Development of an AI-Integrated Smart Sericulture System for Climate- Resilient Silk Production in India

# Abstract

Sericulture is a key agro-based rural industry in India, contributing significantly towards employment generation and socioeconomic progress, particularly in backward and tribal regions. But problems such as outbreaks of pests and diseases, fluctuations in the market environment, weather unpredictability, and inefficient utilization of resources are threatening the industry increasingly. A framework for strategy in developing an AI-enabled smart sericulture system to enhance sustainability, productivity, and climate resilience of silk production is offered in this paper. Emerging technologies such as artificial intelligence (AI), machine learning (ML), deep learning (DL), the internet of things (IoT), and drone-based systems are all incorporated into the proposed model to monitor, predict, and optimize every stage of the sericulture process. Adaptive raising schedules decision-support technologies, disease and pest forecasting algorithms, image processing for cocoon quality assessment, and real-time environmental monitoring within rearing buildings are key aspects. Farmers are provided with direct access to localized knowledge and recommendations through the utilization of digital advisory tools and smartphone applications. Central Silk Board (CSB) pilot project case studies in Karnataka and Assam depict the beneficial benefits of insightful interventions on yield growth, disease management, and efficient post-harvesting. The policy recommendations heavily focus on the necessity of public-private collaborations, capacity- building programs, harmonization of AgriStack and Digital India, and economic support in terms of insurance policies and subsidies. By leveraging digital innovation, the smart sericulture model presents an innovative solution to transform India's silk industry, reduce climate stress exposure vulnerabilities, and support inclusive rural growth. The research concludes that India could emerge as a global leader in sustainable and intelligent silk production if the right balance of technology, governmental support, and mass participation is established.

**Keywords:** Sericulture, Artificial Intelligence (AI), Machine Learning (ML), Drone-based Systems, Smart Agriculture, Climate Resilience, Digital Advisory Tools.

# Introduction

* 1. **Overview of sericulture in India.**

Silk is regarded as the queen of textile fibers because to its special qualities, which combine delicacy and durability, sheerness and strength, and lightness and warmth. Even though it is quite expensive and only the wealthy can afford it, the industry is crucial to the underprivileged. Poor farmers who raise silk worms and make cocoons get the majority of the silk revenue, according to the pattern and structure of its distribution. The allocation of the money from the production and selling of silk is as follows: 54.6% goes to cocoon producers, 6.6% goes to silk rearers, 8.7% goes to twisters, 12.3% goes to weavers, and 17.8% goes to merchants (Naik et al., 2017).

In India, sericulture has grown in importance as a rural business. India is the world's second- largest producer of silk, behind China. The silk sector has significant export possibilities even though the majority of this country's output is consumed domestically (Anitha, 2011). All of the commercially recognized types of silk, including Mulberry, Tasar, Eri, and Muga, are solely produced in India. Mulberry silk, however, accounts for more than 90% of all silk produced. The production of mulberry silk is also growing rapidly and is comparatively more organized. The majority of mulberry silk production is limited to West Bengal, Jammu & Kashmir, Karnataka, and Andhra Pradesh. Jammu and Kashmir produces just 0.66 percent of the world's mulberry silk, while Karnataka produces over 65%.

Sericulture is important in Jammu & Kashmir. This is the only traditional Univoltine belt in India that can produce silk of the same grade as imported raw silk from foreign markets. Its moderate environment is ideal for raising Univoltine and Bivoltine silk worms. Due to the restricted scope for pollution-focused heavy industries, sericulture has gained importance in state industrial strategy. Additionally, this business does not need expensive imports of raw materials from outside the state.

Sericulture is an ancient Kashmiri activity. The business employs 30,000 households part-time via silk worm farming and 5,000 people regularly in the public sector. Additionally, the silk industry employs 10,000 full-time weavers in 2,000 private sector units in the valley. About

2.15 lakh individuals work full or part-time in this business. The silk business was a governmental monopoly until 1988, with growers receiving no profit from the government-set cocoon prices. A considerable consideration was given to reclaim its lost splendor. After de- monopolization, farmers were granted ownership of plants and allowed to sell additional leaves

for profit to assist in preserving the industry. Farmers took care to preserve trees, leading to increasing demand for the plant. Free silk worm seed is provided to rearers, while government and private enterprises buy cocoons (J&K, SILKS). However, Kashmir Sericulture development has been neglected. Traditional silk industry is in risk of extinction. The annual output of seed, mulberry leaf, cocoons, and raw silk has been dropping rapidly in recent years.

# Economic and social importance.

Producing natural silk fabric is the primary goal of sericulture, an agro-based enterprise mostly focused on raising silkworms, particularly Bombyx mori (Singh & Makkar, 2000). From growing mulberries, which are used as food for silkworms, to several post-cocoon procedures including reeling, weaving, dying, and selling silk goods, it includes a broad variety of interrelated business ventures.

For rural families, sericulture is an essential source of income, especially in emerging nations with limited land and capital resources. Silk cocoon production serves as both a raw material for the silk industry and a steady source of revenue for farmers. Beyond cocoons, sericulture produces useful byproducts including moths, rearing waste, and silkworm proteins (sericin and pupae), which may be turned into animal feed and other industrial goods, further diversifying the economy.

Sericulture-related activities are practiced by over 30 million households worldwide (Kim et al., 2010). The industry promotes social structures, creates jobs, and maintains ecological equilibrium in contemporary economies. Mulberry farming, for example, helps preserve the environment (Gamble, 2011) and the production of silk creates jobs at several stages of the value chain, from farmworkers to craftspeople. Sericulture promotes community-based jobs, cultural heritage, and traditional customs on a social level. Many people see it as both a primary and a secondary profession, giving small-scale farmers flexibility. Sericulture is ingrained in the sociocultural fabric of many areas, serving as a component of local crafts, festivals, and rituals.

