Scientific Papers. Series D. Animal Science. Vol. LXIX, No. 1, 2026
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

ADVANCES AND INNOVATIONS IN SERICULTURE - A REVIEW

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Abstract

This review aimed to emphasize recent discoveries and advances in sericulture. Current trends in silkworms rearing include technological progress and a diversification of products. Innovations like genetically modified silkworms, automation, and precision farming techniques including drone technology and monitoring systems are increasing efficiency by further optimized mulberry cultivation and silkworm rearing. There`s a growing effort to use silkworm pupae and sericin for high-value applications in medical, cosmetic, and nutraceutical industries. Genetic engineering has enabled the manipulation of silkworm genomes. Through genetic techniques, scientists can precisely edit the genes responsible for the synthesis of silk proteins. The production of disease-resistant silkworm breeds is part of an innovative line. Automated systems, drive units and artificial intelligence algorithms have offering new opportunities in the field. New opportunities for enhancing silk production have been made possible by biotechnology. Advances in molecular genetics, biotechnology, and engineering are leaving their mark on the evolution of sericulture, making paradigm shifts vital.

Key words*: innovations, sericulture, silkworms, trends.*

INTRODUCTION

Sericulture, the science of silk production, has experienced a remarkable and unprecedented transformation over the past several decades. Sericulture has gradually developed into a complex, technologically advanced field from its beginnings as a traditional agricultural practice passed down through the centuries. These days, it incorporates developments from a wide range of scientific and engineering domains (Kiruba et al., 2024; Thrilekha et al., 2024). Such as, historically, silkworm rearing and silk processing depended largely on manual work, close observation, and practical, experience-based techniques. In contrast, the modern sericulture industry now operates at the crossroads of biotechnology, genetic engineering, materials science, informatics, and sustainable agricultural systems. This transformation mirrors global movements toward precision agriculture, increased automation, environmental stewardship, and the development of high-value, bio-based (Fatima et al., 2024; Kiruba et al., 2024).

The rapid advancement of sericulture is further propelled by a growing worldwide demand for specialized silk-derived products such as medical-grade fibers, sustainable textiles, and bifunctional proteins. This rising interest has pushed scientists and industry professionals to explore new, innovative strategies across the entire production chain, from silkworm rearing and mulberry cultivation to improved disease control, silk processing methods, and the value-added use of materials that were once considered waste (Adikesavan et al., 2025). As a result, sericulture has evolved into a vibrant and multidisciplinary domain that seamlessly integrates long-standing traditional practices with the latest advancements in science and technology. This convergence has transformed the field from a primarily agricultural activity into a sophisticated bioindustry that draws upon innovations in molecular biology, engineering, data science, and sustainable resource management (Savu et al., 2024; Bora et al., 2025).

The growing volume of literature reflects this transformation, documenting significant progress in diverse areas such as silkworm genome engineering, the development of highly automated and AI-assisted rearing systems, and the expansion of silk and silkworm-derived materials into new commercial and biomedical applications. Additionally, precision agriculture techniques, such as sensor-guided mulberry cultivation, environmental monitoring, and

data-driven farming, have further strengthened the efficiency and productivity of sericulture (Yu, 2025). Together, these advancements underscore the field's shift toward a more technologically advanced, economically valuable, and ecologically sustainable industry.

Although technological innovations show promising results their large-scale implementation may be constrained by high initial investment costs, the need for specialized technical expertise, data reliability issues, and limited accessibility in developing countries.

Drawing from contemporary research, industrial advancements, and global market trends, this work provides a comprehensive overview of the changing landscape of sericulture and its far-reaching implications for silk production worldwide (Arya and Sharma, 2025).

Traditionally rooted in agricultural craftsmanship, it has steadily evolved into a multidisciplinary field incorporating biotechnology, engineering, materials science, and sustainable agriculture. This review highlights recent discoveries and technological advances shaping modern sericulture, placing particular emphasis on innovations in silkworm genetics, automated rearing systems, diversified product utilization, and precision farming. Drawing from contemporary research and industry developments, the following pages provide a detailed overview of the new directions in sericulture and their implications for global silk production (Kiruba et al., 2024; Lazar et al., 2025).

