SERICULTURE 4.0

Advancing Silk Production with Cutting Edge Technology and Automation

Editor's

Anita Gehlot, Prof. (Dr.) Rajesh Singh, Vivek Kumar Singh

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Education 5.0: Shaping the Future of Learning in a Digital Age

Sericulture 4.0: Advancing Silk Production with Cutting Edge Technology and Automation

Editor's

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Preface

Sericulture 5.0 has developed as a transformative power, redefining the background of Sericulture the practice of raising silkworms to produce silk. It's an agro-based industry that involves both farming and industrial activities and pushing the limitations of its potential in across all businesses. At the juncture of farmer's training and learning, the quick developments in this field are not only transforming the way we understand and transform sericulture but also paving the way for innovative attitudes to farmers, businesses and other sectors.

The goal of this book, **" Sericulture 4.0-Advancing Silk Production with Cutting Edge Technology and Automation,"** is to give an in-depth review of the innovative advancements that are redesigning the Education sector. Each chapter explores the key themes that are propelling this change, from the advances in computer vision and tailored teaching and learning approaches to the cutting-edge uses of Innovative technologies.

ORGANIZATION OF THE BOOK

The book is organized to include 14 chapters. Details as follows

- **Chapter 1:** The study explores Sericulture 4.0, the traditional silkworm rearing industry, is evolving into a more environmentally friendly enterprise. Silk quality and production have increased thanks to technological advances such as genetic engineering, automated systems, and mulberry growing techniques. Artificial feeding and controlled surroundings for silkworms are examples of biotechnology's long-term applications. Nanotechnology has improved silk fiber quality, processing techniques, and the development of novel silk-based products. High-quality silk production is critical for achieving sustainable development by 2030. Integrating AI, machine learning, and blockchain technology is critical to a bright future.
- **Chapter 2:** The chapter explores sericulture's influence on humans and rural livelihoods, with an emphasis on economic, social, and environmental issues. It emphasizes the possibility for skill development, community involvement, and environmentally friendly ways. The article also addresses technological advancements that are revitalizing the silk business, such as mulberry rearing techniques, biotechnology pest management, and ecologically friendly technologies. It also highlights the importance of noninvasive approaches and the application of deep learning in illness detection systems. The chapter also covers high-throughput sequencing methods and mulberry genomics to boost production and quality.
- **Chapter 3**: The article investigates Sericulture, an old silk producing technique, is evolving to meet current demands through technical improvements, sustainability, and market dynamics. The sector is concentrating on biomedical and tissue engineering research, with Indian non-mulberry silk-based matrices showing promise for tissue regeneration. The research also looks into cutting-edge techniques including 3D printing, bioprinting, microfluidics, and organ-on-a-chip. Balancing production and environmental effect is critical, and pesticides are necessary for pest management. Sericulture's natural products and byproducts have the potential to be used in a variety of sectors, including regenerative medicines, tissue engineering, medical textiles, drug delivery systems, cosmetics, and food additives.
- **Chapter 4**: This study investigates the use of electrical technologies to improve silkworm rearing procedures, including the SeriFarm Automation System (SFAS), an IoT-based framework,

and a mulberry garden water fertilizer integrated machine. The SFAS automates facilities by monitoring temperature and humidity, which improves cocoon growth cycles. The mulberry garden water fertilizer integrated machine use artificial intelligence to maintain nutrient supply throughout the growing cycle. A cloud-based environmental monitoring system is also being developed for sericulture farms. The research also looks into silkworm features, structure, and uses in a variety of fields, including medicine, textiles, and the pharmaceutical, cosmetic, and healthcare industries.

- **Chapter 5**: This article explores the use of silkworms in textiles, biomaterials, biomimetics, and studies on host plants, pests, and illnesses. It highlights the impact of climate change on Indian silk productivity and the need for adaptation to various agroclimatic environments. The article also explores the potential of silk-derived hybrid materials, such as recombinant spider silk and human collagen, and the use of Explainable Artificial Intelligence (XAI) in agriculture to improve crop management, resource allocation, and decision-making, ultimately increasing output and sustainability.
- **Chapter 6**: This chapter explores sustainable textile technology and its implications for the developing world's textile industry. It explores neurobiological research, microbiomics, and environmental entomology, which focus on insect behavior, ecosystems, adaptation, and ecological balance. 3D-printed silk fibroin scaffolds offer benefits in wound healing, while AI-driven printing processes improve wound dressing accuracy, customization, and personalization. Traditional classifiers like SVM and KNN are examined for detecting silkworm pupae sex. These advancements have implications for sustainable ecosystem management and conservation policy.
- **Chapter 7**: Silk farming, or sericulture, has a 5,000-year history and is a sustainable business that raises mulberry trees for various purposes. It produces high-quality silk thread and high-protein foods for humans and animals. India is the world's only country producing muga silk, and the genome of the Bombyx mori silk moth was sequenced in 2004. Advances in genetics and analytical technologies have led to new discoveries in silkworm study and sericulture. However, synthetic fertilizers can degrade leaf quality and soil health, so natural or organic alternatives like compost and bio-fertilizers are being explored.
- **Chapter 8**: Sericultural digitalization, farmer enrichment, and agricultural growth are interconnected, with factors like population aging, industrialization, government support, and resident capability playing key roles. Integrated management policies can help rural communities overcome issues and foster long-term development. Hydrogels, like Silk Fibroin (SF), are popular in tissue engineering and regenerative medicine due to their biocompatibility and low immunogenicity. Silk proteins are also studied for their composition, structure, characteristics, and applications in 3D in vitro models and medicinal applications.
- **Chapter 9**: The study explores the potential of reintroducing ancient handloom processes into fashion culture to promote environmental, cultural, and ethical practices. It aims to involve disadvantaged populations, create fair employment, and improve rural areas' monetary flexibility. Silk-based scaffolds, which mimic extracellular matrix, are being explored for tissue regeneration and medication release. Researchers are also exploring silk sericin's bioactivities, potential for tissue engineering, neural soft tissue engineering, and neuro-protection. The study highlights the transformative role of biomaterial research in healthcare.
- **Chapter 10**: Silk Fibroin (SF) is a versatile material that can be reshaped into various shapes,

including films, carpets, hydrogels, and sponges. Recent advancements in fabrication techniques, such as micro-patterning and bio-printing, have enabled the development of sophisticated SF-based scaffolds for various applications. This study explores the functional features of SF, its preparation procedures, and its application in wound dressing, tissue engineering, sustained medication release, wound healing, adhesives, and bioelectronics. The study compares SF-based therapies to other natural polymers and aims to contribute to future innovation by encouraging the design of novel mechanisms and effective implementation of target applications.

- **Chapter 11**: This chapter explores silk fibroin's structural characteristics and its ability to create composites with natural materials like curcumin, keratin, alginate, hydroxyapatite, hyaluronic acid, and cellulose. It highlights silk's compatibility with natural additives and its potential applications in biomedicine and smart fiber technologies. The article also discusses silk nano-biomaterials, their applications in bio-cargo immobilization, chemo-biosensing, bioimaging, tissue engineering, and regenerative medicine. The chapter also explores an eco-friendly process for making mulberry spun silk fabric, focusing on reducing environmental impact and waste.
- **Chapter 12**: This study explores microencapsulation technology for using silk fibers, focusing on the adhesion between microcapsules and Silk fibroin (SF). It discusses the application and impact of this technology in various applications, including tissue engineering, degradable devices, and controlled-release systems. Silk materials can be converted into inherently nitrogen-doped and electrically conductive carbon materials, which have applications in soft electronics, bio-resorbable electronics, ultra-conformal bioelectronics, transient electronics, epidermal electronics, textile electronics, conformal biosensors, flexible transistors, and resistive switching memory devices. The study also explores new scaffold design techniques using SF and 3D-bioprinting technology.
- **Chapter 13:** Mulberry, a deciduous tree native to the northern and southern hemispheres, faces challenges from urbanization, industrialization, and global warming. To continue farming and provide income for rural people, contemporary biotechnological methods must be exploited to generate novel varieties with increased productivity and adaptability. Mulberry is cultivated for its economic value and sustainability, and is used in the sericulture industry for silkworm feeding and pharmaceutical, cosmetic, food, and beverage industries. Vertical farming techniques, such as hydroponic, aero-ponic, and aqua-ponic systems, can boost protein content in meals and extract beneficial phyto-therapy components.
- **Chapter 14:** The study aims to improve utilization and economic potential of Asian countries' abundant natural fiber resources by examining their availability, technological processing, and economic benefits. Collaborations between national R&D organizations, government policy makers, and academic institutions are crucial for producing national bio-products and advancing the circular economy. Sericulture, including mulberry agriculture and silkworm rearing, provides long-term employment opportunities and is profitable. The study also investigates the interior microstructure of cultivated and wild silkworm cocoons using X-ray micro computed tomography (XCT), revealing that fiber widths rise from the inner to outer layer, aligning better with the cocoon's small diameter for biomaterial development.

This volume brings together contributions from leading experts in the field, offering a comprehensive overview of the current trends and future directions in education sector. The chapters explore a wide range of topics, from cutting-edge research in teacher training and learning to the ethical considerations surrounding these advancements. Each chapter is designed to provide readers with in-depth knowledge and insights, highlighting both the opportunities and challenges that lie ahead.

We extend our gratitude to all the contributors who have shared their expertise and to the readers who will, we hope, find this book a valuable resource in understanding the emerging trends that are set to transform Education sector.

Rajesh Singh
Anita Gehlot
Vivek Kumar Singh
Abhishek Tripathi
Rajat Singh

Sericulture 4.0: Advancing Silk Production with Cutting Edge Technology and Automation

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Chapter 1

Transforming Silk Production: The Future of Sericulture 4.0

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Abstract

Sericulture 4.0, the rearing of silkworms for silk producing goods, has an extensive tradition and economic value. Technological approaches, including genetic engineering, automated rearing systems, and enhanced mulberry growing techniques, have substantially strengthened silk quality and production. Biotechnology breakthroughs have provided sustainable techniques, especially artificial meals and regulated environments for silkworms, hence minimizing the industry's ecological influence. Sustainable approaches involving organic sericulture, integrated pest control, and eco-friendly processing treatments are transforming the business into one that cherishes ecology. Sericulture 4.0 can maintain its tradition of luxury and economic importance while moving towards a more ecologically sound future by integrating these advances. Nanotechnology has transformed sericulture practices, increasing the quantity, quality, and potential use of silk. The article explores the impact of nanotechnology on silk fiber quality, processing methods, and the creation of innovative silk-based products. Nano-scale compounds may enhance silk's antimicrobial characteristics, prolong its shelf life, and have applications in medical materials. Nanotechnology also makes it easier to create silk-based materials with unique features including better electrical conductivity, controlled medication release, and biocompatibility. Sericulture, an extensive cottage industry, demands high-quality inputs involving seeds, nourishment, and skilled labor to run and produce effectively. Traditional approaches may involve manual phenotypic characteristic evaluations. High-quality silk fabrication is crucial for attaining sustainable development by 2030. This article emphasizes the significance of utilizing Artificial Intelligence (AI), machine learning, and blockchain technologies for a flourishing future and economy in the Sericulture industry. Integrating intelligent tools is essential for a flourishing future. This article presents a novel approach for predicting silk quality based on cocoon morphological parameters and the XG Boost algorithm. The technique predicts silk quality with excellent accuracy based on cocoon morphological parameters. The XG Boost algorithm assists in identifying critical characteristics, offering significant insights into the aspects that influence silk quality.