Mulberry monoculture, inferior silkworm breeds, bad infrastructure, poor mulberry management, a lack of equipment, a shortage of rearing area, and a low adoption of current technology are some of the issues the sector confronts despite its advantages. Targeted interventions are needed to address these issues, including better post-cocoon technologies,

farmer training programs, high-yield silkworm breed introduction, and improved infrastructure (Bhat, 2014).

China, India, Japan, Brazil, and Korea are the top producers of silk, accounting for 95% of the world's total production (Nagaraju, 2008). In many nations, the potential of by-products of the silk industry is still underused, despite significant advancements. Concentrated research and development on the processing of these secondary products may reduce industrial waste and increase profitability (Majumder, 1997).

Sericulture is an important sector that supports sustainable rural living since it is cottage, agro, and forestry-based. In addition to maintaining cultural traditions, it boosts rural economies and promotes socioeconomic growth. Because of its many contributions, sericulture is a viable and sustainable business for economic development in the present and the future.

# Current challenges: climate change, pest attacks, low efficiency Climate change:

Sericulture is seriously threatened by climate change as changes in temperature, humidity, and precipitation may have a negative impact on the production of silkworms and mulberries. Floods and droughts are examples of extreme weather occurrences that make these problems worse. The industry's viability depends on adaptation measures including creating mulberry varieties that are climate tolerant and putting microclimate management tactics into practice (Magno, 2015).

# Pest attacks:

The sericulture industry has been facing increasing numbers of pest and predator insects in recent years that affect silkworm larvae, as well as host plants for silk. The intensity and frequency of insect infestations have grown due to ecological disharmonies, monocultures, and climate change situations. These insects present two dangers: a direct decrease in silk production and a growing possibility of environmental pollution from indiscriminate pesticide use (Mandal & Singh, 1990).

Today, the sericulturists' biggest challenge is to ensure environmental safety and pest management. Chemical pesticides can disrupt the ecological balance, harm useful creatures, and make pests resistant to pesticides, even though they are sometimes unavoidable. Therefore, there is a need for a more targeted, sustainable, and ecologically sound approach.

IPM (Integrated Pest Management), appears in the form of a pragmatic and holistic means to address these pressing concerns. IPM invites a blend of mechanical, chemical, cultural, and biological approaches to manage pest populations at tolerable levels with the least possible adverse environmental impacts. It encourages methods that disrupt non-target organisms and natural habitats as little as possible and emphasizes the use of selective insecticides only after all other alternatives have failed (Singh et al., 2004).

In addition to more traditional approaches such as crop rotation and habitat management, current IPM programs employ new scientific techniques such as microbial biopesticides, autocidal methods, and pheromone traps. Possible means to non-toxic pest repellent are offered by the use of semi chemicals, which are chemical signals that affect insect behavior (Heong et al., 1995). For IPM to be effective, natural enemies such as parasitoids and predators need to be maintained and increased (Van Lenteren, 1986). Cognizant of the ecosystem as an integrated whole, IPM synthesizes all pest control strategies to ensure long-term sericulture growth (Van Lenteren, 1986).

The application of integrated pest management (IPM) is becoming a necessity as pest pressure intensifies due to climate change and agricultural development. Pest infestations can potentially jeopardize the silk harvest, farmer incomes, and environmental well-being if coordinated approaches are not applied. IPM in sericulture needs to be implemented on a large scale immediately, as evidenced by the recent outbreak of pest attacks. Its acceptance will depend on research, awareness generation, and government support, which will save silk production and ecological balance for centuries to come.

# Low efficiency:

The largest consumer of raw silk and silk fabrics, and the second-largest producer of raw silk after China, India finds itself well-established in the silk industry. The country annually produces about 18% of global raw silk, and in the year 2009–10, its silk exports earned approximately Rs. 2,892 crores. The United States, Japan, Spain, Germany, Italy, and Eastern Europe were its principal buyers of silk.

In spite of its extensive application, the Indian sericulture industry has experienced a gradual decline in both cultivated land and raw silk production due to primarily ineffective management methods. Indian silk yarn's poor production and quality are among the primary concerns, as these significantly affect its competitiveness on the International market. Not only has non- attainment of quality specs influenced export potential, but it also has created a domestic

preference for imported yarn. In addition, profitability of local production is additionally undermined by dumping of lower-cost Chinese silk in the Indian market. Enthusiasm and investment in sericulture have come down due to this influx, which has depressed local farmers and entrepreneurs. Inadequate infrastructure, absence of innovations, and a poor adoption of modern technology are all partly responsible for the issue, leading to low yields and inefficiencies throughout the value chain. To bridge these gaps, strategic interventions are needed in terms of propelling better silkworm varieties, improving rearing practices, enhancing post-cocoon processing, and strengthening market linkages. Enhancing training, R&D, and developmental schemes will enable India to regain its competitive edge in the global silk market and unlock its true sericulture potential.

# Need for a smart, technology-driven transformation

* + 1. **Precision Farming Techniques**

Precision farming technology is transforming silk production by improving efficiency and productivity via data-driven strategies. In sericulture, GPS, remote sensing, and data analytics are used for precise silkworm farming (Malo, 2022). GPS technology optimizes planting patterns and resource distribution by accurately mapping mulberry farms. Using drones and sensors to monitor silkworm health and environmental conditions in real-time enables tailored modifications to feeding, temperature control, and disease management (Narzary et al., 2022). Providing silkworms with optimal circumstances improves both the amount and quality of silk production. Analysis of historical and real-time data is critical for optimizing care methods, from egg incubation to cocoon harvesting (Schäfer et al., 2020). Using variable rate technology helps reduce waste and environmental effect by tailoring fertilizer and pesticide applications to individual requirements. Precision farming improves cocoon quality and silk output by controlling temperature and humidity (Manzoor and Qayoom, 2024). Successful integration of these technology reduces labor costs, waste, and improves farm management. As technology advances, enhanced precision farming in sericulture is projected to enhance sustainability, production, and efficiency. Precision farming in sericulture has advanced silk output by improving every element via data-driven strategies (Chozhan, 2022).