The objective of this review is to examine and synthesize recent scientific and technological advancements that are reshaping modern sericulture. Specifically, it aims to analyses innovations in silkworm genetics, automated rearing technologies, precision mulberry cultivation, and the emerging high-value applications of silk-derived biomaterials. By integrating insights from contemporary research, industrial developments, and global market trends, this review seeks to provide a comprehensive understanding of how sericulture is transitioning from a traditional agricultural practice into a multidisciplinary, technology-driven bioindustry with expanding economic, scientific, and environmental significance.

MATERIALS AND METHODS

Current findings in the field of sericulture, the review of 120 publications highlights a shift from traditional rearing to a high-tech, bio-based industry. High-impact journals (PubMed, Google Scholar, Research Gate, MDPI, etc.) from 2016 to 2025 were used to compile the data, with an emphasis on the last two years.

Keywords such as "silkworms", "sericulture", "biodiversity" and "trends", "innovation in sericulture", "advancement" were used. Selection criteria for the publications included subject relevance and the language used (English).

RESULTS AND DISCUSSIONS

INTEGRATED SERICULTURE SYSTEMS

Integrated sericulture systems have transitioned from linear silk production to circular bioeconomy models that prioritize total biomass utilization. Specialized literature has centred on silk production (Altman & Farell, 2022; Fatima et al., 2024) and byproduct valorization (Kishore et al., 2024a). There is a growing need for a holistic perspective on the entire sericulture value chain.

This comprehensive review integrates every stage of the process, from the fundamental importance of mulberry cultivation as the primary nutrient source to the latest technological innovations in silkworm rearing and the systematic conversion of all process byproducts into high-value waste valorization streams. In this study, our intention consists on connecting the upstream (farming and reeling), midstream (textile weaving and dyeing), and downstream (recycling) segments.

Briefly, sericulture is no longer viewed as a linear production process but as a circular bioeconomy. A holistic perspective integrates the following critical stages (Figure 1).

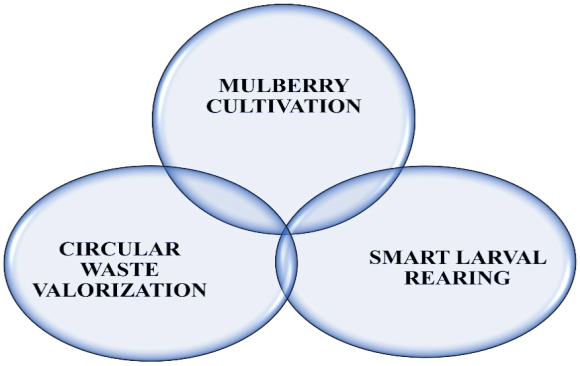

Figure 1. The integrated sericulture circular bioeconomy model (original)

1. Mulberry cultivation: moving beyond simple farming, modern practices emphasize sustainable, nutrient-dense cultivation of *Morus* spp. as the foundation for high-quality silkworm development. Mulberry (*Morus* spp.) is the foundational nutrient source for silkworms (*Bombyx mori*). Modern strategies focus on eco-friendly cultivation, utilizing organic fertilizers derived from recycled sericulture waste to improve soil fertility and leaf quality (Ayman, 2024; Hassan et al., 2025; Rajendran et al., 2025).

Highlighting the discrepancies in reported results is crucial. In practice, the performance of irrigation and fertilization systems varies based on local soil chemistry, water standards, and specific mulberry varieties. Therefore, theoretical findings often diverge from the inconsistent yields reported by farmers operating in different environments (Garai, 2025)

2. Smart silkworm larval rearing: has transitioned into a highly automated, data-driven discipline. Modern sericulture now exploits the "Precision Rearing" model, integrating Internet of Things (IoT), artificial intelligence, and advanced genetics to stabilize silk production against climate volatility while maximizing cocoon quality. Current advancements focus on automated monitoring, climate-controlled environments, and genetic improvements to enhance larvae health and cocoon quality (Dhanapriya, 2025; Veenita et al., 2025).

While Integrated Sericulture Systems offer clear benefits, switching to a high-tech model is difficult due to high costs. For small farmers, such as those in Romania, the price of IoT and AI tools is often too high without government help. This limits these advanced methods to wealthy research centers and large farms, making it hard to grow the industry globally (Manju & Binson, 2024; Garai, 2025). Additionally, high humidity can damage sensors, causing data errors. Finally, these systems require expert workers; without proper training, automation may actually cause more problems than it solves (Reddy et al., 2025a; 2025b)

3. Circular waste valorization: the transition of sericulture toward a circular bioeconomy has fundamentally redefined waste as a primary economic driver. By systematically valorising byproducts, the industry now generates multiple high-value revenue streams while significantly reducing its environmental footprint (Shravanilakshmi et al., 2025a). The industry is transitioning from a traditional linear model to a multidisciplinary field where sericulture supports diverse sectors like biotechnology and pharmaceuticals.