Keywords

Sericulture 4.0, Silk Fibers, Genetic Engineering, Silk Production, Transgenic Silkworms

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1. Introduction

Sericulture products and byproducts have become increasingly essential in the biotechnological, pharmaceutical, and biomedical sectors as sources of high-value innovative products. This provides opportunities for effective business expansion in the sericulture and seri-biotechnology industries. Young individuals and women may begin successful businesses, contributing to the workforce while working for themselves. This has the potential to reduce unemployment in rural and urban areas while also raising socio-economic levels [1]. The sericulture 4.0 sector is embracing biological control technologies to manage insect populations in an environmentally responsible way. These techniques employ natural enemies such as parasitoids, predators, and infections to reduce environmental pollution, preserve beneficial creatures, and promote sustainability. However, these strategies have drawbacks such as delayed action and environmental dependence. Effective implementation necessitates careful planning, interaction with other pest management measures, and continuous monitoring [2]. Biotechnological technologies involving genetic engineering and bio-nanotechnology have transformed silk production, improving its durability and output. The adoption of cutting-edge technology and diversification into medicines, cosmetics, and agriculture might increase sericulture's economic viability. However, research into by-product applications and the creation of sericulture 4.0 models is critical for industry sustainability and profitability. Balancing traditional techniques with technological innovations promises an exciting future [3]. Technological improvements including automated silk reeling equipment and climate-controlled rearing rooms have enhanced silk yield and quality. Farmers can obtain data in real time through digital monitoring systems. Genetic advances like as selective breeding and genetic engineering have resulted in disease-resistant silkworm breeds and a reduction in chemical dye usage. Organic farming and waste recycling are promoted as manifestations of sustainability [4]. Nanotechnology has transformed the silk business by allowing for molecular and atomic-level control over its characteristics. It has boosted silkworm health and growth by employing silver nanoparticles to combat diseases and boost immune systems. Furthermore, nanotechnology has substantially enhanced the mechanical, thermal, and optical properties of silk fibers. Furthermore, nanoscale molecules have given silk antibacterial properties, extending its shelf life and offering applications in medical materials [5]. Despite its infancy, nanotechnology has the ability to preserve plants and silkworms, improve textile performance, and improve fiber quality, nano-fiber and fibroin quality, cocoon quality, and nano-composite fibers. It can also improve product performance during traditional textile processing procedures and offer information on Nano textile qualities [6]. Silkworm seed generation is critical to silk farming, and correct sex categorization is necessary for breeding and increasing output. Traditional techniques entail manually sifting and breaking cocoons, which can harm them and reduce production. A non-destructive technique employs modified histogram of oriented gradients (HOG) features merged with weight features and processed through a machine learning model with recursive feature elimination (RFE) [7].

2. Transforming Silk Production: The Future of Sericulture 4.0

Genetic engineering is transforming silk production by manipulating organisms' genetic material to obtain desired characteristics. It has great potential in Sericulture 4.0, which raises silkworms for silk manufacturing. Scientists may modify the physical qualities of silk, including strength, elasticity, and glitter, by incorporating certain genes into the silkworm genome, resulting in superior-quality silk that fulfills textile industry demand. Genetically engineered silkworms generate silk fibers with improved properties involving tensile strength and durability [8]. Traditional breeding methods prioritize desirable characteristics including yield, silk quality, disease resistance, and growth rate. Transgenic silkworms, which incorporate spider genes, create silk with distinctive features like increased tensile strength. CRISPR technology, synthetic biology, artificial intelligence (AI), and machine learning advancements collectively promise greater precision in modifying genes. Nanotechnology and epi-genetics are emerging technologies that provide novel techniques to improving silk characteristics. Long-term goals include sustainable silk production, worldwide market dominance, and biodiversity protection [9]. Sericulture production, quality, and sustainability have dramatically as technology has advanced. Genetic engineering resources like as CRISPR-Cas9 have allowed for the alteration of silkworm genomes, resulting in increased fiber strength, yield, and resilience to environmental stressors. Disease-resistant silkworm breeds have also been established by selective breeding and genetic manipulation, resulting in more resilient silk production systems. These developments have transformed conventional sericulture techniques [10]. AI is transforming industries especially sericulture by addressing issues including disease, pests, gender categorization, and environmental conditions. To succeed in a changing world, the industry must adapt to new technologies. Advanced technologies like the Internet of Things (IoT), AI, machine learning, blockchain, and mechanizations are being employed to some extent. As AI develops traction, the sericulture business is projected to adopt these technologies [11]. Despite the favorable environment and skilled labor, traditional sericulture has obstacles like insect infestations, variable mulberry leaf yields, resource waste, and the consequences of climate change. AI and drone surveillance are technological advancements that can assist in addressing these challenges. Drones equipped with cameras and GPS can maintain fully grown mulberry farms, while AI systems analyze data to optimize resource management and pest control [12]. The Sericulture 4.0 sector is adopting next-generation farming by integrating IoT and AI. This includes Precision farming, employing IoT devices to collect important information regarding weather and crop development, as well as automate farming operations and resource management. AI additionally assists with disease detection and prevention, irrigation automation, and real-time supply chain management, and minimizing wastage [13]. Blockchain technology has the potential to significantly improve supply chain management in the global silk production and marketing enterprises. Blockchain enables the government, farmers, weavers, and merchants to collaborate, resulting in an immutable sequence of transactions that can be validated by any party. This irreversible shared ledger assures that no one can change the system, revolutionizing the industry's supply chain management method [14]. The XG Boost algorithm is used to create a prediction model for silk quality using cocoon morphological parameters. The model is trained using a large dataset of cocoon size, length, breadth, form parameters, and color variables from a silkworm population. The model's parameters have been fine-tuned to enable accurate silk quality forecasts, proving its ability to handle complicated datasets [15]. Sericulture 4.0 provides byproducts, like silkworm seeds and cocoons, which may be utilized to make value-added goods. These products are used for research, everyday fabrication, and low-cost manufacturing. Sliced and pierced cocoons are used to make yarn and handicrafts, whereas silk waste is spun into silk fabric, decorations, parachutes, and cosmetics. These wastes help to support the sericulture sector and provide additional cash. Thus, silk wastes are a prospective resource for the sericulture sector [16]. **Figure 1** below demonstrates the Sericulture Farming products and by-products.

Figure 1. Sericulture Farming

3. Recommendations

Based on our thorough literature review, we propose following recommendations for the future.

- The integration of contemporary innovations and traditional methods holds promise for the future of sericulture, making silk production more efficient, lucrative, and ecologically friendly. However, challenges must be addressed in order to ensure an equal distribution of benefits across stakeholders, particularly small-scale farmers and rural communities.
- Silk-based biomaterials are gaining popularity in a variety of sectors, including wound dressings, drug delivery systems, tissue engineering scaffolds, electrical and photonic devices, and flexible displays, sensors, and biodegradable electronics, due to their optical characteristics and flexibility.
- Sericulture could boost efficiency and sustainability by employing byproducts and cutting-edge technologies. Research should concentrate on maximizing mulberry utilization for animal feed, investigating medicinal possibilities, treating protein deficits, and minimizing environmental effect.
- Traditional sericulture utilizes mulberry leaves, but artificial diets and climate control technologies have increased productivity options. These diets allow for year-round silk production, which increases productivity and flexibility in controlled environment rearing facilities.
- Silkworm genetic changes can increase silk output and quality, giving economic benefits and ensuring sustainability. However, they raise concerns about societal acceptability and regulatory

systems. Addressing these socio-economic and environmental implications is critical for maximizing benefits while minimizing risk factors.

- Genetic engineering has transformed silk manufacturing by altering the silkworm genome to improve mechanical characteristics for textiles and tissue engineering. CRISPR-Cas9 allows for targeted gene editing, whereas genomic selection predicts and selects superior breeding prospects based on genetic potential.

Conclusion

Sericulture has seen significant modifications as a consequence of technological advances and a greater focus on sustainability. This conclusion highlights significant outcomes, explores socio-economic implications, and recommends additional research and techniques in silkworm farming for the production of silk. Sericulture, a global industry, has expanded beyond conventional silk production to provide opportunities in biopharmaceuticals, bioactive materials, and sustainable practices. Silk proteins are employed in drug delivery systems, tissue engineering, and enzyme encapsulation. Sericulture byproducts including sericin, silkworm pupae, and mulberry leaves produce bio fertilizers, biofuels, and animal feed, all of which contribute to environmental sustainability and economic development. Biological control is an attainable and eco-friendly alternative to standard conventional pest management in sericulture. It manages pests and illnesses by taking advantage of natural enemies involving parasitoids, predators, and pathogens, eliminating the necessity for harming pesticides. This method minimizes environmental and health concerns while promoting sustainable behaviors. Despite problems including delayed action times and limits, its advantages include reducing pollution, safeguarding non-target creatures, and providing long-term pest control solutions, making it a key component of integrated pest management strategies. The study focuses on the advantages of merging AI and drone technology for targeted mulberry plantations. These technologies boost production, conserve resources, and encourage sustainable habits. More study should be conducted on providing smallholder farmers with financial assistance, educational courses, and community participation programs. Training sericulture farmers can efficiently employ drone technology and AI systems, resulting in higher yields, lower costs, and higher revenues. AI promises to minimize time and labor while improving decision-making accuracy, potentially altering the world. Computer-based interventions such as Artificial Neural Networks, IoT, AI, and Image Processing algorithms encourage the secure and healthy production of silkworms by modulating temperature, illness detection, and protection. As AI's potential rises, it will assist sericulture in expanding and overcoming challenges in order to survive and prosper in the future.

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Chapter 2

Automation in Silk: Revolutionizing Sericulture with Technology

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Abstract

This book chapter looks into sericulture's revolutionary impact in empowering women and promoting sustainable livelihoods in rural areas. It examines the economic, social, and environmental aspects of sericulture, emphasizing its potential for money production, skill development, and community participation. The chapter additionally looks into sericulture's sustainable methods, which help to protect the environment and strengthen local economies.

This article examines technical breakthroughs for rejuvenating the silk industry, with an emphasis on current mulberry rearing techniques, biotechnology pest and disease control, and government regulations that promote environmentally friendly technologies. It also emphasizes automation and mechanization's possibilities for productivity and sustainability. The article explores case studies of effective technology and sustainability integration in sericulture, assesses the environmental impact of conventional methods, and makes policy recommendations for sustainable sericulture, with a focus on public-private partnerships. Silkworm diseases, such as Grasserie, can result in 30--40% output reductions. These illnesses can be identified through a variety of scientific approaches and laboratory processes. This article discusses sericulture methodologies, silkworm types and life cycles, current disease detection methods, the need for non-invasive methods, existing method limitations, and the revolution of deep learning, specifically Convolutional Neural Networks (CNNs), in disease detection systems and sericulture byproducts. Plant genomes may be quickly sequenced thanks to high-throughput sequencing methods, which also identify genetic markers associated with desired traits. Breeders are able to more accurately and efficiently select particular traits as a result. There is great potential for improving quality and productivity with mulberry genomics. Researchers can ensure a prosperous and sustainable future for sericulture by figuring out the molecular mechanisms that control development and use that knowledge to direct breeding initiatives

Keywords

Entomology, Sericulture, Silkworm Rearing, Manual Sericulture Management, Sericultural Science

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1. Introduction

The importance of insects in ecology, agriculture, medicine, and the pharmaceutical industry has led to a great deal of research on the subject of entomology. Two of the most studied insects are silkworms and honeybees because of their adaptability to a wide range of habitats. As model organisms and bioreactors, silkworms are useful in the medical field and pharmaceutical sector. In order to improve production and agricultural sustainability, genome editing techniques are being used to improve honeybees, the main pollinators of crops and wild plants, which face difficulties [1]. Sericulture, which primarily consists of the production of food plants to feed silkworms, such as domesticated Bombyx Mori, is a significant agricultural technique in the silk industry. Modern farming operations are mechanized, yet environmental stewardship remains a major concern. Temperature, humidity, air circulation, brightness, and chemicals involving carbon dioxide and smoke can all have an impact on embryonic development in silkworms [2]. Sericulture provides individuals with a steady source of income, allowing them to support their families and communities. It gives them control over resources, decision-making, and leadership positions. Women can improve their marketability by learning skills including mulberry farming, silkworm breeding, and silk production. Sericulture encourages environmentally beneficial farming techniques, which contribute to environmental protection and biodiversity. Sericulture participation also generates business chances for silk goods [3]. With sericulture making up the majority of its GDP, India is a major producer and consumer of silk. Growing food plants and silk cocoons and weaving them into textiles is known as sericulture, and it is a significant economic activity. Production declines of 30–40% can be caused by silkworm illnesses, particularly Grasserie. Numerous scientific strategies and laboratory-intensive procedures are currently being used to diagnose these ailments, ensuring the long-term sustainability of India's silk industry [4]. The study found that rearing practices and environmental factors significantly impact the health and quality of silkworms. It highlights the importance of favourable conditions for silkworm development and the potential for modern technologies to boost silk yield. The study also explores the relationship between cocoon form and filament strength and nutrition, particularly the quality of mulberry leaves. The results underscore the significance of integrating cutting-edge technology with conventional sericulture methods to guarantee sustainable silk production [5]. A key plant in sericulture, mulberry, is being improved through genomics. Scientists are studying genes linked to critical metabolic functions in order to learn more about the mechanisms underlying growth and development. Rapid genome sequencing of plants is made possible by high-throughput sequencing technology, which also identifies genetic markers linked to desired traits. This genomics discovery opens the door to mulberry farming's use of genetic enhancement [6].