# Automation and Robotics

Automation and robots are improving efficiency, consistency, and sustainability in sericulture, the farming of silkworms for silk manufacturing. In the past, silkworm care was labor-intensive, from egg to cocoon (Farooq, 2023). However, AI-enabled automation and robots are

transforming sericulture techniques. Automated methods are used in sericulture, from egg incubation to cocoon harvesting. Robotic devices are being employed to feed and clean silkworms, replacing manual labor (Sharma et al., 2022). These methods provide a more exact and constant environment for worms, decreasing human error and increasing production.

Automation of temperature and humidity management systems enhances silkworm development and maximizes silk quality (Singh et al., 2023). In cocoon harvesting, sensor- equipped robotic systems effectively select and grade cocoons depending on size and quality, unlike human labour. This improves production speed and provides a more consistent end product. Automation also addresses labour shortages in sericulture zones (Buhroo et al., 2019). Automated technologies significantly reduce human labour, making sericulture more scalable and less susceptible to labour supply variations. Integrating data analytics and machine learning with automated systems enables real-time monitoring and modification of environmental variables, optimizing silk production. Robotics enhance sustainability in sericulture by reducing waste and improving resource management. For instance, automated feeding methods reduce feed waste and modern waste management systems effectively treat silkworm waste.

This decreases environmental effect and boosts sericulture's economic viability. Adopting automation and robotics in sericulture is challenging due to high initial investment costs and the necessity for experienced individuals to run and maintain these systems. Automation and robots are expected to become more important in the sericulture business as technology advances and prices reduce. Integrating these technologies brings substantial advancements in silk manufacturing, potentially improving efficiency, uniformity, and sustainability. The sericulture sector can fulfil rising silk demand while addressing environmental and economic issues by investing in innovative technology (Indora and Saharan, 2023).

# Application of artificial intelligence in sericulture

AI is transformative in sericulture, improving efficiency, production, and silk quality via data- driven strategies. AI technologies like machine learning and computer vision are used to more accurately monitor and evaluate silkworm production phases (Bhat, 2024). Example: AI- powered picture recognition systems can identify early indicators of illnesses or pests in silkworms and mulberry leaves, allowing timely interventions to avert outbreaks and reduce damage. Machine learning methods improve silkworm development and cocoon formation (Tassoni et al., 2024) by analyzing environmental variables including temperature, humidity, and light levels, resulting in more consistent and high-quality yields (Cappellozza et al., 2022).

In addition, AI-driven predictive analytics improve farm management by projecting trends and optimizing resource allocation, including feeding plans and harvesting timings. AI-powered automated devices reduce labour expenses and human error while optimizing silkworm conditions during feeding and cleaning. AI helps select and grade cocoons, ensures consistent silk quality via size, texture, and color assessment using advanced algorithms. Sericulture processes are more sustainable due to increases in efficiency, reduced operating costs, and waste reduction (Vasanth et al., 2024). Further advancements in AI technology in sericulture will lead to significant gains in silk output, resource management, and disease control. AI usage in sericulture is a huge breakthrough, leading to more intelligent and sustainable techniques.

# Biotechnological Advances

Sericulture has made significant success in using biotechnology to increase silk output using innovative genetic and molecular methods. In sericulture, selective breeding has been employed for centuries to improve silkworm traits relevant to silk production (Walia and Kaur, 2023). Biotechnological treatments, such as genetic transformation, marker-assisted selection (MAS), and transgenic silkworms, have revolutionized the silkworm business by allowing precise genetic modifications and optimization. According to (Sharma and Kapoor 2020), marker-assisted selection (MAS) involves discovering and exploiting genetic markers to improve silkworm qualities including silk output, fiber quality, disease resistance, and environmental adaptation.

MAS allows silkworm breeders to choose desired traits early in development, speeding up the breeding process and improving effectiveness and efficiency using molecular methods and genomic data. In sericulture, genetic transformation involves inserting foreign genes into silkworm genomes to create transgenic organisms with enhanced silk fiber properties. Recombinant DNA technology enables easier insertion of genes encoding traits such as silk production, fiber quality, or biocompatibility for biomedical applications. (Wani et al., 2018) Suggest that transgenic silkworms may be used in materials science, biomedicine, and agriculture to generate new products and sustainably manufacture silk.

# Current Status of Sericulture in India

One of India's most promising agro-based sectors is sericulture, which is well-known for its ability to provide both significant foreign currency and long-term rural employment. India, the

world's second-largest supplier of raw silk, is essential to the global silk industry, helping to strengthen rural livelihoods in addition to exporting textiles.

# Major sericulture states:

Silk production is concentrated in a few key Indian states:

* Karnataka: The top producer of mulberry silk, with well-developed infrastructure for rearing, reeling, and weaving.
* Andhra Pradesh: A leading state in both mulberry cultivation and silk reeling activities.
* Tamil Nadu: Known for its vibrant silk handloom industry and large-scale weaving clusters like Kanchipuram.
* Assam: The hub of Muga and Eri silk, reflecting the rich cultural heritage and biodiversity of the region.

Other significant contributors include West Bengal, Maharashtra, Manipur, and Jammu & Kashmir.

# Types of silk:

India is uniquely positioned as the only country in the world that produces all four major varieties of silk:

* Mulberry Silk: Dominates Indian silk production, accounting for nearly 72% of total output. It is cultivated mainly in southern states.
* Tasar Silk: A wild silk variety harvested in natural forests and tribal belts, especially in Jharkhand, Chhattisgarh, and parts of Odisha.
* Muga Silk: A golden-yellow silk unique to Assam, known for its natural sheen and durability.
* Eri Silk: Also called “Ahimsa silk” or “peace silk,” it is largely produced in the Northeast, especially Assam and Meghalaya, and is known for its thermal properties.

