Chapter 5

Sericulture 4.0: Technology-Driven Silk Revolution

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Abstract

This article investigates the use of silkworms in textiles, biomaterials, bio-mimetics, and studies on host plants, pests, and illnesses. It investigates online resources for silkworms and allied species, their features, and their impact on research through citation count analysis, as well as the function of sequencing and analysis tools in seri-data science. Climate change is likely to have a substantial influence on Indian silk productivity and the economy. To guarantee long-term viability, researchers are concentrating on adapting genotypes to a variety of agro-climatic environments. Transgenic revolution, tissue culture, transcriptomics, proteomics, and metabolomics in mulberry will result in enhanced biotechnology farming techniques. Silk fibers, which are formed of proteins with mechanical characteristics, can be genetically altered for use in electrical and energy systems. Despite their promise, little research has been conducted into their inclusion. With worries about climate change and the need for renewable energy sources, silk-derived hybrid materials provide exciting research potential. This article investigates the synthesis of novel biomaterials employing proteins such as human collagen and spider silk, emphasizing the need of optimizing upstream processes as well as large-scale downstream operations such as freeze drying and autoclave. The long-lasting nature of recombinant silk and process economics are challenges, but increased demand for recombinant spider silk and human collagen presents potential. This chapter investigates Explainable Artificial Intelligence (XAI) in agriculture, emphasizing its relevance to the Indian economy and cultural legacy. XAI employs data-driven insights to improve crop management, resource allocation, and decision-making, ultimately increasing output and sustainability. It covers the distinctive challenges that farmers and stakeholders encounter.

Keywords

Sericulture, Silk-Derived Hybrid Materials, Thermoelectric Devices, Biomaterials, Surgical Threads, Silk Fibers, Bioinspired Fiber, Silkworm Illnesses

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1. Introduction

Sericulture is a critical business for rural development, providing year-round revenue and employment. It is an ecologically benign, labor-intensive, and commercially desirable agricultural activity. The industry, which comprises mulberry growing and textile manufacturing, has a lengthy supply chain, making it critical to the social and economic progress of rural communities. Its low start-up expenses make it an attractive alternative for cottage and small-scale businesses [1]. Mulberry silkworms, which have been extensively raised for several generations, have a remarkable capacity to adapt to challenging environmental circumstances. Raw silk production's sensitivity to climate change is determined by host plant physiological reactions, silkworm rearing, post-cocoon technologies, and variations in drought or flood frequency. Global warming has a substantial influence on silkworms and other beneficial insects since they play an important part in ecological functioning and contribute considerably to a country's GDP [2]. Silkworms, being ectothermic creatures, are temperature sensitive, which can influence their behavior, distribution, development, survival, growth, and reproductive success. Elevated air temperatures during the larval instars are a severe climatic issue for silkworms and cocoon yields. Mitigating these concerns is possible by using suggested silkworm rearing procedures [3]. Climate influences, including temperature, precipitation, humidity, soil moisture, atmospheric CO_2, and tropospheric ozone, will determine how global climate change affects plant-pest populations. Variations in sericulture production can be induced by plant or system-level variables, such as insect pest prevalence. Physiological reaction, silkworm rearing, post-cocoon technologies, and drought or flood frequency all influence the susceptibility of raw silk production to climate change [4]. Climate change and the depletion of fossil fuels are pushing the development of silk-derived hybrid materials for energy storage, conversion devices, flexible electronics, and photovoltaics. Despite its promise, silk has sparked little attention in hybrid energy uses. These materials are biocompatible, have high tensile strength, are renewable, tunable, multifunctional, and versatile in a variety of systems, including flexible electronics, thermal and thermoelectric devices, mechanical energy devices, sensors, and photovoltaic solar cells [5]. Bombyx mori silkworms were domesticated because their silk fibers may be used to make excellent fabrics. Engineers used regenerated silk fibroin to make biomaterials. However, the emphasis on Bombyx silk has obscured the various silk proteins made by more than a million other arthropods. Researches reveals Plodia interpunctella as an alternative silk source that could be readily raised in controlled conditions, allowing for higher consistency in silk production [6]. Bombyx mori silk fibroin is widely used in a variety of fields, including biomedical devices, optics, electronics, sensing, the food supply chain, and architecture. It has unique qualities such as biocompatibility, edibility, optical transparency, labile compound stability, and controlled conformation and degradation. Its role in the food supply chain and architecture is also being reconsidered [7]. **Figure 1** below shows an image of Bombyx mori silkworm. Commercial silkworm hybrids are evaluated based on cocoon features, resulting in only profit for sericulturists. However, by focusing on quality and quantity features in both cocoons and fibers, revenues may be guaranteed. Silkworm hybrids' paternal and maternal lines cross reciprocally, resulting in genetic variations that influence the ultimate number and quality of the cocoon and silk thread [8].