1. MULBERRY CULTIVATION ADVANCEMENT

Modern mulberry cultivation has transitioned from traditional agrarian methods to a highly sophisticated, data-driven science. The focus of *Morus* spp. cultivation has shifted toward maximizing leaf quality through precision technology and sustainable soil management, as the nutritional profile of the leaf directly

determines the quality of silk produced by the silkworm (Garai & Sadhu, 2025).

Among the benefits of organic mulberry cultivation, we can highlight: 1) enhances soil health and long-term productivity**:** organic fertilizers and composting enrich the soil with essential nutrients and organic matter, fostering a robust foundation for sustained agricultural yield; 2) improves soil structure and nutrient content: composting and green manure applications increase water retention and aeration, leading to healthier plant growth and reduced need for external inputs; 3) provides a sustainable source of nutrients for plants**:** these natural practices create a closed-loop system where waste is recycled into valuable fertilizer, ensuring continuous nutrient availability; 4) reduces dependency on chemical pesticides: biological pest control lessens costs and health risks associated with synthetic chemicals, leading to a more resilient farming system (Ahammed et al., 2025).

The modern practice in mulberry cultivation takes into account the following:

- Integrated Nutrient Management (INM): Modern practices combine organic manures like compost and green manure with scientifically calibrated doses of chemical fertilizers. INM has been shown to increase leaf yield by up to 22% while improving microbial activity and nutrient cycling, leading to foliage that is richer in protein and soluble sugars, key components for larval growth (Giora et al., 2022; Hăbeanu et al., 2024).
- Precision Soil Health Monitoring: Farmers can utilize IoT-based soil sensors to track pH, moisture, and specific nutrient levels such as nitrogen, potassium, and zinc in real-time. This allows for "prescriptive fertilization", where nutrients are applied only where and when needed, preventing over-fertilization and ensuring the optimal soil pH of 6.2 to 6.8 is maintained (Reza et al., 2025; Chen et al., 2025).
- Nano-Fertilizers and Foliar Spray: Nano-fertilizers deliver nutrients slowly and precisely to plants, preventing waste and protecting the environment. Multi-nutrient foliar sprays are also increasingly used to bypass soil-related limitations, directly boosting the chlorophyll content and moisture retention of the leaves (Kekeli et al., 2025; Goyal et al., 2025).
- Smart Irrigation Systems: Traditional flood irrigation is being replaced by smart drip irrigation, which delivers water directly to the root zone. These systems have improved water-use efficiency by approximately 35%, ensuring consistent moisture and reducing plant stress, especially in drought-prone regions (Rahman, 2025; Ali et al., 2025).
- Biotechnological Advancements: Genomic editing tools are being applied to develop mulberry varieties with enhanced photosynthetic efficiency and resistance to environmental stressors like soil salinity and extreme temperatures. These genetic improvements ensure that the leaves remain nutrient-dense even under challenging climatic conditions (Mangammal et al., 2025; Liu et al., 2025).
- Integrated Pest Management (IPM): in sericulture has evolved into a sophisticated, multi-layered framework that prioritizes the health of both the mulberry ecosystem and the silkworms (*B. mori*). This transition is increasingly supported by digital traceability and eco-friendly interventions (Kishore et al., 2024b).
- Drone-Assisted Field Management: Drones equipped with multispectral cameras are deployed to monitor large mulberry plantations. These drones can identify early signs of nutrient deficiency or disease outbreaks that are invisible to the naked eye, allowing for early, targeted interventions that save up to 28% in pesticide costs (Ahmed & Hossain, 2024).
- Soil-Less Cultivation Technologies: Innovations in hydroponics and aeroponics are enabling the year-round production of mulberry leaves in controlled environments. These soil-less systems are particularly valued for their ability to produce highly palatable leaves with increased medicinal components like 1-deoxynojirimycin (Baciu et al., 2025; Tricase et al., 2025).
- Sustainable Waste Recycling: in sericulture involves transforming byproducts like silkworm litter, leftover leaves, and pupae into valuable soil amendments such as biochar and nutrient-rich compost. This approach is central to a circular economy model, which improves soil health and enhances the long-term resilience of mulberry plantations ([a]Kaushik et al., 2025).