# Government initiatives: Central Silk Board (CSB), Silk Samagra.

Government initiatives are essential to the development of India's silk sector. These programs provide resources and financial assistance for a range of sericulture-related activities:

# Central Silk Board (CSB)

In order to tap the enormous employment opportunities in the value chain of the silk industry, the Government of India made a strategic move by setting up the Central Silk Board (CSB). This central organization is instrumental in promoting, developing, and regulating sericulture and silk production in the nation.

The silk industry has the singular advantage of being a low-capital, high-return enterprise, rendering it an appropriate source of livelihood for rural and semi-urban communities. Undertaking both on-farm operations (such as mulberry cultivation and silkworm rearing) and off-farm operations (reeling, spinning, weaving, and marketing), the industry presently offers employment to nearly 9.4 million individuals.

# The CSB executes numerous schemes and programs with the intent of:

* + - * Improving productivity and quality of silk
			* Promoting technological advancements in sericulture
			* Assisting in training and skill upgradation
			* Offering market access to silk producers
			* Promoting entrepreneurship and women empowerment

Through these efforts, the Central Silk Board keeps pushing inclusive growth, empowering rural India, and achieving socio-economic progress of the country through a thriving and sustainable silk industry.

# Silk Samagra

The government's Silk Samagra Scheme is a significant effort to boost India's sericulture sector. Its goal is to increase output by enhancing quality and productivity while empowering underprivileged, backward, and oppressed families via the nation's many sericulture initiatives.

# The scheme comprises four (4) major Components:

1. Research & Development, Training, Transfer of Technology and I.T. Initiatives,
2. Seed Organizations,
3. Coordination and Market Development and
4. Quality Certification Systems (QCS) / Export Brand Promotion and Technology Up- gradation

**Silk Samagra-2,** which has a budget of Rs. 4,679.85 crore for the years 2021–2022 to 2025– 2026, is an expansion of this endeavor. The whole silk manufacturing process—from rearing silkworms to creating high-quality silk textiles—is enhanced by these actions.

* + So far, Rs. 1,075.58 crore has been provided in central assistance, benefiting over 78,000 people.
	+ Financial support has been given to Andhra Pradesh (Rs. 72.50 crore) and Telangana (Rs. 40.66 crore) for the last three years to help with Silk Samagra-2 components.

**In addition to Silk Samagra-2, there are other schemes that support the silk and handloom sector:**

**Raw Material Supply Scheme (RMSS):** The Raw Material Supply Scheme (RMSS), a somewhat modified version of the Yarn Supply Scheme (YSS), has been authorized for deployment from 2021–2022 to 2025–2026. To provide qualifying handloom weavers with affordable, high-quality yarn and mixes. Under the Scheme, 340 lakh kg of yarn were distributed in total for the fiscal year 2023–2024.

**National Handloom Development Programme (NHDP): The National Handloom Development Programme (NHDP)** running from 2021-22 to 2025-26, aims to support weavers in the handloom sector, including silk fabric producers. The scheme takes a need- based approach to foster the integrated development of handlooms and improve the welfare of handloom weavers. It provides support for raw materials, design, technology upgrades, and marketing through exhibitions. Additionally, it helps create permanent infrastructure like Urban Haats and marketing complexes, benefiting weavers both within cooperatives and in Self-Help Groups.

**Scheme for Capacity Building in Textile Sector Scheme (SAMARTH):** This initiative, which was started by the Ministry of Textiles, is focused on placement and demand. With a budget of Rs. 495 crores, it is extended for two years (FY 2024–25 & 2025–26) to teach three lakh individuals. In addition to upskilling and reskilling in apparel and garmenting, handloom, handicraft, silk, and jute, the program emphasizes entry-level training.

# Production statistics and growth trends.

From 2017 to 2022, the state of Karnataka in south India was the top producer of raw silk, as shown in Fig 1 and Table 1. Tamil Nadu, West Bengal, Andhra Pradesh, Assam, and Meghalaya all shown consistent output during a five-year period. Raw silk output was lowest

in Sikkim. The remaining states displayed a declining raw silk production trend. Maharashtra state's silk output trended upward (Naphade et al., 2023).

*Table 1 State wise raw silk production (metric tons) in India for during 2017-2022 in metric tons (Statista Report 2023, CSB Report 2021)*

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **State** | **2017-2018** | **2018-2019** | **2019-2020** | **2020-2021** | **2021-2022** |
| Karnataka | 9322 | 11592 | 11143 | 11292 | 11,191 |
| Andhra Pradesh | 6778 | 7481 | 7962 | 8422 | 8834 |
| Assam | 4861 | 5026 | 5316 | 5450 | 5700 |
| Tamil Nadu | 1984 | 2072 | 2154 | 1834 | 2373 |
| West Bengal | 2577 | 2394 | 2295 | 872 | 1632 |
| Meghalaya | 1076 | 1187 | 1192 | 1213 | 1234 |
| Jharkhand | 2220 | 2375 | 2402 | 2185 | 1052 |
| Maharashtra | 373 | 519 | 428 | 428 | 523 |
| Manipur | 388 | 464 | 504 | 327 | 462 |
| Telangana | 163 | 224 | 297 | 309 | 404 |
| Uttar Pradesh | 292 | 289 | 309 | 316 | 355 |
| Mizoram | 83.6 | 92 | 104 | 43 | 315 |
| Chhattisgarh | 532 | 349 | 480 | 300 | 224 |
| Tripura | 87 | 230 | 111 | 86 | 113 |
| Odisha | 116 | 131 | 137 | 117 | 108 |
| Jammu & Kashmir | 132 | 118 | 117 | 80 | 99 |
| Nagaland | 615 | 620 | 600 | 264 | 59 |
| Bihar | 63 | 55 | 56 | 58 | 56 |
| Arunachal Pradesh | 54 | 59 | 64 | 43 | 53 |
| Uttarakhand | 35 | 36 | 40 | 25 | 42 |
| Madhya Pradesh | 103 | 100 | 61 | 47 | 28 |
| Kerala | 15 | 16 | 13 | 5 | 9 |
| Punjab | 3 | 3 | 3 | 1 | 3.5 |
| Haryana | 0.7 | 0.7 | 1 | 1 | 0.75 |
| Sikkim | 0.001 | 0.4 | 1 | 0.08 | 0.03 |

