Chapter 3

Digital Silk: Embracing Innovation in Sericulture 4.0

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Abstract

Sericulture, an ancient silk producing process, has a long tradition and is adaptable to modern demands. The article looks at worldwide sericulture developments, with a focus on technology, sustainability, and market dynamics. Technological advancements are propelling the sector ahead, satisfying current customer needs while competing in an international market. Sustainability is becoming more essential, as techniques involving organic silk production and circular economy ideas are incorporated. However, sericulture confronts obstacles that may jeopardize its future possibilities. The essay makes proposals for policymakers, industry stakeholders, and researchers to ensure sericulture's long-term significance and growth in the global economy. This study examines the advancements achieved in biomedical and tissue engineering research involving silk proteins, notably fibroins and sericin. It highlights the potential of matrices made from non-mulberry silk from India for tissue regeneration and looks to the future of regenerative medicine and tissue engineering. The development of innovative methods such as organ-on-a-chip, microfluidics, bioprinting, 3D printing, and other applications based on electrical, optical, and thermal properties is another goal of the study. This review discusses the challenge of raising mulberry silkworms to produce silk while balancing environmental impact and production. Pesticides can have a negative impact on the environment, even if they are necessary for managing pests. Sericulture cultivation requires meticulous planning and collaboration in order to be sustainable. By using the right insecticides and looking into alternative pest management strategies, farmers may protect the mulberry silkworms' health and encourage long-term silk development. Sericulture natural products and byproducts have potential use in a number of fields, such as tissue engineering, regenerative medicine, medical textiles, drug delivery systems, cosmeceuticals, food additives, and biomaterial fabrication. Silkworm pupa has demonstrated potential in treatments, nutrition, cosmetics, animal feed, and fertilizer. Sericulture waste may also be utilized to generate sustainable biofuels, proving the value of traditional sericulture operations in the burgeoning field of biorefinery.

Keywords

Sericulture, Non-Mulberry Silkworm, Polylactic Acid Silk, Silk Farming

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1. Introduction

Silk has been a popular fashion item in recent years, and sericulture, a multidisciplinary activity, entails mulberry leaf production, silkworm rearing, egg generation, yarn production, twisting, weaving, finishing, garment design, and marketing. Sericulture is a labor-intensive, farm-based economic activity for rural farmers, business owners, and artisans. It is also a living culture. Rural residents, especially those with small landholdings and socially marginalized groups, benefit from the high returns on investment and employment it generates [1]. Technological advancements including genetic modifications and mechanization have improved the efficiency and quality of silk production. Nonetheless, eco-friendly practices like organic farming and waste recycling have been made possible by customer demand for sustainable textiles. These processes are threatened by climate change, and silk's hegemony in the market could be challenged by competition from synthetic fibres. Therefore, the industry's survival depends on sustainable textile production [2]. A type of mulberry silkworm called Bombyx mori L. is used in the ancient practice of silkworm farming for the production of silk. However, silkworm development and productivity are significantly impacted by environmental factors such as pests in the mulberry ecosystem that are managed with pesticides. Concerns are raised over the possible negative impacts of pesticide use on the environment and non-target insects like the mulberry silkworm. A balanced approach is needed to maximize output while reducing environmental impact [3]. In silk cultivation, preventive measures are essential for the health and productivity of silkworms. In order to control silkworm problems, disinfection is a crucial method since it eliminates harmful germs.The technique focuses on worm dwellings and regions where disease transmission is more likely during warm feeding. Final disinfection takes place after the conclusion of the current worm feeding season, especially in locations with a high incidence of infectious illness. Employing a mechatronic system in preventative actions enhances healthier silk production [4]. Sericulture generates a number of economically valuable secondary goods, including compost, human medicine, handicrafts, and cosmetics. The correct application of sericulture and silk waste adds up to 40% to the industry. Mulberry, the primary food plant of the silkworm Bombyx mori L., has high protein content, making it promising in the medicinal and food sectors. Cocoon craft by-products can help to develop human talents, create self-employment, and generate revenue [5]. The necessity to lower manufacturing costs for silk quality and value is emphasized. Mechanization at different stages, including tractor-powered mould-boards, disk ploughs, and Auger Diggers, may drastically cut labor costs. Power-operated sprayers improve efficiency and crop yield. Mechanization in the post-cocoon industry, which includes cocoon stifling, cutting, and spinning, can boost quality, production, and lower costs. This not only eliminates drudgery and labor reliance, but it also improves quality of life, minimizing overall production costs [6]. Bioinformatics is a computational tool for understanding biological processes, which frequently employs genetic sequences. While genomic and proteomic approaches have advanced our understanding of insect physiology, biochemistry, genetics, and evolution, obtaining a holistic picture of these processes remains difficult. Bioinformatics has also identified hidden omics traits in other species, leaving insects with a substantial knowledge gap. Bombyx mori, the first Lepidopteran species to have its genome sequenced, has attracted worldwide research interest [7].