2. Revolutionizing Sericulture with Technology

The technique of raising silkworms to produce silk in response to climate, humidity, and light intensity is known as sericulture. Environmental circumstances have a significant impact on the growing of silkworms. Automation and the Internet of Things (IoT) are needed to upgrade outdated methods. For silk production to be improved, environmental conditions must be closely monitored. Improving silk production requires the integration of smart sericulture and the Internet of Things [7]. Significant influences on silkworm growth and development are caused by temperature, humidity, and light intensity. The IoT paradigm makes it possible for products to monitor and control these variables by establishing wireless connections through intelligent mobile devices. The auto-controlled actuators that help to maintain these conditions include sprinklers, heaters, and exhaust fans. The unique feature of this concept is the system that can use sensors to monitor these attributes [8]. Figure 1 below shows the perfect environment for IoT-assisted sericulture. The production and efficiency of silk farming can be significantly increased by integrating IoT. Traditional methods are constrained by environmental regulations and labor, particularly Manual Sericulture Management (MSM). Using IoT, the Seri-Farm Automation System (SFAS) provides silkworms with real-time health monitoring, automated feeding, and precise climate conditions. SFAS significantly improves the quality and quantity of silk produced in comparison to MSM [9]. Artificial intelligence (AI) is the technology used to create robots that are capable of thinking, understanding, and learning so they may form opinions based on past experiences. Digitization has made AI more relevant, and with the right development and application, it can revolutionize a number of industries. The production of tasar silkworm seeds using AI could improve human comfort and increase the use of tasar sericulture [10]. Biotechnological treatments, particularly genetic engineering and molecular biology, can improve processes, enhance yields, and overcome conventional challenges related to sericulture. The shift from conventional approaches to improved scientific understanding is critical for conservation and breed enhancement. Modern high-throughput technologies, especially allele-specific hybridization and DNA arrays, are replacing traditional gel-based procedures. Advances in Next-Generation Sequencing technology open up new possibilities to explore tasar silkworm genetics [11]. Contemporary biotechnology has created new opportunities for silk production, allowing for the diversification of the sericulture process. Techniques including marker-assisted selection and transgenic expression of foreign genes can be exploited to fully realize the silk industry's enormous potential. Probiotics and artificial silkworm feed can also help improve silk quality. Silk has also been employed for biomedical processes [12]. Seri-biotechnology and bio-nanotechnology are contemporary bioscience advancements that have created a substantial influence on worldwide sericultural science research. However, India is still in its early phases, therefore concentrating on creating technology to promote silkworm and host plant growth is critical. Seasonal fluctuations in host plant nutritional content and composition, influenced by weather, pests, diseases, and agricultural methods, have a substantial impact on silkworm development [13]. Gene therapy, nano-biotechnology, and transgenic technology are being utilized to solve problems related to silkworm production, including the development of transgenic silkworms with increased cocoon quality and volume. Silk's distinct properties, like strength, elasticity, biodegradability, biocompatibility, and mechanical resilience, make it an important biomaterial for a variety of medical and pharmaceutical applications. Silk fibroin and sericin have high biocompatibility, manageable bio-degradability, and minimal immunogenicity [14]. Genome editing has expedited research and revealed promising application in sericulture, especially in breeding and treatment. CRISPR technology is a powerful yet fundamental technique in molecular biology. Genome editing techniques have been developed in silkworms, a model organism of Lepidoptera insects, which has aided research and may disclose novel mechanisms and targets in entomology and pest control [15]. Nanoparticles (NPs) have demonstrated potential in increasing mulberry cultivation and silkworm performance, notably in zinc oxide and iron oxide. These nanoparticles increased silkworm larvae's growth metrics, feed efficiency, and cocoon characteristics. They also increase silkworm reproduction, fertility, and resistance to illnesses involving BmNPV. TiO_2, silver, and chitosan nanoparticles have antibacterial capabilities against silkworm pathogens, which contribute to inhibit illness transmission [16].

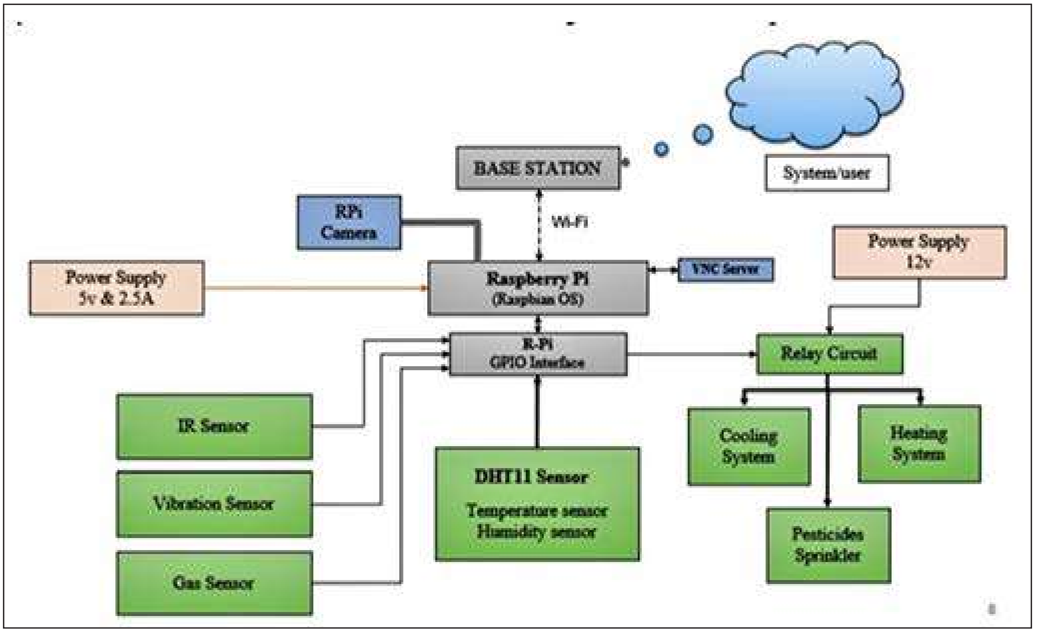

Figure 1. An Ideal IoT Assisted Sericulture Environment

3. Recommendations

Based on our thorough literature review on the current sericulture farming practiced across the globe, we propose the following recommendations.

- To stay competitive globally, the sericulture business must adapt to technological changes; failing to do so may have a severe influence on future production capacity.
- Promoting the use of silkworms in scientific research provides novel solutions and insights that benefit not only the sericulture industry, but also science and society as a whole.
- Micro-cocoons have the ability to deliver drugs such as alpha-synuclein in Parkinson's disease and ibuprofen in ocular illnesses. More research is needed to investigate the bioactive qualities of silk products and increase their socio-economic wellbeing.
- Climate control systems and automated rearing procedures are predicted to dramatically improve silk output and quality, transforming sericulture into a more sustainable and profitable sector.
- For silkworm health and productivity to be at their best, environmental stresses including temperature and humidity fluctuations must be controlled with the use of climate control systems and humidity regulation.
- Biotechnology has a huge impact on sustainable practices and innovation, thus incorporating sophisticated technologies into tasar sericulture is prospective.
- Scientific progress has been accelerated by the significant impact of bioscience on sericulture research. The diversification of products based on nanotechnology, sophisticated research on the negative effects of microbial bio-pesticides, and biotechnological solutions for sericulture-related

problems like host silkworm diseases and pests are still obstacles, though, and they are still in their infancy.

Conclusion

This study, in conclusion, emphasizes how important environmental conditions and contemporary raising techniques are to the physiology of silkworms and the caliber of silk produced. While cutting-edge technology like automated control systems and precise sericin curing processes greatly increase production efficiency, optimal temperature, humidity, air quality, and light exposure are crucial for optimizing silkworm health and cocoon quality. By combining these contemporary methods with age-old wisdom, silk consistency and sustainability can be enhanced, providing important information for sericulture's future. Transgenic technology was used to make silk filament, a double strand of fibroin joined by silk sericin, for pharmacological and therapeutic uses. Silk fibers are biocompatible, have no cytotoxicity, and disintegrate to non-toxic byproducts. Large-scale manufacturing of silk proteins for a variety of applications, including drug carriers, sensors, and tissue engineering scaffolds, has become possible because to technological advancements. Silk sericin, which is discarded by the silk industry, may be recovered and reused, and sericin can be extracted from silk in a variety of methods. Several countries are deploying artificial intelligence (AI) technologies to enhance productivity and gain data on product and marketing strategies. AI can quickly examine collected material and recognize patterns, giving businesses a competitive advantage. AI has the potential to increase its application in tasar silkworm seed production, but systematic research, planning, and execution are required to maximize its benefits. Tasar sericulture's biotechnological research aim to improve its practicality in the tasar silk production industry. These developments not only accelerate the industry to new heights, but also strengthen its resilience to environmental and economic challenges. Advances in DNA sequencing and analytics are hastening genomic research, making trait-gene association studies as straightforward as PCR amplification. However, bottlenecks such as germplasm evaluations, parental choices, progeny studies, characteristic introgression, and genetic engineering for mulberry development continue to exist, necessitating more study and breakthroughs in these areas.

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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].

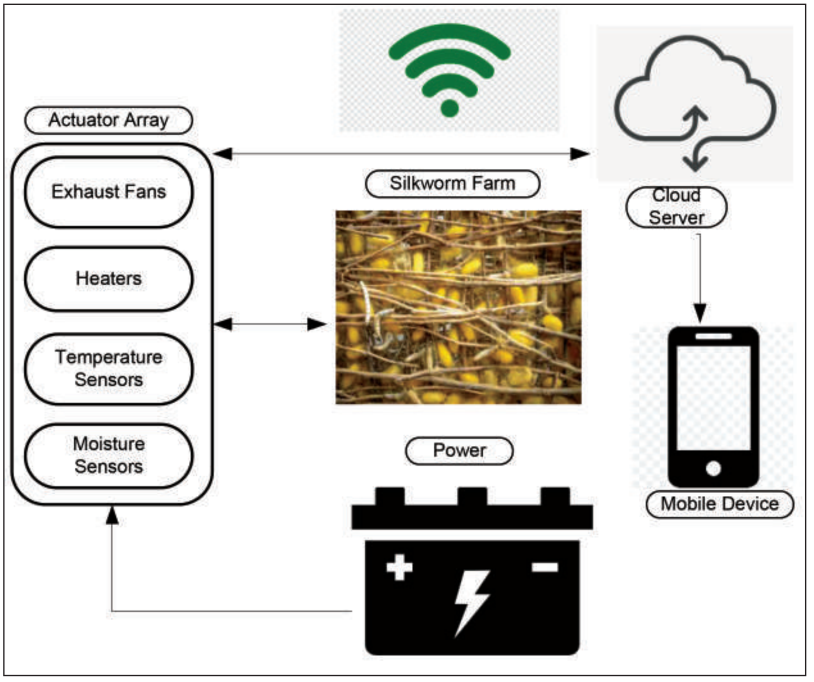

Figure 1. Real time Silkworm Monitoring by Employing IoT Techniques

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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Chapter 4

Smart Sericulture: The Next Era of Silk Farming

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Abstract

Sericulture provides a profitable revenue stream, self-employment, and higher returns on investment. This study explores employing electrical technologies for enhancing existing silkworm rearing processes. It automates facilities by monitoring temperature and humidity, enabling for improved control of cocoon growth phases with the use of micro controllers. This method guarantees the best outcomes at each step of cocoon growth. The SeriFarm Automation System (SFAS) is an Internet of Things (IoT)-based framework which incorporates advanced sensors to improve silkworm health and productivity. In contrast with Manual Sericulture Management (MSM), SFAS enhances silk production by 0.40% and optimizes labor efficiency by 0.25%. This innovative method offers a sustainable, scalable, and more productive alternative to silk farming, bringing in an era of innovation for the organization. The article emphasizes research on the mulberry garden water fertilizer integrated machine, which controls irrigation and fertilization with artificial intelligence (AI). This unique technique ensures that mulberry plants receive the nutrients they require at all phases of growth. It also examines the machine's future development tendencies, with an emphasis on mulberry garden growth and water fertilizer integration technologies. A cloud-based monitoring system for environmental factors has been developed at a sericulture farm. The system detects temperature and humidity on a regular basis and transmits the results to a platform-as-a-service cloud. This permits monitoring from anywhere in the world. The system may be expanded to monitor several silkworm rearing properties by installing wireless data gathering devices at each one and transmitting the data to a centralized PC for cloud service updates. This review explores at the qualities, structure, and applications of silkworms in a variety of sectors such as science, research, and engineering. It goes over how they are utilized in surgical meshes, textiles, wound healing, tissue engineering, medicinal applications, industrial materials, electricity, and optical devices. The research additionally looks at silk materials including sericin and fibroin, which are employed in pharmacological, cosmetic, and healthcare industries.