*Fig 1: State wise raw silk production in India for during 2017-2022 in metric tons*

# Need for Smart Sericulture Systems

14000

12000

10000

8000

6000

4000

2000

0

2017-2018 2018-2019 2019-2020 2020-2021 2021-2022

The sericulture business is entrenched in the socio-economic life of rural India, supporting livelihoods of millions of people. Nevertheless, conventional practices are subjected to mounting pressures from a cluster of interdependent challenges. Climate change, pest attacks, market volatility, wastages at the post-harvest level, and the absence of advisory services have taken a major toll on productivity, profitability, and sustainability of the sector. Under these circumstances, the call for a smart, comprehensive, technology-led transformation in sericulture has never been so pressing.

# Climate uncertainty impacting rearing cycles.

Silkworms are more sensitive to environmental conditions, where even slight changes in temperature or humidity can strongly affect their development and cocoon formation. Uncertainty of the climate due to global warming, uneven precipitation, and disrupted seasons has created disrupted rearing cycles, increased silkworm death, and lower cocoon yield.

Climate-conditioned rearing houses have emerged as a meaningful solution to this problem. Highly sophisticated structures, these buildings ensure scrupulous control over rearing conditions - temperature, humidity, lighting, and ventilation—creating an ideal environment for silkworm development. These houses enhance rearing performance, allow multiple crop cycles per year, and ensure round-the-year silk production by minimizing the adverse effects of weather (Buhroo et al., 2018; Rathna Kumari, 2022).

# Pest and disease management inefficiencies.

The host plants and silkworms are prone to numerous diseases, pests, and predators. If not immediately identified and addressed, these threats can wipe out entire batches, causing huge financial losses. Chemical pesticides are the backbone of traditional pest control methods, which are usually expensive, ineffective, and environment-damaging.

Pest and disease monitoring technologies combined with the Integrated Pest Management (IPM) approach offer a wiser solution. Silkworm health parameters and climatic conditions can be monitored in real time by IoT-based pest and disease monitoring systems. Abnormalities can be detected early on using sensors, cameras, and machine learning techniques, allowing more efficient and environmentally sustainable targeted interventions (Singh et al. 2023; Panwar, et al., 2022). Apart from reducing loss of crops, it helps to maintain ecological balance.

# Market price fluctuations and post-harvest losses.

Farmers' income from sericulture is extremely vulnerable to price fluctuations in the market. The absence of organized markets, inadequate storage facilities, and lack of organized trading networks lead to distorted pricing and exploitation. In addition, post-harvest losses caused by careless handling, storage, and transportation of cocoons and raw silk are the farmers' additional woes (Tesema & Fetene, 2024).

Smart sericulture systems mitigate these problems through:

* Digital Market Linkages: Websites that link farmers with buyers, processors, and exporters directly, providing fair prices and lower middlemen exploitation.
* Blockchain-based Traceability: Technology that increases transparency along the value chain, guaranteeing quality assurance and consumer trust.
* Cold storage and packaging technologies: These lower cocoons' spoilage and increase shelf life.

These systems allow farmers to make value-informed market choices, minimize reliance on local marketers, and receive premium prices for quality.

# Lack of real-time advisory support for farmers.

One of the biggest gaps in the sericulture ecosystem is the lack of real-time knowledge dissemination. Most farmers rely on outdated practices or delayed advice from extension services, leading to suboptimal decision-making.

To overcome this, mobile-based advisory platforms and AI-driven helplines are now being developed. These platforms offer:

* Instant guidance on rearing schedules, feeding routines, and pest control.
* Weather forecasts and alerts to prepare for climate impacts.
* Video tutorials and multilingual content for easy understanding.
* Chatbots and expert connections for personalized support.

This democratization of knowledge empowers farmers, especially smallholders, to become more self-reliant, skilled, and responsive to changing conditions.

# Proposed Smart Sericulture Framework

* 1. **IoT-Based Monitoring:**
* Variations in the environment are thought to play a significant role in the growth and development of silkworms.
* Temperature, humidity, and light intensity are three key parameters that affect how silkworms develop and each stage requires different forms of appropriate optimism.
* Irrigation to mulberry crop using soil and moisture sensor connected to this system make mulberry cultivation and silkworm rearing easier.
* The model aims to leverage automation and emerging IoT technology for smart sericulture.
* This model's unique feature is the improvement of a system that uses sensors to monitor temperature, humidity, and light power using Node MCU. If any of the parameters gets altered, the system notifies the user via a mobile application that connects to the internet in real time.



*Figure 2: IoT based smart sericulture proposed system (Source: Karthik Mani Bharathi & Susikaran, 2024)*

# Sensors for temperature, humidity, leaf moisture.

* + The DHT11 digital humidity and temperature sensor is an incredibly affordable, basic digital sensor for measuring temperature and humidity.
	+ This sensor provides a digital signal on the data pin and measures the temperature and humidity in the silkworm rearing house.
	+ The humidity will be monitored and managed by the controller with the assistance of sensor data.

# Real-time data for rearing house conditions.

Keeping the environmental conditions in silkworm rearing houses within optimal limits is essential for larval development and cocoon quality. IoT-powered real-time data monitoring systems are transforming conventional sericulture by facilitating constant monitoring of the primary parameters of:

* Temperature
* Humidity
* Light intensity
* CO₂ concentration
* Air circulation

These intelligent systems enable farmers to get instant warning and take prompt interventions using mobile applications or automated control units. Due to this, fluctuations that may result in disease outbreaks, stress, or mortality of silkworms can be reduced to a great extent.

Through the utilization of real-time environmental information, sericulturists are able to provide uniform rearing conditions, enhance silkworm health, increase cocoon production and quality, and ultimately profitability. This digital revolution is a major milestone toward precision sericulture and sustainable production methodologies.