- Climate-Resilient Agronomy: has become the primary defence for the silk industry against environmental volatility. By integrating specialized genetics with advanced soil management, sericulture achieves stable leaf production despite increasing global temperatures and erratic rainfall (Kruthika et al., 2025).

2. LARVAL REARING INNOVATIONS

Larval rearing has fundamentally transitioned from a traditional agricultural practice to a sophisticated, technology-driven bio-industry (Reddy et al., 2025a; Arya & Sharma, 2025). This evolution is characterized by three pillars: i) integration of cutting-edge biotechnology; ii) intelligence automation; iii) circular economy principles (Kotsou et al., 2024; Reddy et al., 2025a). These advancements have significantly enhanced the productivity, efficiency, and sustainability of silk production, driven by a convergence of genetic engineering, automated environmental controls, and zero-waste models (Reddy et al., 2025a). The goal is no longer just producing silk, but creating a resilient and highly efficient value chain that can withstand modern environmental and economic pressures (Kaza, 2024; Reddy et al., 2025a).

The application of biotechnology in sericulture has undergone a profound shift, moving beyond passive data collection to proactive, intelligent decision-making systems. This transformation is particularly evident in the development of "super-industrial" silkworms, a term used to describe genetically optimized strains. The ability to monitor processes in real-time and apply genomic precision allows for unparalleled optimization of silk production. This new paradigm ensures maximum yield and quality while minimizing resource input and environmental impact (Thanga et al., 2025).

A key aspect of these biotechnological advancements is the widespread adoption of genome editing tools like CRISPR/Cas9, a revolutionary gene-editing technology, derived from a bacterial immune system (Chen et al., 2024). CRISPR-Cas9 driving significant advancements in medicine, and transforming agriculture with climate-resilient crops. This technology enables scientists to precisely modify silkworm genes, moving beyond traditional breeding's limitations. Specific modifications aim to enhance crucial industrial traits, such as increasing the raw fiber strength, improving tensile elasticity, and building resistance to pervasive environmental stressors and diseases. These engineered silkworms represent a new generation of robust, high-performance biological assets (Fan et al., 2025; Reddy et al., 2025b).

Scientists have also developed transgenic silkworms that produce specialized, high-value fibers. Furthermore, scientists have created strains that produce naturally fluorescent or colored silk, effectively eliminating the environmental need for chemical dyes and streamlining the production process. This innovation not only adds value but also aligns with the growing demand for eco-friendly manufacturing practices (Kiruba et al., 2024).

Modern rearing facilities utilize PCR and LAMP diagnostics to detect pathogens like pébrine at early stages, shifting disease management from reactive to proactive. These molecular tools safeguard high-value genetic investments by enabling rapid intervention, effectively preventing widespread crop losses and ensuring production stability (Fu et al., 2016).

The advent of precision sericulture utilizes the IoT and AI to create optimal, stable environments (Kaya, 2024). Modern facilities, often referred to as "smart rearing houses", use sophisticated IoT sensors to continuously monitor and automatically regulate key parameters such as temperature, humidity, and CO_2 levels in real-time. This data-driven approach ensures optimal growth conditions for the silkworms, leading to consistent, high-quality cocoon production and reducing the variability associated with manual management (Kaya, 2024).

Automation extends beyond environmental controls into the physical handling of the process. The introduction of automated silk reeling machines and robotic harvesters has significantly reduced manual labour requirements while ensuring high thread uniformity and minimizing waste. These automated systems increase efficiency, lower operational costs, and help maintain the strict hygienic standards necessary for disease prevention in large-scale operations (Saikia & Kaushiki, 2024). Sericulture adopts circular economy principles by transforming waste like