Keywords

Sericulture, Sericulture Innovations, Eri Silkworm Rearing, Mulberry Plants, Digitized Silkworm Breeding

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1. **Introduction**Sericulture, the art and science of silkworm farming, provides employment and revenue for India's rural people through both on-farm and off-farm activities. Sericulture innovations, especially revolutionary mulberry growing techniques, can assist farmers in planting large areas and ensuring mass-scale silkworm production. Resource staff-led programs, trainings, and seminars can encourage farmers to embrace new approaches, promoting technology transfer and innovation acceptance [1]. Sericulture, a labor-intensive sector in the Indian economy, supports a large section of the population by providing farmers and their families with profitable self-employment opportunities. Technological developments have resulted in contemporary sericulture operations at the farm and industry levels, increasing silk yield. Innovations are simple to learn, maintain, and cost effective, making them critical for creating high-quality cocoons and boosting silk output. This technological advancement makes a substantial contribution to sericulture's development [2]. Sericulture, a significant agricultural business, involves the production and extraction of silkworms, which helps to create jobs in rural areas, alleviate poverty, and generate foreign revenue. Silkworms require proper care, especially during their temperature and humidity-sensitive larval cycle. Advanced image processing identifies infections and developmental phases, resulting in a dynamic dataset for business advancement [3]. Silkworms produce silk, a fibrous animal protein, which is mass-produced through sericulture. This labor-intensive industry employs the majority of the population and promotes the socio-economic level of rural communities. Technological innovations are critical for the sector's development since they have resulted in contemporary sericulture operations at the farm and industry levels, increasing silk output. Innovations are simple to learn, maintain, and cost-effective, and investments in technology, training, and marketing help to improve the sericulture industry's overall competency [4]. Silkworms are essential for basic silk production and domestication, and they offer several applications in biology and science. Bombyx mori silk, a silkworm, has acquired popularity due to its natural production, biocompatibility, and distinct mechanical characteristics. Silkworm production is commercially significant, and they may be managed for a variety of applications. The correct utilization of silkworms requires an assessment of their characteristics [5]. Agriculture, like numerous other aspects of life, is being transformed by innovation. However, sericulture is still trailing behind in terms of integrating these innovations. Detecting diseases in silkworms is a time-consuming operation, but early diagnosis might assist farmers avoid disease spread. A system developed to diagnose healthy and sick silkworms employing deep neural networks, resulting in a promising accuracy rate. This breakthrough might assist farmers in taking the required security measures to avoid disease spread [6]. Choosing silk fiber based on technical qualities and identifying the relationship between fiber and reproductive and cocoon productivity is critical for efficient production. This includes developing breeds and industrial hybrids with high fiber indicators that match global market and industry standards, as well as enhancing the genetics and selection methods of mulberry silkworms [7]. Domestication of silkworms enables for the extraction of enormous amounts of fibroin from silk cocoons, although this approach has sustainability and quality challenges. Recombinant DNA technology is an achievable solution for addressing these challenges, but further optimization is required due to the enormous size and repetitive structure of fibroin's DNA and amino acid sequencing [8].

2. **Smart Sericulture: The Next Era of Silk Farming**

Sericulture is the most common technique for producing silkworms for silk products, with healthy growth dependent on temperature and moisture levels. Disinfection is essential for effective rearing. An Arduino-enabled Internet of Things (IoT) platform been designed to monitor and activate the system, which employs image processing technology for identifying silkworm life cycle stages and allows for real-time data gathering [9]. The implementation of the IoT within Sericulture offers the promise to substantially strengthen efficiency and productivity. Traditional approaches, especially Manual Sericulture Management (MSM), have limited output due to labor-intensiveness and the lack of ability to manage the rearing environment. IoT-driven sericulture approach employs cutting-edge sensors and management systems to provide silkworms more accurate environmental parameters, automated feeding mechanisms, and real-time health monitoring [10]. An Arduino microcontroller and IoT devices are employed to manage the silkworm by considering temperature, humidity, and light. Sensor data from field devices is transmitted over a cloud server, allowing farmers to monitor from anywhere. The objective is to produce high-quality silk with minimum human interaction, offering an efficient solution for the sericulture industry at a low cost [11]. Market demand contributes to an increase in the utilization of silkworm cocoons as raw silk resources. However, the existing identification procedure is inadequate, with manual selection determining which cocoons are superior and which are substandard. Automated optical equipment, notably the YOLO algorithm, are needed for assisting employees in cocoon selection, as Deep Learning has increased in popularity for image categorization [12]. The eri silkworm rearing process can be monitored through wireless sensor network-based devices, with an emphasis on temperature, relative humidity, and light intensity. The sensor is connected to a microprocessor, and additional sensor nodes must exist for comprehensive monitoring. A master node connects each node in the wireless sensor network, creating a star-shaped design. Before being placed for data collecting throughout the rearing process, the system is evaluated in a laboratory and compared to conventional equipment [13]. The water fertilizer integrated machine is a novel agricultural device that employs artificial intelligence (AI) to regulate irrigation and fertilization in agricultural crops. It makes sure that mulberry plants in fields receive adequate nutrients during all growth phases, increasing the efficiency of agricultural activities [14]. The digital power of technology, that includes machine learning, deep learning, and blockchain technology, has transformed several industries, including communication media, finances, real estate, and copyrights. These technologies have boosted efficiency and minimized dangers, allowing for the effective application of blockchain in supply chain networks, notably in the sericulture business [15]. Precision farming is a sericulture management approach which employs site-specific information to control production inputs and outputs. GPS, GIS, decision support systems, remote sensing collection, variable rate technology (VRT), and sensor-controlled atomization all contribute to cost reduction, yield optimization, and revenue maximization. These components collaborate to build a geo-referenced field map, offer location-specific parameter values, and manage pesticide delivery through VRT technology [16]. Cloud computing has proven beneficial for a variety of industries, notably sericulture monitoring. The preservation of measurement data is critical for a variety of applications, including silkworm development and cocoon quality control. Temperature and humidity are important elements impacting insect physiology, and farmers must ensure that these factors are accurately measured in their silkworm raising environment. Cloud providers provide a variety of services to help individuals meet their requirements [17]. The autonomous guided vehicle transfers a silkworm dropping shifting structure, which is subsequently processed by an assembly that removes waste and feeds silkworms. Currently, large silkworm breeding is difficult due to the short 4-to-5 stage breeding time and the high labour specialization necessary for mulberry leaf delivery. Additionally, the procedure of adding silkworm beds and mulberry to the tray raises manufacturing costs due to the high labor required. To overcome this challenge, technology that allows digitized silkworm breeding has been developed [18]. A novel approach, factory-like silkworm rearing using artificial feed for all stages, promises to boost efficiency and minimize expenses. Accurate feeding is critical in this procedure. A machine vision system is utilized to capture digital images of silkworms during their primary stages. An enhanced Mask R-CNN model is offered for detecting silkworms and fake diet residue. The initial model is enhanced employing noise data annotations, pixel reweighting, and bounding box fine-tuning techniques. A more robust model has been created to increase detection and segmentation capacities [19].

3. Recommendations

Based on our thorough literature review, we propose the following recommendations for a robust and thriving sericulture.

- Future research should focus on the ecological effects of fibroin production throughout its life cycle, identifying critical hotspots and optimizing for green chemistry principles. Ideally, highly concentrated and pure soluble fibroin should be manufactured in a cruelty-free and ecologically responsible conduct, yielding a higher-quality product.
- Research into the metabolic specialization of silkworm cells to produce reiterated fibroin has the potential to maximize the expression platform. This might lead to increased yields and scalability in recombinant fibroin manufacturing, potentially replacing existing silk extraction procedures in the biomedical sector.
- IoT technologies can boost cocoon output and profitability by allowing farmers to modernize old methods, enhancing the sericulture industry's overall competency through technological and training expenditures.
- The study of silkworm genetics at the grassroots level could enhance its attributes through biotechnological techniques, balancing innovation and tradition by employing sophisticated IoT technology for accuracy and efficiency, thus strengthening the entire silkworm research process.
- Modernizing silk manufacturing operations and rearing techniques can enhance silk output while reducing labor and costs, potentially leading to increased silk production and quality.
- In the near future, the Indian government will probably attempt to control the commercial release of transgenic silkworms, with an emphasis on their particular benefits. This will boost overall silk output and provides greater profits to seri-farmers.
- Manylabs platform-as-a-service (PaaS) provides a user-friendly platform for downloading and deleting data from any location, as well as statistical analysis tools for sericulture farmers that need technical programming experience. The cloud service is user-friendly, and data access is effortless, making it an invaluable tool for farmers.

Conclusion

Silk fibroin is a biopolymer with unique mechanical characteristics that potentially outperform synthetic polymers. Its intricate hierarchical structure self-assembles, beginning with silk glands and ends with the formation of cocoons. Fibroin is biocompatible and biodegradable, making it an excellent choice for biomedical applications. However, production and processing present issues in terms of repeatability, sustainability, and ethics. Future research should focus on the environmental performance of current fibroin manufacturing throughout its life cycle. Technological advancements are critical to attaining the objective of employing silks for novel biomaterials and applications in medicine, cosmetics, and other industries. Farmers-linked sericulture and advancements in sericulture technology can aid in the creation of novel silk-based biomaterials. Silk nano powder has previously been employed in medical and cosmetic purposes. Researchers are looking at protein-based biomaterials, and India is a suitable area for commercial release of genetically modified silkworms due to the absence of close relatives in the wild and the mulberry silkworm's need on humans for life. India's closeness to Bombyx mori and reliance on people make it a suitable place for commercial silkworm cultivation. Sericulture, a labor-intensive industry, has to be strengthened and expanded via technological innovation. By concentrating on farmers and advancing sericulture technology, new ideas may be produced. Managing obstacles and implementing novel technology can result in high-quality cocoon manufacturing. Farmers should learn about emerging technology and gladly accept them. Sericulture, India's labor-intensive sector, provides a huge number of people with profitable self-employment opportunities. However, worker wages exceed total cocoon output, lowering labor reliance and manufacturing costs. Sericulture development relies heavily on innovation, which involves the exploration of new ideas, equipment, and procedures. Investment in technology, technological promotion, and training programs may all help to increase competency. Accepting problems and adopting innovations can lead to advances in sericulture, as both acceptance of obstacles and adoption of innovations promote overall growth.

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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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Chapter 6

Weaving the Future: Automation and AI in Sericulture 4.0

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Abstract

Basic textile production techniques that have been used since antiquity include spinning, weaving, knitting, braiding, sewing, and dying. But new environmental risks have been brought forth by modern technologies. This chapter explores recent developments in sustainable textile technology and how they affect the textile sector in developing nations. It also examines the sustainability challenges these contemporary systems face in meeting the expanding needs of the population. By studying the brain mechanisms behind insect behaviour, neurobiological research will further our understanding of biology and may find use in robotics and artificial intelligence (AI). Micro-biomics investigates the relationships between insects and microorganisms and suggests innovative approaches to pest control. Insect populations are vital to the preservation of biodiversity, and environmental entomology examines how habitat change and climatic variability affect them. By using cutting-edge technology and interdisciplinary approaches, the field advances our knowledge of insects' functions in ecosystems, adaptation, and ecological balance. There are fascinating scientific research implications for conservation policy and sustainable ecosystem management along this future path. Several advantages of 3D-printed silk fibroin scaffolds for wound healing include waste disposal, tissue regeneration, nutrient exchange, and cell infiltration because of their porous nature. Stability and assistance during recovery are ensured by altering the printing settings. Artificial intelligence (AI)-powered printing techniques improve wound dressing precision, personalization, and customization while also speeding up research and development and saving time and money. By integrating patient-specific data to improve design and manufacturing, AI algorithms result in speedier production, improved wound healing outcomes, and dressings that fit better. Traditional classifiers like support vector machines (SVM) and K closest neighbors (KNN) were investigated in order to determine the sex of silkworm pupae from various species and years. A CNN model was trained with hyperspectral spectra to identify the gender. CNN performed more accurately than SVM and KNN, per principal component analysis (PCA). Additionally, HSI technology in conjunction with CNN proved to be successful in identifying the gender of silkworm pupae.