# AI & Machine Learning:

**Artificial Intelligence:** It is the area of computer science that can mimic human intelligence and brain function, and it is used to computers that need to be able to solve problems, reason, make choices, and do other tasks that humans do. It is essentially a collection of algorithms and curtain rules designed to let the machine to learn from the input data.

**Machine Learning:** This system gains knowledge from historical data. It builds the prediction models and projects the outcomes for it as it gets new data. The amount of data used determines how effectively the result is anticipated since a bigger data set facilitates the development of a model that more accurately predicts the outcome.

# Applications in Sericulture

Technologies like artificial intelligence (AI), machine learning (ML), and deep learning (DL) are being used into sericulture and other related industries more and more. The silk industry is now taking use of the advantages that these technologies are providing, such as real-time monitoring, effective resource management, and precision farming techniques. They have prospective uses in sericulture, including decision assistance for ideal rearing circumstances, disease and pest prediction, and cocoon quality evaluation.

# Disease and pest prediction models:

The development of models of disease and pest prediction is among the primary applications of AI/ML in sericulture. Several diseases and pests can cause substantial reduction in the yield of silkworms as well as the crop they infect. Predictive models driven by AI can foretell pest or disease outbreaks based on sensor inputs, past data, and environmental factors. This reduces environmental impact and the requirement of chemical pesticides by facilitating timely preventative action. In entomology, where machine learning algorithms and X-rays are

employed to track pest infestation in seeds, such technologies have already demonstrated potential (X-rays) (Shah & Khan, 2014).

# Cocoon quality assessment:

The assessment of cocoon quality is another significant topic. Cocoon grading has traditionally been a time-consuming, manual process that tends to produce inconsistencies. Automated means of measuring cocoon size, shape, and shell ratio are offered by ML and DL-based image processing technologies. Silk becomes increasingly competitive in overseas markets due to these processes, which also enhance accuracy, minimize waste, and ensure uniformity in silk threads. The same image-based technologies are applied for quality control of agro-industries, e.g., detecting altered bottle labels in automatic processing (Kumar et al., 2020). The approach is analogous to advancements in these areas.

# Decision support for optimal rearing periods:

AI is also being promising as a decision-support tool for determining the optimal times for bringing up children. ML-based systems can recommend optimal plans for rearing by considering mulberry leaf availability, silkworm developmental stages, and weather. This enhances production, better silkworm health, and mortality risks reduction. Dairy farming, in which automated monitoring technologies are employed to determine milk production and animal well-being, already employs such decision support systems (Porto et al., 2015).

In addition, post-harvest operations such as thread processing and silk reeling are employing AI and DL technology. Automated technology is replacing conventional hand methods of silk reeling. This significantly increases production apart from improving consistency as well as lessening wastage. Moreover, IoT-based climate-controlled rearing homes allow for precise management of ventilation, humidity, and temperature—all key to the health and disease prevention of silkworms.

All things considered; sericulture is transforming from a traditional cottage industry to a forward-looking, data-driven enterprise through the adoption of smart technology. Such advances have the ability to enhance productivity, sustainability, and profitability while addressing long-standing issues such as insect infestations, labor inefficiencies, and climatic uncertainty. It can be supported by more intensive and internationally competitive sericulture industry through AI/ML/DL technologies, as in other agricultural industries such as horticulture and food processing (hi-tech nurseries) (Dorj et al., 2017).

# Drones and Remote Sensing Mulberry farm monitoring:

Drones, also known as Unmanned Aerial Vehicles (UAVs), are becoming more effective instruments for observing mulberry plantations, which are crucial to sericulture. By using real- time imagery, these remotely controlled or autonomous aircraft provide farmers with an effective substitute for conventional monitoring techniques, allowing them to evaluate crop health, growth phases, and field conditions. High-resolution aerial observation by drones’ aids in the early detection of water stress, nutritional shortages, and insect infestations. Their capacity to gather timely and comprehensive data enables well-informed decision-making, enhancing the productivity of silkworm rearing operations as well as the well-being of mulberry farms (Berner & Chojnacki, 2017; Ahirwar et al. 2019; Dutta et al. 2023).

# Aerial spraying and health mapping:

Precision agriculture has advanced significantly using drone-based aerial spraying, particularly in sericulture. Drones generate smaller droplets (200–250 µm vs. >1000 µm) than traditional knapsack sprayers, which ensures consistent chemical distribution while lowering resource consumption and chemical waste (Nansen et al., 2021). Significant gains in plant growth and output have resulted from this efficiency. In addition to reducing the possibility of pesticide exposure for farmworkers, drone spraying provides a more sustainable and safer alternative. In addition to increasing efficacy, advanced technologies like RNA-based pesticide delivery and electrostatic sprayers (Werner et al., 2020) also lessen their negative effects on the environment (Nandhini et al., 2022; Werner et al., 2020; Majumdar et al., 2021). The use of hexacopter drones to apply lime and bleaching powder at CSB-CTRTI in Ranchi, India, is a real-world example of this technology that shows how drones may transform field-level pest and disease control in sericulture.

# Mobile Applications & Digital Platforms:

**Farmer advisory services:**

SeriApp: SeriApp was created to provide field-focused solutions for Seri-farmers' advantage (Gowda et al., 2020). First of all, it serves as a guide for disinfecting silkworm rearing houses, enabling silkworm farmers to easily and accurately prepare disinfection solutions for the rearing house by calculating a very specific quantity of disinfectants of interest. No matter their level of education, farmers can easily input the length, breadth, and height of their different

rearing houses in the appropriate windows using the easy-to-use SeriApp. The built-in software calculates the input data in accordance with the established guidelines for the particular disinfectant (Balavenkatasubbaiah et al., 2014) and shows the results. The Seri-farmer may produce the necessary concentration and quantity of disinfection solutions according to the raising house's dimensions by simply clicking on the disinfectant of interest, which also shows the quantity of components to be taken. The software is the first of its type in sericulture and has a lot of room to grow (we are working on it in our lab) with modules tailored to various uses.