2. Sericulture 4.0: Technology-Driven Silk Revolution

Recent advances in sequencing and analysis have resulted in an increase in data and the development of data science techniques. This has led in the development of multiple databases, which are becoming increasingly popular in a variety of biological fields, including sericulture. Silkworms, an economically

Figure 1. Bombyx mori silkworm

important creature, are actively explored for their potential uses in textiles, biomaterials, and biomimetics. Host plants, pests, and diseases are also studied to better understand seri-resources [9]. India's historic sericulture has transformed from traditional ways to technology-driven smart sericulture. Artificial intelligence (AI) improves agricultural management, resource allocation, and decision-making, hence enhancing production and sustainability. It enables precision farming, which improves yields while saving resources. AI has advanced from Machine Learning to Deep Learning and Explainable Artificial Intelligence (XAI), increasing the sector's capabilities [10]. Deep fakes, AI and blockchain are a few instances of technological advancements that improve corporate performance and encourage organizational commitment. The textile sector, especially in India, is critical to the country's growth and prosperity. The factors of organizational devotion and new techniques are equally important in the sericulture business [11]. Biomaterials' suitability for biomedical applications is determined by their physical, mechanical, and biological characteristics. Non-immunogenic and biocompatible biomaterials are required for certain biological applications. Finding the right material is difficult. Making bio-composite materials from two recognized polymers is an effective way to integrate native polymer functionality. However, the qualities formed in the composite may not always satisfy requirements, hence it is critical to assess the material's unique features prior to application [12]. Silk has several natural and human applications, including surgical threads and wound dressings. However, the need for high-performance, organically derived biomaterials is growing because to the problems of considerable batch-to-batch variation, limited availability, high immunogenicity, and rapid biodegradation. To overcome these challenges, recombinant techniques to silk protein production have been devised, allowing for the generation of high-performance, naturally produced biomaterials [13]. Silk fibers have unique physical and biological features, which has prompted substantial study into genetic engineering, biotechnological synthesis, and bioinspired fiber spinning. The engineers intends to synthesize silk proteins on a large scale and improve their characteristics, potentially leading to improved synthetic biomaterial engineering and new biological and medicinal applications for silk [14]. Silk fibers are gaining popularity in a variety of industries due to its remarkable mechanical qualities, biocompatibility, and biodegradability. Modified silk has been created using genetically edited silkworms, notably spider silk genes. However, obstacles remain in terms of transformation tactics and DNA integration. Efforts to increase the mechanical characteristics of silk fibers by spider silk protein production are similarly limited by expression methodologies [15]. Reverse engineering of silkworm fiber has resulted in substantial advances in silk materials, converting silk fibroin into robust, adaptable, and resilient structures. This has expanded silk production techniques to encompass photolithography, digital light processing, and extrusion-based 3D printing. Silk may now be utilized for a variety of purposes, including ocular prosthesis, bio-adhesives, tissue engineering matrices, green biodegradable LEDs, batteries, on-skin sensors, and bioplastics [16]. Silk dyeing is an expensive and environmentally harmful procedure that produces waste water and has severe consequences. A transgenic silkworm approach that employs green fluorescent protein (GFP) has been created to make bright green cocoons while retaining silk's natural qualities. This genetically engineered silk may be used to make linear threads, 2D textiles, and 3D materials, increasing value while minimizing waste and conserving water. GFP genes can be substituted by different fluorescent proteins [17]. Nanoscience and nanotechnology are multidisciplinary sciences concerned with the control, manipulation, and structure of matter at the nanoscale, often known as the atomic or molecular scale. This new topic has broad ramifications for energy, aircraft, electronics, medicine, mechanics, optics, polymers, and textiles. Nanotechnology has the ability to defend against plant and silkworm illnesses, improve fabric performance, and enhance product performance by using nanoparticles during traditional sericulture processing procedures including finishing, coating, and dyeing [18]. Animal-derived polymers such as spider silk and human collagen confront supply issues as demand for sustainable products grows. However, investments in non-animal manufacturing systems are generating interest in biomedical applications. Optimization of upstream processes and large-scale downstream procedures, such as freeze drying and autoclaving, has enabled large-scale production and capacity development, with the goal of delivering hundreds of tons of product each year [19].