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Keywords

Cocoon Classification, Silkworm Illnesses, Artificial Intelligence (AI), 3D-Print Silk Fibroin, Wearable Textile Electronics

1. Introduction

Sustainable technologies, particularly sustainable ones, are increasingly being studied in the textile industry due to their environmental friendliness and economic viability. Spinning, weaving, knitting, braiding, stitching, and dyeing are all examples of traditional textile production processes that have been in use since antiquity. As a result, sustainable technology is an attractive option for textile production [1]. Early detection of plant leaf disease is a potential topic for research in smart agriculture which employs computer vision. Automatic detection can minimize human effort and increase efficiency. Terminalia Arjuna, a multi-purpose tree in India, is utilized in medicine and sericulture as a moth meal. Leaf spot disease is prevalent, and treatment should begin very once to prevent it from spreading to adjacent leaves and trees. Regular observation and automated detection may assist to reduce labor [2]. After mulberry cocoons are screened before silk reeling, the quality of the cocoons directly affects the quality of raw silk. Cocoon sorting and categorization are essential for the silk product sector. However, the majority of factories that produce mulberry cocoons select them by hand. Machine vision can be used to classify cocoons intelligently, and automatic methods can significantly improve the efficiency and accuracy of plucking [3]. Mulberry cocoon quality, which must be screened prior to silk reeling, is directly tied to the quality of raw silk. The silk industry depends on the categorization and sorting of cocoons. But most mulberry cocoon factories pick their cocoons by hand. Automatic techniques might greatly increase the efficiency and accuracy of plucking, and machine vision could be used to classify cocoons in an intelligent manner [4]. The manufacturing of Tasar seeds involves the rearing of silkworms to yield Disease-Free Layings (DFLs) and superior seed cocoons. In this procedure, mechanization includes plantation management and raising. Brush cutters, centrifuges, chain saws, cocoon transportation baskets, egg drying machines, electric sprayers, ladders, lime dusters, microscopes, and secateurs are among the tools used to alleviate hardship. These machines minimize labor needs and accelerate the drying of DFLs, enhancing efficiency in the tasar seed manufacturing industry [5]. Silkworm illnesses result in huge economic losses in silk production. Early diagnosis of infections is critical, especially during the larval period. To identify illnesses in silkworms, an automated strategy is recommended, namely the application of Convolutional neural networks (CNNs). The model employs Deep Learning to distinguish between infected and healthy silkworms, with an accuracy rate of 99%. Early diagnosis and identification can assist farmers prevent disease spread and boost silk production [6]. The silkworm business relies heavily on the sex determination of pupae. Multivariate analysis approaches are employed in hyperspectral imaging spectroscopy for classification, although they need spectral preprocessing or feature extraction. CNNs may learn interpretable presentations without requiring ad hoc preparation. Conventional classifiers based on a single silkworm pupae species may underperform when testing different species, resulting in low generalization ability [7]. Sericulture, the rearing of silkworms, has difficulties in generating high-quality silk. To address this issue, a method for distinguishing male and female cocoons using X-ray pictures is presented. The strategy computes cocoon width and height using a unique point interpolation method, as well as several dimensionality reduction strategies. The preprocessed features are input into the AdaBoost ensemble learning algorithm, which uses logistic regression as the base learner, thus enhancing the model's performance [8].

2. Weaving the Future: Automation and AI in Sericulture 4.0

Sericulture, an essential industry for human life, demands solutions for preserving its resources. The Internet of Things (IoT), Artificial Intelligence (AI), UAVs, and Blockchain technologies have the potential to substantially enhance the overall state of sericulture by promoting to the preservation of these vital domains [9]. In sericulture, IoT is utilized to intelligently perceive, identify, and process environmental variables and silkworm developmental state. This is accomplished via a deep residual neural network method (DRCNN), multi-feature data extraction, hierarchical fusion processing, rapid data standard correction, real-time production monitoring, output technological solutions, and automated decision-making. This technology may be used as a model for developing an intelligent sericulture platform [10]. Mechatronics, an AI participant, has long been employed in the textile industry for a variety of applications, including 3-D braiding, weaving, yarn tension compensation, texturing, spinning, measurement automation, expert systems, automated garment manufacture, and clothing production. Workers in the early textile industry used electrical and mechanical artifacts in their experiments and products. Mechatronic design in textile engineering emphasizes the relevance of mechatronic design in the textile industry, as well as its applications in Passementerie stripes and textile machinery design [11]. Subcellular procedures have been capitalized in advanced ways to enhance tissue regeneration during wound healing. Silk fibroin, a molecularly engineered substance, may be controlled by 3D printing technology to create tailored scaffolds that replicate the original tissue environment. The objective is to employ an AI-based algorithm to 3D-print silk fibroin scaffolds and apply it in clinical environments. These scaffolds' porous construction allows for cell infiltration, nutrition exchange, waste disposal, and tissue regeneration [12]. AI incorporates multiple technologies and basic sciences, with an emphasis on intelligent biomedical medicine, the atmospheric environment, and large-scale monitoring. It is similar to functional polymer films or coatings, which provide flexibility, variety, biocompatibility, and superior electrical, magnetic, and optical capabilities. Thin-film technology, which comprises preparation, production, and design, has connections to micro-electronics, optical information, infrared, laser, display, material surface modification, space technology, and biochip technology [13]. The ConvNeXt-Attention-YOLOv5 (CA-YOLOv5) model is designed to reliably detect and pinpoint sick silkworms in the sericulture sector. Currently, existing deep learning approaches rely on picture categorization, which does not give geographic information. The model uses a large kernel with depth-wise separable convolution and the ECANet channel attention mechanism to strengthen feature extraction and increase receptive fields, therefore increasing precision control technology and equipment development in the sericulture business [14]. The YOLOv4 model, which is not suitable for mobile or embedded terminals, significantly decreases the detection accuracy of dense silkworm targets due to its lightweight MobileNetv3-YOLOv4 network. A lightweight YOLOv4 detection method (KM-YOLOv4) is described that employs multi-scale feature fusion to increase detection accuracy. The Kmeans method reconstructs anchor boxes for various objects, and the revised deep learning separable convolution MobileNetV3 lightweight backbone network replaces the YOLOv4 backbone network, minimizing computational burden and model complexity [15]. **Figure 1** below demonstrates the silkworm cocoon detection framework. Nanotechnology and electroactive materials have turned textiles into wearable electronic platforms, accelerating the development of next-generation flexible electronics. The application of nanoscale conductive particles facilitates personal interactive communications and portable sensing, while also providing greater stretchability and usefulness in smart textile systems. However, real-world applications necessitate an understanding of the functional dependability of wearable textile electronics

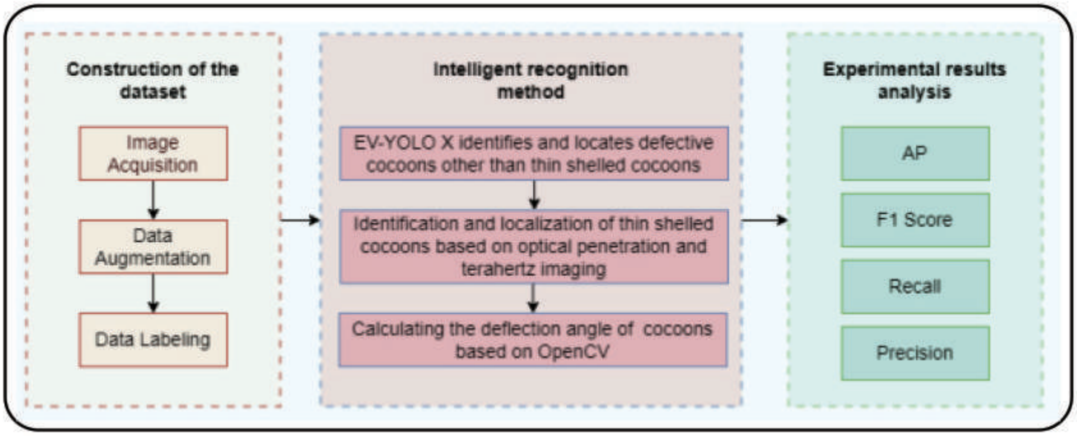

Figure 1. Silkworm Identification Framework

[16]. Tenebrio molitor, a nutritious and low-carbon bug, has been included to the European Food Safety Authority's list of new foods due to its nutritional content. To monitor Tenebrio molitor breeding, a three-module system is being developed, which includes an instance segmentation module for recognizing development phases, a semantic segmentation module for extracting feed, and a larval phenotyping module for calculating characteristics for individual larvae and the population [17].

3. Recommendations

Based on the thorough literature review of AI technologies currently being employed by the sericulture industry, we propose the following recommendations.

- Future seed production interventions will include a tasar cocoon sorter, garlander, garlanding thread maker, de-garlander, moth catcher, grainage house disinfection, disease scanner, and pierced tasar cocoon grader.
- Entomology is entering a new era with technical advancements and multidisciplinary techniques that will improve our understanding of insects' roles in ecosystems, adaptation, and ecological balance. This future path provides interesting scientific potential and consequences for sustainable ecosystem management and conservation policy, necessitating the collaboration of researchers, academic institutions, and funding agencies.
- I and machine learning are gaining ground in entomology, allowing for automated insect species identification and predictive modeling of population dynamics in a variety of environments. These computational tools can manage enormous volumes of data and provide insights that traditional approaches may find challenging to obtain.
- CRISPR technology is transforming entomological research by allowing researchers to change individual genes in silkworms, allowing for the investigation of gene function, behavior, physiology, and adaption methodologies.

- A scanning tool might offer thorough information on pebrine and other disease-causing factors in Tasar silkworms and their phases, therefore considerably enhancing silk production.
- Living pupa, heavy cocoon weight, shell weight, and dead, or infected cocoons all impact seed cocoon selection, which may be prevented with an auto AI sorting machine.

Conclusion

Sericulture, particularly in India, is critical to a country's cultural and economic growth. To increase silk quality, male and female cocoon fibers are reeled separately to minimize mingling. A model based on x-ray pictures may determine pupa form characteristics without destroying the cocoon. The suggested approach additionally includes width and height extraction for more precise feature extraction. The adoption of LDA as a dimensionality reduction approach boosts the classifier's efficiency. Multidisciplinary incubation centers, seed money for companies, and increased funding are all being used to support the long-term viability of AI applications in the textile industry. This involves maintaining leadership and management throughout the research and development, manufacture, design, and innovation of product consumption machines, marketing and promotion, and after-sales services. International brands are increasingly relying on technology in their operations. The study provides a CNN model for categorizing silkworm pupae using HSI spectra, which outperforms existing machine learning approaches such as SVM and KNN. The CNN model relies less on preprocessing and feature extraction, making it an important addition to online intelligent sex recognition of silkworm pupae. Entomology is changing because to technology developments and new study areas. Traditional approaches are being integrated with new tools such as eDNA analysis and CRISPR genome editing to broaden the breadth of entomological research. Emerging studies including insect neurobiology and micro-biomics provide fresh insights into insect physiology, behavior, and ecology. The application of light penetrating and terahertz spectrum data for thin-shelled cocoon selection and classification has been found to increase silk reeling enterprise production efficiency as well as raw silk quality. This non-contact method detects various flaws in mulberry cocoons, allowing for a quantitative assessment of faults in resource-constrained settings.