# Weather forecasts and alert systems:

For silkworms and mulberry harvests to be healthy and productive in sericulture, timely and correct weather information is essential. For sericulture producers, mobile apps with real-time weather forecasting and alarm systems have become indispensable tools. Localized predictions, early warnings of severe weather occurrences (such as heat waves, cold spells, or heavy rains), and temperature or humidity variations that may have an impact on silkworm rearing are all provided by these applications. Farmers may take proactive steps to modify rearing house conditions or better regulate irrigation and pests by getting timely notifications. In the end, these digital technologies assist minimize crop loss, avoid silkworm infections, and maximize cocoon output by bridging the gap between field-level activity and meteorological data. In isolated rural locations where access to conventional meteorological information may be restricted, these mobile platforms are very helpful.

# Blockchain for transparent pricing and traceability:

ReshaMandi is the first and biggest natural fiber supply chain in India, including all farmers, reelers, weavers, and merchants from farm to retail. Reshamandi is a corporation that offers it in six distinct languages. The software does not assist farmers in developing their skills while conducting sericulture operations; instead, it is only focused on commercial objectives rather than technology.

# Case Studies / Pilot Projects

* 1. **Case Study 1: Digital Sericulture Models under CSB**

The Indian Central Silk Board (CSB) initiated several pilot programs to make traditional sericulture practices more digital. One of these initiatives was the setup of Internet of Things (IoT)-based monitoring devices in rearing homes that would continuously monitor

environmental factors such as humidity and temperature. These models of digital sericulture, implemented in some areas of Andhra Pradesh and Tamil Nadu, involved traceability technology and mobile advisory services for assessing the quality of cocoons. Farmers experienced an increment of 20–30% in the production of cocoons and a reduction in the outbreak of diseases as a result. As evidenced through the success of these pilot models, the silk industry is able to modernize sustainably through the integration of traditional knowledge with digital technologies.

# Case Study 2: Use of Mobile Apps in Karnataka for Silkworm Disease Alerts

A mobile-based illness alarm system was implemented by Karnataka, India's biggest producer of mulberry silk, to assist sericulture producers. The smartphone app, which was created in partnership with the Department of Sericulture and regional agricultural institutions, gives farmers early alerts about potential silkworm illnesses based on field data and meteorological conditions. For professional investigation, users may also submit pictures of potential infestations. The app has enhanced disease monitoring and farmer knowledge since it was implemented, and it has dramatically decreased cocoon loss from bacterial and viral illnesses. As a vital decision-support tool for sericulturists, the pilot has already grown to include modules on pest control and weather forecasts.

# Case Study 3: Community-Based Smart Rearing Centers in Assam

The government established community-based smart rearing centers in Assam, a state famous for Muga and Eri silk, to assist small-scale farmers in using contemporary sericulture methods. These facilities provide training facilities, automated feeding trays, and climate-controlled surroundings. They are shared areas where farmers may raise silkworms together in ideal circumstances, and they are run by neighborhood cooperatives. In addition to improving cocoon quality and silkworm survival rates, the pilot initiative in the districts of Kamrup and Kokrajhar also lessened the financial strain on individual farmers. In order to promote group- based sustainable sericulture techniques, these smart rearing centers are now being duplicated in other Northeastern states.

# Climate-Resilient Model for Sericulture

Sericulture is not an exception to the growing issues that agriculture faces because to climate unpredictability. The raising cycles of silkworms, the quality of mulberry leaves, and the total yield of cocoons have all been negatively influenced by temperature fluctuations, unpredictable

rainfall, and extended droughts. As a result, a climate-resilient sericulture model is taking shape, focusing on sustainable, adaptable, and tech-integrated methods.

# Integration with IMD weather data.

The Indian Meteorological Department's (IMD) real-time weather forecasting capabilities, when combined with sericulture advising systems, have changed the game. By connecting mobile-based systems with IMD's district-level prediction data, sericulture departments may promptly notify people about changes in temperature, rainfall, or the possibility of pest outbreaks. These recommendations aid farmers in more efficiently scheduling leaf harvests, disease control measures, and raising times (Mohammad and Dey, 2025).

# Adaptive rearing schedules.

Another important tactic is to schedule silkworm rearing cycles in a way that adapts to the climate. Flexible windows based on regional weather patterns are replacing traditionally defined rearing periods. Larval survival rates and cocoon output are increased when rearing start dates are modified according to short- and medium-term weather forecasts, according to pilot studies conducted in Tamil Nadu and Karnataka (Jhansdakshmi and Rao, 2021). This dynamic method reduces the incidence of illnesses linked to humidity and heat stress.

# Development of stress-tolerant mulberry varieties.

Mulberry cultivars including "S13," "S36," and "V1" that can withstand heat and drought have been created by scientific organizations like the Central Sericultural Research and Training Institute (CSRTI). Under less-than-ideal circumstances, these types preserve leaf production and nutritional content, guaranteeing consistent silkworm development even in the face of heat waves or water shortages (Babu, 2018). When compared to conventional types under stress, the leaf biomass of these cultivars has increased by 15–25% in climate-sensitive zones.

# Sustainable waste and water management.

The use of organic waste and water conservation are essential components of climate-resilient sericulture. Resource efficiency is enhanced by practices including mulching, drip watering, and vermicomposting of sericulture waste (such as decomposed cocoons and silkworm litter). Another way to lessen the effect on the environment is to reuse the waste from silkworm pupae for fertilizer or animal feed. In mulberry farms in drought-prone regions of Andhra Pradesh and Telangana, micro-irrigation pilot projects have preserved harvests while conserving more than 40% of water.

