statistics between employment in sericulture and agriculture in one agronomic year in one acre of land is very interesting [41]. However, rising deficits in allied agricultural products necessitate a comprehensive structural reorientation.

3.4. Knowledge Gaps and Technical Constraints: West Bengal's sericulture sustainability is compromised by technical knowledge gaps and high-risk economic structures. Farmers' reliance on traditional methods, coupled with fragmented extension services and middleman exploitation, creates significant income volatility. The sericulture industry in areas such as Malda faces significant challenges due to an aging group of farmers and a major lack of technical knowledge. This issue is mainly caused by low literacy levels and the absence of involvement from educated young people. This situation leads to a long-standing reluctance to move away from old, less productive methods towards modern, scientific techniques [42]. A key technical problem is the continued use of traditional bamboo *chandrikas* instead of plastic collapsible frames, which have been shown to improve larval spacing, reduce the formation of defective double cocoons, and greatly lower the spread of diseases. As pathogens increasingly develop resistance to harsh synthetic chemical disinfectants like Labex and bleaching powder, sericulturists can instead utilize cost-effective, ecologically benign botanical formulations derived from turmeric (*Curcuma longa*) and Tulsi (*Ocimum sanctum*) to maintain biosecurity [43]. High humidity levels during the monsoon season can be controlled using low-cost natural materials such as banana pseudostem rings placed in the rearing areas or solar neem dehumidifiers made from neem leaves and paddy husks.

4. Mitigation and Adaptation Strategies

4.1. Climate-Resilient Sericulture: The silk industry relies on consistent, high-quality mulberry leaf production, currently threatened by climate-induced abiotic stresses. While conventional breeding has historically sustained yields, recent advancements in genetic engineering have facilitated the development of climate-resilient, transgenic cultivars [44]. This approach involves developing resilient mulberry varieties and heat-tolerant silkworm breeds, optimizing mulberry cultivation practices, developing and popularization of drought-resistant varieties and breeds, and improving irrigation schedules [45]. Additionally, integrating agroforestry practices and organic farming techniques can reduce the carbon footprint of sericulture, enhance biodiversity, and promote environmental sustainability. Advanced technologies, including remote sensing, artificial intelligence, and precision agriculture, play a vital role in improving resource efficiency and reducing waste. Biotechnology advancements, such as genetically modified mulberry plants with enhanced pest and disease resistance, can further align sericulture with sustainable agricultural practices [46]. Climate-smart frameworks are vital for stabilizing both mulberry agronomy and silkworm rearing. In the field, resource footprints are minimized through Regulated Deficit Irrigation (RDI), drip systems, mulching, and legume intercropping, which collectively optimize soil hydrology and fertility. These are complemented by climate-aligned pruning schedules and protected propagation [45].

4.2. Sustainable Farming Practices: Sustainable sericulture necessitates a transition from synthetic fertilizers to organic amendments to mitigate environmental degradation and enhance soil health. Incorporating compost, green manures, and animal waste significantly increases soil organic matter, improving structural integrity, water-holding capacity, and nutrient bioavailability. These organic inputs foster robust microbial communities within the rhizosphere, which are essential for efficient nutrient cycling and natural disease suppression [47]. Regular soil testing allows sericulturists to monitor pH levels, identify nutrient imbalances, and detect trace element deficiencies. By leveraging these diagnostic data, practitioners can implement precise Integrated Soil Fertility Management (ISFM) plans. It ensures that nutrient application aligns with specific crop requirements, optimizing mulberry productivity while maintaining ecological equilibrium and long-term soil fertility [48]. This diversification mitigates climate shocks by securing household nutrition, conserving up to 60% of farm resources, and offering alternative income streams when primary silkworm crops fail [49].

4.3. Farmers' Education and Capacity Building: Despite promising strategies, challenges persist, particularly for smallholder farmers who often lack access to necessary resources and knowledge. To counter this, policy frameworks must strengthen public extension networks, regulate agrochemical advertisements, and leverage NGO collaborations to disseminate objective knowledge and institutionalize sustainable, participatory pest management practices. Structured training initiatives in sericulture significantly enhance farmers' knowledge and expedite the adoption of innovative, recommended practices compared to reliance on traditional methods. These findings underscore the critical efficacy of formal education programs in driving the successful implementation of advanced cultural protocols and modern agricultural techniques across the sector [50]. The *Mera Resham Mera Abhiman* (MRMA) initiative bridges India's critical lab-to-land gap. It addresses technology adoption challenges among silk farmers through localized training, awareness campaigns, and field demonstrations. The Central Silk Board implements *Silk Samagra,* a Central Sector Scheme aimed at enhancing silk quality, productivity, and socio-economic empowerment through sericulture. The initiative integrates four primary components: Research and Development (including technology transfer and training), Seed Organizations, Coordination and Market Development, and Quality Certification Systems, combined with technology upgradation [1].

5. Conclusion

Climate change poses a systemic threat to the sericulture industry, primarily through thermal stress on silkworm physiology and reduced nutritional quality of mulberry foliage. In West Bengal, these environmental constraints are exacerbated by shrinking land availability and labor shortages, risking significant economic loss for smallholder farmers. To mitigate these impacts, immediate adaptation must prioritize the adoption of climate-resilient mulberry genotypes and the implementation of low-cost, energy-efficient microclimate controls within rearing houses. Future research should focus on the molecular breeding of heat-tolerant breeds and the development of automated sericulture technologies to offset labor scarcities. Ultimately, a multidisciplinary approach linking traditional wisdom with biotechnological advancement is essential to secure the socio-economic future of sericulture in a changing climate.

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