protein-rich pupae into high-value aquaculture feed, pharmaceuticals, and cosmetics. Furthermore, the industry repurposes sericin from wastewater into biocompatible materials for skincare and tissue engineering, turning former pollutants into sustainable, revenue-generating biomaterials (Hăbeanu et al., 2024; Lazăr & Pătruică, 2025). Finally, the sericulture industry has reached peak efficiency by integrating IoT-driven smart rearing houses and robotic management, reducing manual labour by over 80% while utilizing AI diagnostics to detect diseases with 99% accuracy (Reddy et al., 2025b). Despite the implementation of sophisticated models, such as Support Vector Machines combined with Histogram of Oriented Gradients and Kernel Principal Component Analysis (KPCA) proposed by Manju and Binson (2024) significant variability in outcomes remains a critical challenge. Improvements in cocoon yield and disease resistance are often dependent on climatic conditions, silkworm strains, and regional infrastructure; therefore, the high productivity increases reported in controlled studies may not be consistently reproducible across all production systems (Garai, 2025).

Environmental sustainability is prioritized through organic cultivation and green enzymatic processing, complemented by the development of climate-smart, heat-tolerant breeds that maintain high productivity in fluctuating temperatures (Reddy et al., 2025a).

3. CIRCULAR WASTE VALORIZATION

The sericulture industry has transitioned to a "*Pharma-Farming*" model that treats every byproduct as a high-value resource rather than waste. This circular approach is driven by the following key pillars:

- **Nutrient cycling and soil health**: silkworm litter (excreta and residual leaves) is processed into liquid organic manure or vermicompost and reintroduced into mulberry fields. This sustainable cycle improves soil structure and reduces reliance on chemical fertilizers while enhancing the nutritional quality of mulberry leaves (Shravanilakshmi et al., 2025b).
- **Functional byproduct valorization**:

Sericin Recovery: once a wastewater pollutant, sericin is now recovered for high-end biomedical and cosmetic applications, including use as a scaffold for tissue engineering and a moisture-retaining agent in anti-aging skincare.

Sericin used to be thrown away as waste from silk production, but today it is seen as a very valuable material for science and medicine (Chetia et al., 2025). This protein, which acts as the gummy binder holding silk fibroin fibers together, was traditionally chemically stripped and discarded, creating a significant environmental burden in the sericulture, however, advanced extraction methods and a shift toward circular economy principles have transformed sericin into one of the industry's most valuable functional byproducts (Darith, 2025). This paradigm shift not only solves a long-standing disposal problem but also unlocks new, high-margin revenue streams that align with global demands for sustainability and natural ingredients.

The sustainable recovery process fundamentally aligns with the industry's overall commitment to reducing its environmental footprint and maximizing resource efficiency, proving that industrial byproducts can become premium, sought-after biomaterials (Dragojlov et al., 2025).

The integrated approach not only minimizes waste and environmental impact but also significantly enhances the economic viability of silk production, driven by a convergence of technological innovation and circular economy principles (Dragojlov et al., 2025).

Pupae protein: silkworm pupae have transitioned from a low-value byproduct to a cornerstone of the circular bio-industry, providing a sustainable, high-protein alternative to traditional animal feeds. Generating roughly 6 kg of pupae for every 1 kg of raw silk produced, the industry now utilizes this vast biomass to reduce global dependency on fishmeal and soybean meal in aquaculture and poultry sectors (Hăbeanu et al., 2024; Naan et al., 2025; Xue et al., 2025). Pupae meal is not only nutrient-dense but also acts as a natural growth promoter, improving weight gain, specific growth rates, and feed conversion ratios while significantly lowering mortality rates. The "Pharma-Farming" model further elevates this byproduct by extracting high-value pharmaceutical proteins and health supplements ([b]Kaushik et al., 2025; Gokulakrishnaa et al., 2025).

Beyond bulk nutrition, biotechnological advancements allow for the precise extraction of bioactive peptides and omega-rich oils for specialized industrial use. Silkworm pupae oil, which can contain up to 44% alpha-linolenic acid (omega-3), is now a primary ingredient in anti-aging cosmetics and nutraceuticals designed to lower blood sugar and blood pressure. These oils and peptides also serve as functional food ingredients, acting as natural α-glucosidase inhibitors to manage post-meal glucose levels, thereby addressing the rising global demand for metabolic health solutions (Gokulakrishna, 2025).

Innovative applications also extend into regenerative medicine and biomanufacturing, where pupae-derived materials are used as pharmaceutical scaffolds for tissue engineering. Bioengineered hydrogels incorporating pupae extracts demonstrate potent antioxidant and anti-inflammatory properties, significantly accelerating wound closure in diabetic models by enhancing tissue re-epithelialization and vascular growth (Geng et al., 2025).