# Challenges and Limitations

* 1. **High Initial Investment**

The use of smart sericulture technologies like IoT-based environmental sensors, automated silk reeling machines, drone-based spraying equipment, and climate-controlled rearing sheds needs huge capital. For marginal and small farmers, who make up a large majority of India's sericulture industry, such initial investments are prohibitive. Although the technology holds out the hope of long-term cost savings and efficiency, the absence of initial capital or availability of low-interest credit proves to be a huge discouragement. Lack of sufficient government subsidies or financing schemes is holding the uptake of smart technologies back.

# Digital Literacy Among Rural Farmers

One of the foundation problems in digital sericulture is low digital literacy among rural farmers. The majority are not aware of using smartphones, operating mobile applications, or reading digital advisory platforms' data. This digital deficiency hinders farmers from accessing decision-support tools for pest predictions, weather alarms, or monitoring cocoon quality. The absence of adequate training and extension services also contributes to this problem, diminishing the efficacy and relevance of these intelligent interventions.

# Infrastructure and Connectivity Gaps

Smart sericulture depends heavily on strong infrastructure like stable power supply, internet connectivity, and technical support services. Most sericulture-growing areas—particularly remote and tribal belts—lack proper connectivity and power supply. These restrictions make smooth functioning of IoT devices, mobile-based advisory systems, and automated machinery difficult. Without adequate infrastructural support, even the latest technologies cannot function up to their potential, causing disrupted services and farmer discontent.

# Policy Recommendations

1. **Digital India and AgriStack Integration Strengthened for Sericulture**

Integration of sericulture-related data onto national platforms such as AgriStack—designed to have a common database of farmers—has the potential to offer customized digital services to silk farmers. Connecting sericulture data (for example, plantation records of mulberry, breed usage of silkworm, and rearing cycles) with farmer profiles will enable delivery of farmer- centric advisories, predictive disease notifications, and input suggestions. This action will also facilitate traceability and quality control in silk production, improving competitiveness in the

global market. In addition, connecting the Digital India program with the programs of the Central Silk Board (CSB) will make sure that infrastructural and technological assistance extends to last-mile users.

# Public-Private Partnerships (PPPs) for Technology Deployment

Government agency partnership with research institutes (such as CSB, CTR&TI), agri-tech startups, and silk cooperatives can promote development and deployment of innovative tools in sericulture. PPP arrangements can drive large-scale diffusion of technologies like climate- controlled rearing houses, IoT-based monitoring systems, and AI-based pest prediction platforms. Private companies can also be used to enable manufacturing and servicing of low- cost, region-specific tools, and the public sector can ensure regulatory support and subsidies to drive down entry barriers.

# Farmer Capacity-Building Programs

Digital solutions are only so good as the capability of the users to use them. Therefore, capacity- building programs for digital literacy, smart rearing technologies, pest and disease forecasting, and market information should be made institutional. These programs should be provided through Krishi Vigyan Kendras (KVKs), CSB regional offices, and community-level smart rearing units, preferably in the local languages and by both in-person and digital means. Particular care must be taken of tribal sericulture areas in Assam, Jharkhand, and Odisha where digital penetration is low.

# Financial Support by Way of Subsidies and Insurance Schemes

For covering high capital expenses and climate-related risks, financial tools need to be increased and rendered sericulture-oriented. These are:

* + Subsidies on climate-resilient infrastructures such as automated rearing houses, drones, and cocoon drying machines.
	+ Insurance products covering silkworm crop damage as a result of pest infestation, disease infection, or weather aberrations.
	+ Credit-linking arrangements for marginal and small sericulture farmers to implement intelligent tools with low-interest credit.

Government programs such as PM Fasal Bima Yojana and Kisan Credit Card should be extended with customized modules for sericulture operations. Moreover, financing through

CSR (Corporate Social Responsibility) by textile and fashion sectors can facilitate sustainable silk value chains.

# Conclusion

The integration of artificial intelligence (AI), the Internet of Things (IoT), and other smart technologies into India's sericulture sector is a crucial step in creating a silk industry that is sustainable, climate-resilient, and competitive worldwide. Despite its rich history and strong roots in rural life, traditional sericulture is becoming more and more susceptible to contemporary issues such changing weather patterns, disease and insect outbreaks, dwindling land productivity, a lack of workers, and volatile markets.

The production, efficiency, and quality of silk may be greatly increased by smart sericulture systems that are based on real-time data analytics, adaptive rearing techniques, and precision- based resource management, as this research demonstrates. Technologies that are changing farm-level operations and enhancing post-harvest and market connections include drone-based aerial spraying, disease alarm smartphone applications, climate-controlled rearing buildings, and digital traceability systems. In the areas of illness prediction, cocoon grading, and decision- making assistance, AI/ML algorithms are very helpful. This makes sericulture more data-driven and less reliant on experience or conjecture.

Furthermore, new opportunities for smallholder silk producers to access financial inclusion, insurance coverage, and individualized consulting services are created by the integration of these technologies with national platforms such as AgriStack and the Digital India program. The full potential of smart sericulture, however, necessitates overcoming structural obstacles including expensive upfront investment costs, low digital literacy among rural farmers, and limited infrastructure in isolated areas.

Interventions from policy are essential to this shift. For the advantages of technological innovation to be dispersed fairly, assistance must be strengthened via targeted subsidies, insurance plans, public-private partnerships, and regional capacity-building initiatives. Promising outcomes have already been shown by pilot programs, including digital models backed by the Central Silk Board, mobile illness advising applications in Karnataka, and community-based smart raising centers in Assam. These initiatives provide scalable models for widespread use.

Finally, the sector is undergoing a complete transition with the use of smart sericulture systems, not just a technical advancement. It is an embodiment of the intersection of legislative change,

economic empowerment, ecological sustainability, and digital innovation. India may become a worldwide leader in sustainable, technology-driven silk production and preserve and revive its sericulture legacy if the proper conditions are met. There is a lot of potential for this change to enhance rural lives, encourage environmental conservation, and establish Indian silk as a high- end, cutting-edge commodity globally.

Disclaimer (Artificial intelligence)

Option 1:

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 the writing or editing of this manuscript.

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