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Chapter 7

Redefining Silk Farming: A New Age with Sericulture 4.0

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Abstract

Silk farming, also known as sericulture, has a 5,000-year history. It promotes employment opportunities, economic growth, and well-being by raising mulberry trees for a variety of purposes. The industry produces high-quality silk thread and high-protein foods for both humans and animals. It relies on a multipurpose plant to improve human health and soil conservation. A sustainable silk derivatives sector might replace petrochemicals with fibroin molecules found in common health items, biopharmaceuticals, and implants. Sericulture is an agricultural-based business that produces food plants and breeds silkworms. Common silkworm species include Bombyx mori caterpillars, Eri, Muga, and Tasar for 'wild silks'. India has a long history of silk manufacture, extending back to the 14th century. It is the world's only country that produces muga silk. Silkworms go through four stages in their life cycle: egg, larva, pupa, and adult. Filaments from numerous cocoons are wrapped together to form a single raw silk thread. The genome of the Bombyx mori silk moth was sequenced in 2004, a significant step forward in insect genomics research. This finding has uncovered crucial genes involved in silk manufacture, development, immunology, and other biological processes. This information has applications in agricultural enhancement, silk quality, disease resistance breeding, and molecular breeding techniques. Advances in genetics and analytical technologies point to new discoveries in silkworm study and sericulture. Sericulture, a traditional agribusiness, exploits mulberry silkworms to generate natural silk in cocoons. However, synthetic fertilizers can degrade leaf quality and soil health, posing a threat to silkworm health. Natural or organic alternatives to mulberry leaf improvement include farmyard manure, compost, vermin compost, green manures, and bio-fertilizers. These solutions seek to increase the industry's success. This chapter investigates the environmental implications of collecting natural or synthetic fibers including cotton, wool, silk, polyester, nylon, rayon, and acrylic. It focuses on water and air pollution, solid waste creation, freshwater usage, dangerous toxic compounds, and wastewater generation. The manufacture of textile fibers requires enormous volumes of fresh water, harmful chemicals, and wastewater, emphasizing the importance of sustainable textile industry approaches.

Keywords

Seri-Compost, Organic Mulberry Production, Silk Fibroin, Bombyx Mori, Sericin, Genome Sequencing

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1. Introduction

Sericulture is a rural enterprise that includes separating silk filaments from cocoons and winding them onto reels to produce raw silk. This agro-based economy provides more revenue and distributes funds from the wealthy to the poor, making it ideal for small and marginal farmers. Waste generated by sericulture operations, especially silk worm litter and mulberry leaves, is collected and turned into beneficial seri-compost using appropriate equipment. Sericulture activities in villages discourage people from migrating to cities to find work [1]. Sericulture is an important cash crop since it requires minimal investment, has a short gestation time, has significant employment potential, and yields a good return. It is appropriate for all socioeconomic groups, including wealthy farmers and those without land. It necessitates limited technology and generates employment and revenue in rural and semi-urban environments, particularly among low-income and socially marginalized communities [2]. Silk cocoons from foothill plantations had stronger technical indicators, implying that developing mulberry plants on recently recovered soil in the foothills improves sericulture feed and preserves agricultural crops from erosion. This demonstrates the significance of strategic planning and sustainable land use methods in agricultural growth. Policymakers can boost silk production, contribute to environmental conservation, and conserve agricultural areas by concentrating on appropriate places such as foothills [3]. Silkworm larvae go through four moults and five instars, chawki and late-age, before spinning cocoons. They get their nourishment from mulberry leaves, but their needs change as they become older. Chawki Rearing Centers (CRCs) help to sustain cocoon crop yield in sericulture by providing controlled settings, boosting silkworm health, promoting uniform development, and raising survival rates. These facilities are critical to the sector's success and long-term existence [4]. Fibers are utilized in fashion and textile manufacturing and can be sourced from natural or petroleum resources. Traditional natural fibers, such as cotton, require a lot of water and pesticides, whereas synthetic fibres are non-renewable and non-biodegradable. Given their end-of-life status, the extraction and usage of these fibers are not sustainable, rendering them unsuitable for sustainable production. As a result, it is critical to examine the longevity of these basic materials [5]. The demand for high-quality mulberry leaf for silkworm breeding has resulted in the adoption of natural or organic alternatives including farmyard manure, compost, vermi-compost, green manures, and biofertilizers. Organic mulberry production is seen as essential for reviving the world silk industry. Awareness of the damaging effects of toxic chemicals, and the necessity for eco-friendly natural resource management, has resulted in a new lifestyle that has the potential to substantially enhance the sericulture business, including leaf, cocoon, and silk production [6]. Sericulture, a historic rural agro-based sector, has greatly improved social and economic conditions in emerging nations. Tasar sericulture, with its on-farm and off-farm operations, has a high employment potential. It directly employs people in tasar nursery and seed production, silk worm raising, spinning, weaving, and waste processing, as well as indirectly trading silk goods. Tasar sericulture has also benefited the rural economy by providing income-generating entrepreneurship options [7].

2. Redefining Silk Farming: A New Age with Sericulture 4.0

Sericulture is a sustainable enterprise that manufactures high-quality silk thread and protein-rich foods for people and animals. It is based on a versatile plant called silk fibroin, which is biodegradable and flexible like plastic. With advancements in bio-harvesting technology, markets may now get silk fibroin on a big scale, benefiting human health and soil conservation. Sericulture is a unique end-to-end sustainable sector with a low environmental effect [8]. New materials for the food, water, and agricultural industries must exceed performance standards while also addressing biodegradability, circular life cycle, and sustainable sourcing. Regenerated silk fibroin is a structural biopolymer recovered from Bombyx mori cocoons via a water-based technique. Silk fibroin is harmless, natural, and competitively orientated. Although it degrades slowly in the human body, it is both ecologically stable and biodegradable, giving it a viable alternative to conventional materials [9]. Genome sequencing and public databases have combined molecular technologies with traditional breeding methods to create silkworm hybrids with greater production, quality, and long-term yields. Researchers discovered genes and proteins related with illness resistance and tolerance, which led to the formation of Bombyx mori breeds. Molecular diagnostic tools for silkworm illnesses have enhanced precision and innovation in characteristics such as silk productivity, disease tolerance, high temperature, and relative humidity [10]. The Bombyx mori mulberry silkworm, which is infected with the Bombyx mori nucleo-polyhedro virus (BmNPV), produces grasserie disease and considerable economic losses in the silk industry. Despite the introduction of diagnostic kits, they are rarely employed. The best emerging methods include antibody-based biosensors and lateral flow assays, which have great specificity and sensitivity. Disease-resistant silkworm breeds or natural silkworm resistance may be the most cost-effective method of preventing grasserie disease. A comprehensive investigation of host gene responses to BmNPV infection is also expected [11]. Silkworm genetic variety is a cause for worry since it can make them more susceptible to pests and illnesses. Maintaining genetic variety is critical for long-term genetic improvement management techniques, as silkworms are domesticated all over the world for their glossy silk. Studies based on quantitative qualities, biochemical and genetic markers, and factors contributing to biodiversity loss should be investigated [12]. Recent biotechnology advances, especially recombinant DNA methods, genetic engineering, and stem cell research, have transformed plant and animal sciences. However, their influence on sericulture is restricted due to a lack of practice in industrially developed nations, which impedes the development of biotechnological methods to sericulture [13]. Sericulture is an agricultural cottage enterprise that promotes long-term growth through social interaction. Muga silk, an organic fiber composed of fibroin and sericin, is a flexible, long-lasting material excellent for emerging technologies. Sericin, a globular protein, is suitable for biological purposes. Muga silk is known for its applications in textiles, clothing, biomaterials, pharmaceuticals, dietary additives, and biofuel synthesis. Its adaptability makes it a viable alternative for a variety of sectors [14]. Eri silk, a darker and thicker variety of silk, is recognized for its thermal characteristics, keeping it warm in winter and cool in summer. It consists mostly of fibroin and sericin, with minor paraffin components, mineral salts, and coloring materials. Its distinctive features, including as fineness, density, and surface, make it ideal for commercial usage in the production of high-quality blankets, sweaters, and suiting fabrics. Eri silk is extremely popular in eco-friendly items since it does not disrupt the silkworm's normal life cycle [15]. Silkworm genomics has had a tremendous influence on sericulture, exposing the genetic basis of silk production and other biological processes. This has resulted in the development of molecular breeding methodologies for more effective silkworm trait improvement. Engineers can reduce economic losses by discovering resistance genes in silkworm breeds. This understanding has implications for agricultural development, allowing researchers to create silk of higher quality and quantity, breed silkworms with better disease resistance, and investigate novel molecular breeding strategies [16].

3. Recommendations

Based on the thorough literature review, we propose the following recommendations for the future.

- New concepts and technology are increasing the application and value of silk fibroin in consumer products and healthcare, making sericulture a greener, more sustainable alternative to petrochemical manufacturing. It also provides low-impact farming, making for an exciting future.
- Sericulture, a worldwide, sustainable, and safe alternative to petrochemicals, is gaining appeal across a variety of sectors. Sustainable cultivation techniques can assure the long-term viability of this natural technology, both in production and utilization.
- Sericulture enriches soil fertility, avoids erosion, and promotes sustainable forest management. It maintains wild flora and animals, controls precipitation, cleanses the air, and prevents pollution. Promoting sericulture activities is critical to preventing soil erosion and preserving biodiversity in the Ecosystems.
- Sericulture, a simple and accessible technique, helps all segments of society, including farmers and landless people, and has offered employment and income in rural and semi-urban regions, notably for low-income and socially under-privileged groups.
- Due to its multifunctional capabilities, the sericulture sector is a very useful agro-based venture, particularly for socio-economic development. According to studies, it is the best agro-based industry for current and future socioeconomic progress.
- Silkworms from Asian nations have the potential to produce medicinal proteins, vaccines, and nano-materials. Understanding the host protein process can aid in the development of further commercial uses for this species.
- Genome editing technology may be employed to create innovative commercial B. mori variants with higher silk production, quality, and virus resistance. The silk gland of B. mori is suitable for creating useful proteins, and while expression methods have been devised, further work is needed to optimize the silk protein-encoding genes.
- Improving silkworm resistance to BmNPV is critical for minimizing economic losses and promoting sericulture advancement. Identifying grasserie disease-predisposing variables and functionally evaluating potential genes can contribute to the development of novel treatments, improving sericulture output, and protecting farmers' interests.

Conclusion

Sericulture, a historic and important aspect of society's past, may be utilized in environmentally conscious and responsible ways. Sericulture, as an integrated agricultural production system, is a low-capital, high-yield technique with advantages on a small scale. It's flexible to climate change, sustainability, and fair trade. Silk fibroin, a fundamental component of the silk production supply chain, is being employed in consumer products and healthcare owing to new concepts and technology. This chapter investigates the environmental and social consequences of textile fiber production for fashion and textiles. It highlights the difficulties in collecting traditional natural textile fibers, as well as the significant environmental effect of synthetic fibers including cotton, wool, silk, polyester, nylon, rayon, and acrylic. The chapter also discusses how these fibers pollute the environment. Silkworm genetic variety is critical for developing long-term management techniques to increase silk quality. Greater homogeneity might make you more vulnerable to pests and illnesses. Seri-biodiversity conservation seeks to save various ecotypes from extinction and use them in breeding operations for commercial silkworm advancement. Promoting sericulture activities can help to minimize soil erosion and preserve the Biosphere's unique biodiversity. Millions of people worldwide rely on silkworms to produce beautiful silk, the Queen of Textiles. The sericulture industry, which was once primarily focused on silk fiber for textiles, has evolved into a multi-purpose agro-based industry that contributes to socioeconomic development by providing jobs, food security, income generation, women's empowerment, environmental safety, agricultural integration, and infrastructure development. Sericulture uses have recently been broadened to include human and cattle nutrition, cosmetic manufacturing, medicines, biomedical and bioengineering, cars, home construction, and art craft. The genetic elucidation of silkworm B. mori has sparked considerable interest in its use in labs worldwide. Advanced genetic technology have permitted functional investigation of B. mori genes and advanced genetic manipulation of silkworms, hence increasing their commercial worth. This has also aided the development of comparable technology in non-model insects. Enhanced genetic modification skills will result in newer enhanced phenotypes, increasing sericulture economic success. Traditional breeding procedures have not resulted in higher silk quality and quantity from individual silkworms. BmNPV grasserie disease is a serious setback in sericulture, resulting in financial losses for producers. Prevention and therapy are ineffectual, and the relationship between genetic and host variables is unknown. Early diagnosis of BmNPV infection in silkworm rearing is critical to preventing its spread. Advanced disease diagnostic methods, such as antibody-based biosensors and lateral flow assays, have great sensitivity and specificity, making them suitable for unprocessed and crude materials.