- **Resource and water efficiency**: advanced water management has become a pillar of large-scale sericulture, achieving up to a 35% increase in water-use efficiency through the systematic recycling of reeling effluents. Once considered a waste product, this nutrient-rich wastewater, packed with proteins like sericin and essential minerals, is now treated and redirected for the irrigation of mulberry fields. This "closed-loop" approach significantly reduces the industry's dependence on primary freshwater sources, such as borewells and surface water, while providing a reliable moisture supply that is resilient to climate-induced scarcity (Ashrith et al., 2025).

The adoption of these circular practices extends beyond simple conservation, acting as a "liquid biofertilizer" that enhances both soil fertility and crop productivity. Modern operations utilize real-time sensors and AI-driven predictive algorithms to optimize the delivery of this reclaimed water, ensuring that it meets the precise needs of different mulberry varieties while preventing salt accumulation. By transforming reeling effluents into a strategic resource, the sericulture industry not only mitigates its environmental footprint but also stabilizes the entire value chain, fostering a sustainable model for high-efficiency silk production (Ashrith et al., 2025).

ECONOMIC, SOCIAL AND ENVIRONMENT IMPACT

Advancements in sericulture have profound economic, social, and environmental effects.

Economic impact. Modern techniques, such as AI-driven precision farming and IoT monitoring, can increase productivity by 20-30% while significantly lowering operational costs.

The transition to integrated sericulture systems is significantly boosting rural economies by diversifying farmer income and tapping into high-growth biomedical markets. Integrated farming models allow farmers to maximize land use by cultivating secondary crops alongside mulberry trees.

Shifting from raw silk to diverse value-added products, such as silk fibroin for biomedical implants and biopharmaceuticals, is opening massive new revenue streams in non-textile sectors (Kairy, 2020; Mala et al., 2024). From a practical perspective, the initial expense for automated housing, IoT sensors, and climate control is often unaffordable for small-scale farmers without subsidies. However, economic feasibility depends on farm size, access to financial support, technical training, and market stability. Cost-benefit analyses are essential before adopting advanced automation technologies. For example, fluctuating of global silk prices can make it hard to predict the return on investment, creating financial risk for those with heavy debt from technology upgrades. Furthermore, high maintenance c**osts** increase long-term expenses compared to traditional methods.

Social impact. Sericulture is a primary vehicle for gender equity, with women making up approximately 58-60% of the workforce in major producing regions like India. Advancements provide women with flexible, home-based income, improving their financial independence and social status. The industry provides a stable livelihood for tribal and marginalized communities (Mala et al., 2024).

Environmental impact. Byproducts previously considered waste are now recycled: silkworm litter is used as high-protein animal feed or organic manure, and mulberry prunings are

composted into fertilizers, reducing reliance on chemical inputs. Innovations like drip irrigation and waterless dyeing technologies have drastically reduced the industry's water footprint. Perennial mulberry cultivation acts as a carbon sequestration and prevents soil erosion. Silk fibroin is increasingly replacing petrochemical-based plastics in various industrial applications due to its natural biodegradability and high mechanical strength (Popescu et al., 2025).

RECENT CHALENGES AND TRENDS IN SERICULTURE

Sericulture is currently confronted with a range of environmental, biological, and socio-economic challenges that threaten its sustainability and productivity. Climate change has emerged as a major environmental stressor, with increasing temperature extremes and unpredictable weather patterns adversely affecting mulberry cultivation, the primary food source for silkworms. Variations in temperature and humidity directly influence leaf quality, thereby impairing silkworm growth and cocoon yield. These climatic stresses are compounded by persistent disease outbreaks, notably pébrine and flacherie, which continue to pose a significant risk of large-scale crop losses. The transition toward mechanized rearing systems has further complicated disease management, as effective disinfection protocols remain technically challenging. Additionally, concerns over excessive water use and the environmental impact of chemical pesticides have intensified the need for sustainable waste management practices within the sericulture sector (Singh & Massey, 2025).