2. Digital Silk: Embracing Innovation in Sericulture 4.0

Sericulture, often known as silk farming, is the practice of cultivating silkworms for commercial output. Temperature, humidity, and light intensity all play important roles in silkworm growth. Environmental differences also have an influence on growth. The Internet of Things (IoT) technology enables items to communicate over the internet via wireless smart phones. Automatic actuators such as exhaust fans, heaters, and sprinklers keep humidity and temperature levels within acceptable limits, allowing silkworms to grow and thrive [8]. A comprehensive view of the agricultural environment is provided by artificial intelligence (AI) algorithms that analyze data collected by Internet of Things (IoT) sensors on temperature, humidity, soil moisture, and crop health. While AI-powered anomaly detection helps identify issues with crop yield, predictive analytics predicts the results of fertilization and irrigation. Early detection of pest and disease symptoms using AI-powered image identification lowers crop losses. AI is incorporated into autonomous farming systems to perform precise tasks including as monitoring and planting [9].

Silk, the queen of textiles, is derived from silkworm cocoons. Silkworm development is temperature and humidity dependent. A novel prototype for silkworm incubators built on Raspberry Pi monitors environmental variables such as temperature, humidity, and brightness. The data gathered is stored for examination. This low-cost, high-capacity prototype promises to increase silkworm cocoon quality while also ensuring silkworm contentment [10]. Understanding the species' features and silkworm productivity is critical for improving sericulture operations. The Random Forest model captures complicated interactions between predictor variables utilizing a dataset containing information on silkworm production, leaf kinds, and species characteristics. Comparative assessments provide deep insights into each approach's forecasting potential [11]. Figure 1 below shows the real time monitoring of silkworms by employing IoT approach. Terahertz (THz) technology is being combined with AI to expedite its application in high-speed wireless communication, non-destructive testing, food safety inspection, and medicinal applications. Researchers may acquire insights into the interior anatomy of silkworm eggs using THz video imaging, with a deep learning algorithm accurately recognizing their development phases with high accuracy [12]. Visual recognition systems identify items by extracting key attributes from digital photos, which is very useful in agriculture for determining quality. AI technology, such as deep-learning approaches like convolutional neural networks (CNNs), has transformed picture identification. These algorithms may self-learn to extract feature points for each neural layer, increasing their performance in discrimination and image classification [13]. An agricultural business called sericulture breeds, raises, and grows silkworms to produce raw silk. In the past, sericulture was focused on producing a wide range of silk kinds, with leftovers being thrown away as waste. The therapeutic uses of sericulture products and byproducts include antimicrobial drug screening, life sciences, laboratory research, and environmental monitoring. The medicinal properties of silkworm eggs and larvae include intestinal fiber and substances that reduce blood sugar. Pupae of silkworms may be useful in treating cancer, hepatoprotection, and anti-aging [14]. Silk proteins, such as fibroin and sericin, are being researched for tissue engineering. Non-mulberry silkworm species such as Antheraea mylitta, A. assamensis, and Samia ricini have distinct features that make them promising biomaterials. These silk proteins include tripeptide motifs, making them excellent for tissue engineering. Sericin, which is extracted from these wild species, has distinct features and is employed in regenerative medicine as an anti-apoptotic and growth-promoting agent [15]. Natural fibers have been increasingly popular in green material development in recent decades as a result of worldwide concerns for sustainability and eco-friendliness. The transition from non-biodegradable to renewable sources is attracting scholarly and industry interest. Silkworm silk fibers, which are recognized for their biocompatibility, bio-resorbability, and biodegradability, are being utilized to create polylactic acid silk fibre bio-composites. Further advancement in processing, characteristics, and applications is required [16]. Current bone healing technologies have limits, necessitating the investigation of novel tissue engineering approaches. Tissue engineering employs biomaterials to produce scaffolds that mimic the natural bone environment, allowing cells to proliferate and differentiate. Silk proteins are a good candidate for 3D printing because of their mechanical strength and biocompatibility [17].