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Chapter 8

The Silk Industry's Digital Leap: Sericulture 4.0

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Abstract

The association between Sericultural digitalization, farmer enrichment, and agricultural growth is complicated and varied, with population aging, industrialization, government backing, and resident capability all playing important roles. Policies should take spatial implications into account when designing and implementing them. Income disparities, the elderly population, and financial self-sufficiency are all key factors. Differentiated, accurate, and integrated management policies may be devised to aid in developing, constructing, and overseeing smart communities and digital sericulture. Rural communities may benefit from this approach in overcoming their problems and promoting long-term growth. Hydrogels' biocompatibility, tunable breakdown, and minimal immunogenicity have made them popular in tissue engineering and regenerative medicine. The chemical functionalization possibilities and physical characteristics of Silk Fibroin (SF) materials are examined in this work. The promise and constraints of methacrylate compound functionalization are covered, along with other functionalization techniques and cross-linking ideas. The study also looks at functional SF hydrogels and how they are used in tissue engineering, bio-fabrication, and regenerative medicine. The suggestions are meant to support SF hydrogel and composites development in the future. This study investigates the composition, structure, characteristics, and activities of silk proteins, as well as their significance in 3D in vitro models and current breakthroughs in medicinal applications. It emphasizes the physiological properties of silk matrix ingredients in in vitro tissue constructions, as well as current research problems and complications, with the goal of developing complex and biomimetic silk protein-based micro-tissues. Multiple photo-crosslinking techniques have been used on modified silk fibroin, resulting in a novel method for light-based crosslinking and micro-fabrication. Both the photo-crosslinking techniques and the molecular design characteristics of silk fibroin inks suggest that they might find use in biology in the future.

Keywords

Digitization, Silk Fibroin (SF), 3D Printing Inks, Photo-Crosslinking, Bio-Ink, Polymer Hydrogels

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1

Introduction

Digitization is critical for rural rejuvenation, and it has a complicated relationship with farmer enrichment and agricultural growth. This is something that governments throughout the world appreciate. A quantitative assessment of this relationship can expose the underlying mechanisms, giving evidence for rural government, agricultural firms, and stakeholders [1]. Nature provides essential insights into the development of novel materials, but replicating biological form, function, and sustainability remains challenging. Major challenges involve employing biological knowledge for material innovation, recognizing the differences between synthetic and biological materials and understanding how form and function are related. Promising methods for creating bio-inspired materials are needed to overcome these issues [2]. Although the exact mechanisms are unknown, spinning natural silk has advantages over spinning synthetic fibers. Proteins called fibroin and sericin make up silkworm silk, particularly that of B. mori. The majority of research focus on fibroin self-assembly and gelation, with little emphasis paid to sericin's role during spinning. The basic processes of the process are yet to be investigated [3]. The silkworm Bombyx mori makes silk fibroin (SF), a proteinous fiber obtained from nature that is highly mechanically strong and biocompatible. Chemical and genetic engineering techniques have been used to increase its characteristics for use in electronics, textiles, and biomedicine. The fiber's solubility and mechanical strength both increased, but its crystalline structure stayed the same. During the degumming procedure to eliminate a covering protein, intramolecular and intermolecular cross-linking most likely produced these alterations [4]. The properties of silkworm silk proteins make them significant in a variety of fields. A large amount of waste SF, or filature silk, is produced in India and can be used to increase the physiochemical properties and strength of biopolymers. Fiber-matrix adhesion is difficult, nevertheless, because of the hydrophilic sericin coating on the fiber surface. Filature silk Bombyx mori fiber reinforcement is used by engineers to create natural composites based on wheat gluten for low-strength green applications [5].

Sustainable, biocompatible, and biodegradable SF is utilized as a carrier for pharmaceuticals and functional substances in the food, personal care, and biomedical industries. Green, natural biopolymer-based stabilizers are in great demand for Pickering emulsions. Size and interfacial tension between SNB, regenerated silk nanofiber, and nano-whisker are assessed, and a brush-like silk nano-brush (SNB) acts as a stabilizer [6]. Fluorescent SF fibers have biological applications, notably in labeling and tracking. A simple and ecologically friendly technique for producing these fibers has been discovered, with silkworms serving as bioreactors. Under the laser, the modified silk showed vivid green hues. This green, ecologically friendly, and simple approach is appropriate for large-scale production. According to the research, for a wider range of applications, SF fibers can be combined with other fluorescent materials to display distinct colors at particular wavelengths [7].

2. The Silk Industry's Digital Leap: Sericulture 4.0

A protein with strong mechanical properties called silk fibroin (SF), is an exciting contender for 3D printing inks in tissue engineering, bioelectronics, and bio-optics. Photo-crosslinking is very advantageous because of its speedy kinetics, adaptable dynamics, form control with light assistance, and biocompatible visible light use. Numerous photo-crosslinking methods, such as free radical methacrylate polymerization and photo-oxidation, have been used to treat SF. SF's molecular properties make it an ideal material for light-based cross-linking and micro-fabrication [8]. SF, a biopolymer with biocompatibility and customizable mechanical characteristics, is being investigated for possible 3D printing applications. By allowing methacrylate groups to be inserted, chemical functionalization of SF increases its processing capabilities and versatility. Because metha-crylation procedures use monomers like glycidyl methacrylate (GMA), isocyanatoethyl methacrylate (IEM), and/or methacrylic anhydride (MA),SF is an effective bio-ink in 3D printing [9]. The incorporation of biological macromolecules in 3D printing provides a flexible solution for a variety of criteria, including printability, buildability, and biocompatibility. These molecules have an important role in physical and chemical cross-linking activities, contributing to the success of the process. Gelatin methacryloyl (GelMA) is a common bio-printable substance used in tissue engineering [10]. 3D in vitro models are essential for investigating tissue development, drug screening, and disease modeling. They accurately imitate tissue microstructures and physiological characteristics, in contrast to typical 2D cell cultures. These models are made from bio-macromolecules including collagen and synthetic polymers, with silk proteins being employed more frequently to overcome the limits of 2D growth. These models provide a more realistic picture of the in-vivo microenvironment [11]. Bio-printing, despite its popularity, has limits owing to poor bio-ink design. SF, a prospective bio-ink candidate, is popular for its process ability, biodegradability, and biocompatibility. However, because to its poor gelation characteristics, functionalization procedures are required to properly employ SF in bio-printing applications. These tactics enable SF to be compatible with certain bio-printing procedures, enabling its best utilization in bio-printing applications [12]. Biosensors are becoming increasingly important in health research as a result of the necessity for continuous monitoring of biological signals and increased public health spending. Conducting polymer hydrogels are intriguing materials because of their biocompatibility, electro-activity, resorption, and selectivity for certain bio-analytes. These qualities may be improved by creating conductive polymer hydrogel-based composites with specialized capabilities for certain end applications, making them an attractive candidate for biosensor applications [13]. Thermoset silicone elastomer materials, such poly-dimethyl-siloxane (PDMS), are widely used in wireless, skin-interfaced bio-electronic devices to create soft encapsulating frameworks for radio frequency antennae, rechargeable batteries, and electrical components. These materials provide non-invasive skin interfaces, even with extreme curvature and substantial deformations. However, previous research has neglected the potential for designing versions of these materials to improve multimodal safety against failure modes including mechanical damage and thermal instability [14]. Traditional electrical and photonic devices are inflexible because of their substrates, but the environment is not flat and stiff. Applications like as interacting with live creatures necessitate the incorporation of soft devices and non-planar geometry. This entails using elastic, flexible technologies that can be mechanically stretched, twisted, folded, bowed, and squeezed without losing their useful properties [15]. Sensors, intelligent control, artificial intelligence, visual intelligence, and soft robotics all depend on soft actuators. They enable a variety of actions involving bending, rolling, and leaping. To lift and move objects, soft robotics requires artificial muscles. Advanced intelligent systems require multifunctional actuators for sensing, signal transmission, and control. A range of soft actuators, such as hydrogels, liquid crystal polymers, shape memory polymers, twisted fiber artificial muscles, electro-chemical actuators, and natural materials, may perform tensile and torsional actuations [16].

3. Recommendations

Based on our thorough literature review, we propose the following recommendations for the future.

- The engineers recommends integrating experimental data sets using machine learning techniques and artificial intelligence (AI) to forecast the biophysical properties, form fidelity, and printability of GelMA biomaterial inks for therapeutic tissues.
- Polymer hydrogels (CPH) are being investigated for their potential in bio-medical sensors, with the objective of developing bio-resorbable portable biosensors that are remote owing to electronics. However, their distinctive properties and work demonstrate significant advances in the production of flexible electrical parts. CPHs have demonstrated significant potential as materials for all-organic diagnostic, wearable, and implantable sensing structures.
- The investigations reveal the distinct physiological properties of evaluating the importance of the silk matrix components in in vitro tissue constructs, outlining present research concerns, and suggesting future lines of inquiry for creating intricate and biomimetic silk protein-based microtissues.
- It is critical to evaluate, characterize, and standardize Silk Fibroin-based bioink formulations in order to avoid possible photo-initiator harmful effects in vivo. Prior to designing in situ systems that satisfy tissue mechanical, cellular, vascular, and innervation demands, improvements must be made.
- The research reveals that sericin allows for the long-term preservation of silk feedstocks, which is crucial for the natural silk spinning process and possible industrial uses. It can also induce long-range conformational and stability control in silk fibroin.
- Sericulture digitization is critical for a digital society because it enables wiser industrial growth and scientific rural government. In rural digital development, national assessments lower the risks of uncertainty, especially when resources are scarce, and look into efficient ways to apply and expand digital technology in villages.

Conclusion

Silk fibroin (SF) is an important component in 3D printing inks due to its biological significance, biodegradability, and immunological tolerance. With a short crosslinking period and a regulated projection region, photo-crosslinking allows for high-resolution 3D printing. SF was recently treated employing a variety of photo-crosslinking techniques, including photo-oxidation, which preserves protein structure while removing chemical alteration. Methacrylate free radical polymerization necessitates chemical modification and organic solvents, but it improves photo-crosslinking efficiency. SF has been effectively converted into multiple 3D printing/additive manufacturing processes, demonstrating anatomical precision and cytocompatibility, making it attractive for therapeutic applications. Various printouts, including trachea and bone scans, show encouraging outcomes. SF, a soft material, possesses distinguishing characteristics including biocompatibility, biodegradability, nontoxicity, mechanical strength, and simplicity of procurement. However, its softness limits its practicality. Functional groups that involve metha-cryloyl and norbornene are used to generate cross-linkable sites. Several ways are described, including the impact The primary sources and the procedure from extraction and degumming to the ultimate alteration. MA, IEM, GMA, and norbornene are some of the metha-crylation reagents employed. The storage moduli of SFMA and SFNB hydrogels may differ based on parameters such as SF source, modification degree, initiator concentration, UV intensity, pH, and solvent variety. The study looks at the potential of SFMA and SFNB-based bioinks, as well as their composites, in regenerative medicine and tissue engineering applications. It anticipates that new micro-fabrication processes, like microfluidics and wet-spinning, will broaden the applications of these materials, including micro-capsules and micro-fibers. However, superior ink compositions and characterization are required for optimal in situ 3D printing.

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Chapter 9

Sericulture 4.0: Innovation Meets Tradition in Silk Production

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Abstract

This study investigates the significance of reintroducing ancient handloom processes into current fashion culture in order to encourage environmental, cultural, and ethical practices. Its goal is to involve disadvantaged populations, create fair employment, and boost rural areas' monetary flexibility by assisting local artisans and communities. According to the study, reinstating these approaches can help to build resilience and lead to a more socially and environmentally sustainable future. Silk-based scaffolds, which imitate the extracellular matrix, are excellent for tissue regeneration and regulated medication release. Researchers are working to improve their characteristics, integrate silk with other biomaterials, and create sophisticated production processes such as 3D bioprinting. The use of bioactive compounds in silk matrices is also being investigated. Combining silk's natural qualities with new technologies such as nanotechnology, microfluidics, and stem cell engineering might result in next-generation biomedical devices and therapies, possibly changing patient care. This paper examines silk sericin's characteristics and bioactivities, as well as its uses in tissue engineering and regenerative medicine, as well as its potential for the development of flexible electrical devices and 3D bioprinting. It shows that sericin-based biomaterials may enhance clinical results in tissue engineering and smart implanted devices. This article discusses the application of silk in neural soft tissue engineering, emphasizing its potential for neuronal development, nerve guidance, and controlled medication release. It also explains how silk-based biomaterials can be used to preserve and regenerate the injured nervous system. Previous research has employed silk to improve therapies for diseases such as stroke, Alzheimer's, Parkinson's, and peripheral trauma. The article also highlights research on altering silk biomaterials to increase neuroprotection and regeneration. Biomaterial research has transformed healthcare by integrating natural biological macromolecules into high-performance, versatile materials. This has resulted in a search for low-cost, environmentally beneficial, and renewable biomaterials. Silk along with other bioinspired materials are becoming more popular because to their superior mechanical qualities, flexibility, bioactive component sequestration, controlled biodegradability, biocompatibility, and low cost. These materials have the ability to govern temporal, spatial, biochemical, and biophysical processes.