Beyond environmental constraints, sericulture faces pronounced socio-economic pressures. The labor-intensive nature of silk production has become increasingly difficult to sustain due to rural-to-urban migration, particularly among younger populations, resulting in a shortage of skilled labor. Market instability and fluctuating cocoon prices further exacerbate the vulnerability of small and marginal farmers. These economic challenges are intensified by competition from low-cost synthetic fibers, which continue to dominate global textile markets. Inadequate infrastructure, including unreliable electricity supply and limited access to high-quality, disease-free silkworm eggs, further undermines productivity and profitability. Consequently, there is a growing imperative for the industry to transition toward ethical, eco-friendly, and quality-driven production systems in order to align with evolving consumer expectations and global sustainability standards (Dhane et al., 2004; Singh & Massey, 2025). Despite these challenges, significant opportunities are emerging through the diversification of sericulture-based products. A biorefinery approach is gaining prominence, emphasizing the comprehensive utilization of sericultural by-products to enhance the overall value of the seri-economy. Silk-derived biomaterials and silkworm by-products have demonstrated considerable potential in high-value applications such as regenerative medicine, tissue engineering, medical textiles, drug delivery systems, and cosmetic formulations. In particular, silkworm pupae are increasingly recognized as valuable resources for therapeutic compounds, human nutrition, animal feed, and organic fertilizers. Moreover, residual sericulture waste is being explored as a renewable feedstock for sustainable biofuel production, contributing to circular economy models and environmental conservation (Jaiswal et al., 2020).

In summary, while sericulture faces mounting environmental and socio-economic challenges, technological innovation, sustainable management practices, and by-product valorization offer promising pathways for enhancing resilience, profitability, and long-term sustainability of the industry (Table 1).

Table 1. Constraints and technological trends shaping modern sericulture

Category	Key Issues / Trends	Impacts and Implications	References
Environmental & Biological Challenges	Climate change, unpredictable weather, temperature extremes	Degradation of mulberry leaf quality, reduced silkworm productivity	Singh & Massey, 2025
	Silkworm diseases (pébrine, flacherie)	High risk of disease outbreaks and potential total crop failure	
	Disinfection challenges in mechanized systems	Increased difficulty in disease control and hygiene management	
	Environmental pollution and resource use	Need for sustainable waste management due to pesticide use and high-water consumption	
Socio-Economic Challenges	Labor shortages and aging workforce	Reduced availability of skilled labor due to urban migration of youth	Singh & Massey, 2025
	Market instability and price volatility	Financial insecurity for small-scale farmers	Singh & Massey, 2025
	Competition from synthetic fibers	Decline in demand for natural silk products	Dhane et al., 2004
	Inadequate infrastructure	Unreliable electricity and limited access to disease-free silkworm eggs	Singh & Massey, 2025
	Changing consumer preferences	Need for ethical, eco-friendly, and sustainable silk production	Singh & Massey, 2025
Emerging Trends & Opportunities	Biorefinery approach in sericulture	Value addition through utilization of sericulture by-products	Jaiswal et al., 2020
	Use of silk by-products in healthcare	Applications in regenerative medicine, tissue engineering, medical textiles, drug delivery, and cosmetics	
	Utilization of silkworm pupae	Sources of therapeutics, nutrition, animal feed, and fertilizers	
	Sustainable energy solutions	Exploration of sericulture waste for biofuel generation	

CONCLUSIONS

Sericulture has transitioned from a traditional craft into a sophisticated bio-industry defined by "Precision Rearing". By integrating molecular biology, IoT-driven automation, and AI diagnostics, the industry achieves real-time environmental control and early disease detection.

Mulberry cultivation has evolved into a data-driven science using soil sensors, drones, and nano-fertilizers to optimize leaf quality. Precision irrigation and biotechnological breakthroughs, such as genomic editing and hydroponics, ensure a consistent supply of nutrient-dense, climate-resilient foliage.

Larval rearing now centers on "super-industrial" silkworms, genetically optimized via CRISPR/Cas9 for superior strength and natural fluorescence. Managed by robotic systems, these biological assets thrive in smart rearing houses featuring full environmental autonomy.

The industry has fully embraced a circular "Pharma-Farming" model, upcycling byproducts like sericin and pupae into high-value revenue streams. The zero-waste approach transforms potential pollutants into sought-after biomaterials, ensuring a sustainable and economically robust future for global silk production. Advancements in sericulture continue to reshape the industry into a sustainable, technology-driven bioeconomy with widespread global impact.

ACKNOWLEDGEMENTS

This research was funded by Romanian Ministry of Agriculture and Rural Development (MADR), grant ADER 24.1.3.

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