3. Recommendations

Based on our thorough literature review on the technology-driven Sericulture practices currently being implemented, we propose the following recommendations.

- Recent research indicates that mulberry fruits and leaves contain bioactive compounds such as alkaloids, flavonoids, steroids, and anthocyanins, which have antioxidant, antibacterial, and anti-inflammatory activities. These bioactive components' metabolic processes and responses to environmental challenges contribute to health advantages, opening up new avenues for pharmacological and natural product development.
- The research region endures sericulture concerns due to technical transfer gaps, market accessibility issues, and insufficient stakeholder relations. Supply-side constraints, including as technology, cost, labor, and market inefficiencies, jeopardize silkworm rearers' ability to generate money.
- Transgenic silkworms and functional food additives can produce reinforced and stronger silk, laying the groundwork for new possibilities. Biofactory and bioreactor techniques can generate this silk in a scalable and environmentally sustainable way, satisfying the requirement for continuous nano-biomaterial manufacturing.
- The development of drought-tolerant types and hardy silkworm races is critical for combating climate change and creating alternative livelihoods for tribal communities. Raising tasar host plants on private wastelands can store carbon while reducing crop loss, demanding government engagement.

- Exploration in recombinant collagens and recombinant spider silk has resulted in substantial advances in industrial bioprocessing, with both compounds now under development. However, more engineering of the molecules and host strains is required to fully exploit the promise of these interesting polymers.
- The demand for a recombinant collagen platform that reduces animal reliance is likely to grow, opening up new prospects for applications in industry.
- Nanotechnology has the potential to considerably transform the sericulture business, which provides a living for millions of people. Nanotechnology has the potential to greatly enhance production, productivity, and quality faster than traditional approaches.

Conclusion

Mulberry, a crucial crop for the Indian economy, is under severe stress across the world. Biotechnology has accelerated mulberry research by employing standardized tissue culture techniques to produce stable transgenic plants with critical features. The Morus genome resources provide unique candidate genes for producing stress-tolerant and disease-resistant plants, allowing for the generation of improved plants in response to changing climatic circumstances. This has resulted in additional suggestions for mulberry enhancement. Sericulture provides income-generating possibilities in rural and semi-urban areas, including low-income and socially disadvantaged communities and contributing to export earnings. It is critical for rural employment, minimizing migration, environmental conservation, socioeconomic change, heritage, and cultural values. The entire family may work, and downstream jobs like reeling and weaving grow in both households and organized companies. Sericulture also helps to protect the environment, preserve heritage, and enhance socio-cultural values. Silkworm engineering, using transgenesis and diet-enhanced techniques, can produce silk with reinforced or improved qualities that are not present in naturally occurring materials. This approach is comparable to metamaterials, which are intended to provide unique reactions. Negative refractive index and invisibility cloaks are examples of optical metamaterials with controllable electric and magnetic characteristics. Climate change has resulted in the extinction of several silkworm species, including mulberry, muga, tassar, and eri silkworms, which contribute considerably to a country's GDP through raw silk. The exact impact of climate change on the sericulture sector has yet to be determined, thus future study should focus on these areas to ensure the industry's long-term viability.

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