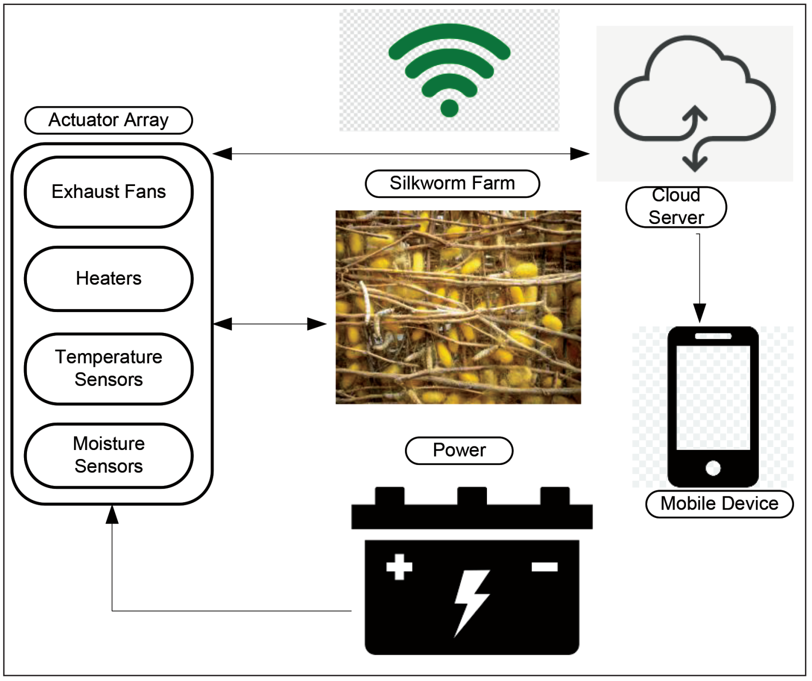

Figure 1. Real time Silkworm Monitoring by Employing IoT Techniques

3. Recommendations

Based on our thorough literature review on the current digital Sericulture practices, we propose the following recommendations for future.

- Sericulture, with its rich cultural legacy and major economic influence, must embrace environmentally responsible practices to maintain not just silk quality but also the health of ecosystems and surrounding communities.
- Promoting collaboration between scientific research, technological advancements, and stakeholder involvement can help create a balance between silk production, environmental stewardship, and social well-being. This guarantees that silkworms continue to thrive in the global textile industry, paving the path for sericulture's long-term viability.
- Functional sericulture, which substitutes silk-producing sericulture, improves patient care. Future modifications will result in a real biotechnology-based sericulture, benefiting the entire industry by enhancing functional aspects.
- The sericulture business could flourish in the global market by embracing technological improvements, encouraging collaboration, and emphasizing sustainability. Silk's enduring appeal, combined with contemporary procedures, will ensure that sericulture remains a viable and beloved sector for future generations.

- Sericulture is an important cash crop with little investment, a short gestation time, significant employment potential, and a remunerative return that is suited for all socioeconomic groups, including big and landless farmers, the elderly, youth, and the society as a whole.
- The sericulture industry is critical to rural employment, migration prevention, environmental protection, sustainable development, and socio-economic transformation.
- For sericulture, a significant part of our cultural past, to continue producing and maintaining its quality, it needs to adjust to contemporary machinery, sustainable practices, and current technologies. Mechanization can improve the working environment, reduce costs, and boost productivity—all of which affect people's quality of life in general.
- Seri-bioinformatics databases, such as SilkDB, MorusDB, WildSilkbase, KAIKObase, and SilkPathDB, provide essential resources for increasing silkworm health, disease resistance, and production via internet access to silkworms and related species.

Conclusion

Genetically modified silkworms and mechanical reeling techniques are two examples of technological advancements that pose challenges and potential for sericulture in the twenty-first century. Environmentally friendly projects like recycling waste and cultivating organic silk are propelling the industry's expansion. With these developments and a greater focus on sustainability, sericulture is now positioned as a key player in the global shift to responsible production. Environmental, physiological, metabolic, and financial problems arise from the long-term effects of pesticide treatments on silkworms. To effectively manage pests while preserving silkworm health and promoting environmental sustainability, a comprehensive strategy is needed. Non-target species and beneficial insects can be harmed by careless pesticide use, which can negatively impact biodiversity and natural ecosystems. Limiting adverse effects on beneficial insects and enhancing sericulture ecosystems need the integration of cultural techniques, biological control methods, and responsible chemical pesticide use. Despite the challenges posed by pesticide use, it also presents chances for creativity and cooperation in sustainable sericulture methods. Production of silk, a byproduct of sericulture, was the main focus of the ancient silk industry. The pupa, cocoons, and litter of silkworms are used to manufacture health drinks and dietary supplements. One of the proteic extracts from silkworm eggs is used in health drinks. Current research is looking at silkworm larvae for potential human pharmaceuticals, including anti-cancer and anti-diabetic medications. The study on predicting silkworm production using machine learning, artificial intelligence (AI), and different types and species of leaves produced valuable information for sericulture. It shows that the productivity of silkworms is significantly influenced by the type of leaf and that different species of silkworms respond differently to varied environmental conditions, necessitating specific methods. The vast amount of data in molecular biology that has been produced by advancements in genomic research tools and information technology has served as the basis for bioinformatics, which uses computational and statistical methods to get a deeper understanding of biological processes.

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