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Keywords
Bi-Voltine Silkworm Rearing, Sustainable Sericulture, Sericin, Cordyceps, Sericultural Byproducts

1. Introduction

Craft history highlights variations in the evolution of a craft, yet the basic features and essence are maintained. Craftsmen, workmanship, customer requirements, and market trends all play an important role. Consumer requirements drive craft innovation, and lifestyle changes have resulted in considerable modifications in handloom silk weaving. In the midst of a crisis, weaving in locations with various materials and textures offers enormous profitability, popularity, and advertising opportunities for professionals [1]. Handloom textures include natural filaments and dyes, lowering the textile industry's environmental effect. The decentralized strategy decreases energy reliance on hardware and transportation while adhering to economic requirements. Reviving handloom skills assists civilizations in regaining their social identity, promoting happiness and continuity. It also has tremendous financial importance, since these techniques have served as the foundation for decades of employment. Restoring handloom skills involves marginalized populations, encourages fair employment, and increases rural communities' monetary flexibility [2]. To maximize the benefits of heterosis, sericulture globally concentrates on developing first-generation hybrids. One key problem is precisely sorting breeds for hybridization based on sex in order to achieve pure hybrids free of contamination. The current methods for classifying grenas, caterpillars, cocoons, pupae, and silkworm moths by sex are time-consuming and imprecise [3]. Sericulture, which combines agricultural and non-farm activities, provides many job options for both men and women. However, there is little information on the adoption trends and profitability of hybrid Bi-voltine silkworm rearing. Given sericulture's rising relevance in rural areas, the purpose of this study is to look into the amount of adoption and socio-economic features of farmers [4]. Intangible cultural legacy can greatly contribute to rural revival in the modern era. Scholars have explored non-sericulture's significance in rural regeneration from a macro viewpoint while ignoring its influence on local revitalization from a micro one. To achieve local economic development, theoretical assistance for other sericulture bases can be offered in order to strengthen the overall sericulture sector and so promote local economic growth [5]. To maintain the community's artistic heritage, it is critical to analyze the circumstances that led to its cultural and industrial growth, as well as improve preservation strategies. Sericulture theory, and sericulture farmhouse architecture are essential. Former farmhouses and their surrounding landscapes must be adapted for both industry and the environment. Plans for the preservation and rehabilitation of Sericulture Farm, its surroundings, and underlying concerns are presented, as well as a clear path for future preservation efforts [6]. To nurture, community-based sericulture, an old practice, requires modern technology as well as ongoing socialization. However, raw supplies, human resources, and marketing issues must be handled. To address these challenges, a community-based sericulture cluster based on a partnership approach is required. Active government participation, supportive institutions, and the entrepreneurial community are all critical to its success and long-term viability [7].

2. Sericulture 4.0: Innovation Meets Tradition in Silk Production

Silk, a natural fabric spun by spiders and silkworms, is used in the textile industry and healthcare settings to mend tissue and bind wounds. Its biocompatibility, mechanical performance, predictable degradation, and silk-based materials have made it a popular choice for regenerative medicine, neural soft tissue creation, and controlled drug release. Silk also helps in the encapsulation and implantation of therapeutic stem and progenitor cells [8]. Sustainable sericulture is a global challenge, necessitating environmentally benign, commercially successful, and culturally meaningful food production. Muga culture, a traditional silk production system in Assam, India, is a model of sustainable agriculture that incorporates indigenous traditions, biodiversity protection, minimal environmental effect, economic rewards, and cultural preservation. This approach exemplifies the power of combining old knowledge with contemporary ecological ideas [9]. Silk biomaterials, particularly those derived from Bombyx mori and spiders, are highly valued in biomedical engineering because to their remarkable mechanical characteristics, biocompatibility, and biodegradability. Tissue engineering, medication delivery, wound healing, and implanted devices all benefit from their resilience, flexibility, and strength. Silk-based scaffolds, which imitate the extracellular matrix, aid in cell adhesion, proliferation, and differentiation, making them helpful in repairing tissues such as bone, cartilage, skin, and nerve. Silk fibroin matrices permit regulated drug release, allowing for focused and long-term therapeutic delivery [10]. Silk is a valuable bio-sourced material due to its mechanical properties, flexibility, bioactive component sequestration, controlled biodegradability, biocompatibility, and low cost. It regulates temporal-spatial, biochemical, and biophysical processes, and its structural and functional characteristics are being studied as scaffolds. The objective is to explore the body's natural potential to regenerate by analyzing its biophysical properties and ability to meet tissue functional requirements [11]. Sericin, a natural biomaterial generated from silkworms, is gaining popularity due to its distinctive bioactivity and great compatibility. Silkworms are classified as wild-type or silk fibroin-deficient mutants, with the latter producing varied and high-quality sericin. This sericin has uses in cell culture, tissue engineering, medication delivery, and cosmetics [12]. Sericin, a biodegradable protein found in silk, has several uses in medications, textiles, and cosmetics. In India, degummed silk is discarded, yet its potential as a nutritional supplement remains untapped. Sericin's nanotechnology has resulted in advances in biomedicine and tissue engineering, notably pharmaceutical formulations and biomaterials. Sericin conjugated nano formulations are an example of a biocompatible, cost-effective, and bio-degradable substance [13]. Sericin, a protein derived from silkworm cocoons, has been considered a waste product for ages due to a lack of knowledge. Recent research has shown that sericin-based biomaterials have cytocompatibility, low immunogenicity, photoluminescence, antioxidant characteristics, and cell-function regulating activities, making them intriguing for biomedical applications [14]. Fibroin, a crucial component in silk, is a biomaterial that is both biocompatible and biodegradable. It's employed in medication delivery systems and the creation of three-dimensional tumor models to better understand cancer biology. Sericin, a cytotoxic drug, has been utilized as a nano-carrier for therapeutic medicines. Mulberry components, such as polyphenols and anthocyanins, have anticancer activity. Sericultural byproducts have been employed in cancer treatment, suggesting their potential for designing successful medication methods [15]. **Figure 1** below shows an image of Silk Sericin that can be utilized in bio-medicines. The documentation and distribution of cultural heritage is critical, and 3D models are becoming increasingly popular for this reason. Historical silk textiles are delicate and sophisticated, making documentation difficult owing to their precise geometries and weaving processes. A novel technology, Virtual Loom, is utilized to realistically represent and make 3D prints, making them more interactive and accessible [16]. Cordyceps militaris, an entomopathogenic fungus, is famous for its anti-cancer agent, Cordycepin. Despite its rarity, artificial culture is gaining worldwide popularity. After suffocating cocoons for raw silk manufacturing, the silkworm, a major economic participant in Asian food and silk industries, produces lifeless pupae. Sericulture waste in India has the potential to be utilized as a culture media for the Cordyceps industry, helping silk growers and tribal tribes. This might lead to future financial and social development [17]. The research identifies historical silks that have had degumming, a procedure that removes sericin, to

Figure 1. Silk Sericin for Bio-medicinal purposes.

differentiate between hard and soft silk. Non-invasive ATR-FTIR spectroscopy was used to evaluate samples of silk fabrics. The ER-FTIR approach, which is rapid, portable, and commonly utilized in cultural heritage research, was applied to solve data interpretation issues for firm silk, demonstrating the difference between hard and soft silk for informed conservation [18].

3. Recommendations

Based on our thorough literature review, we propose the following recommendations for the future.

- Silk scaffolds imitate the extracellular matrix, offering structural support as well as pharmacological signals for cell adhesion, proliferation, and differentiation. They are effective in tissue regeneration and controlled medication release, allowing therapeutic substances to be administered in a targeted and sustained manner.
- Sericin, a byproduct of silk fabrication, has both ecological and commercial importance, with potential applications in food and biology. Additional study must be conducted for assisting the silk industry produce value-added products.
- Mulberry's complex composition, high in bioactive compounds, has been shown in multiple studies to have anticancer properties, showing its potential as a viable alternative medicine for cancer treatment.

- Cordyceps militaris culture could promote resource efficiency, waste reduction, and energy efficiency by recycling and reusing silkworm pupae waste and researching alternate cultivation substrates.
- Advances in biotechnology, including as genetic engineering and tissue culture techniques, may increase the efficiency and productivity of Cordyceps militaris expansion utilizing silkworm pupae as artificial medium.
- Expectations and limitations for Cordyceps militaris and silkworm pupae cultivation may be required, since adherence to food safety, animal welfare, and environmental standards can raise operational complexity and expenses.
- The analysis suggests that indirect degumming extent assessment in the industrial environment might be a potential future trend, but it will require more research and chemo-metrics for effective management.
- The suggested approach for detecting hard silk is simpler than prior ATR-FTIR spectroscopy methods since it only evaluates one wide band. Visual comparison of spectra with reference textiles can aid in identification, however principal component analysis provides a more objective comparison that focuses on anomalies.

Conclusion

Sericulture, an appealing job option for farmers, generates waste from silkworm larvae and pupae during rearing and cocoon stifling. The efficient utilization of these byproducts can benefit a farm's profitability and sustainability. This study focuses on waste formation in sericulture, both mulberry and non-mulberry, and its collection, consolidation, and reutilization in agriculture and pharmaceutical sectors as prospective media for Cordyceps militaris fungal cultivation. Silk, a natural protein fiber, is an attractive choice for biomedical engineering because to its superior mechanical qualities, biocompatibility, and biodegradability. Its distinct molecular structure offers resilience, elasticity, and strength, making it suited for a variety of applications including tissue engineering, medication administration, wound healing, and implanted medical devices. Silk biomaterials have variable degradation rates, controlled mechanical characteristics, and promote cellular development and tissue regeneration, making them excellent for a wide range of biomedical applications. The case study recommends that sericulture bases create tourism goods and experiences to attract varied consumer groups, improve their relationship with local culture, and leverage multimedia and internet platforms for successful publicity. It suggests creating additional goods and services that complement local sericulture culture, expanding collaboration with tourism, culture, and education departments to promote silkworm culture, and using network media to increase brand visibility and market impact. Sericin, a valuable biopolymer with environmental advantages, has found commercial application in a variety of sectors, including cosmetics, medicines, food, and biomaterials. Its environmental benefits and diverse uses make it an important biopolymer. Sericin's anti-aging, antibacterial, anticancer, anticoagulant, hydrophilic, moisture-absorbing, antioxidant, biodegradability, cell compatibility, and UV-protection qualities make it ideal for cosmetic and biomedical uses. Nanoscience, with its tiny size, interaction with tissue, and high surface area, holds promise for biomedical and tissue engineering applications. However, sericin is frequently thrown as effluent due to a lack of understanding. Sericin, a useful biological component found in silkworms, has a variety of applications in cell culture, tissue engineering, medication delivery, cosmetics, and functional foods. Its biological activity and extraction process improvement have the potential to broaden its applications in a variety of industries. Sericin, which contains 18 amino acids, is very beneficial in silk fibroin-deficient silkworms, which have been researched for functional food. However, there has been little research on sericin's potential in functional food.

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Chapter 10

The Future of Silk: Integrating Technology with Sericulture

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Abstract

Silk Fibroin (SF) is a versatile material that can be reconfigured into a variety of shapes like films, carpets, hydrogels, and sponges using a variety of processes. Recent advances in fabrication techniques, including as micro-patterning and bio-printing, have enabled the development of sophisticated SF-based scaffolds. These scaffolds have uses in bone, cartilage, ligament, tendon, skin, wound healing, and the tympanic membrane, with future opportunities and difficulties to address. This study examines the functional features of SF, including di-electricity, piezoelectricity, electron loss, and environmental sensitivity. It discusses silk fibroin preparation procedures as well as current advancements in its application as a basic material. The study also examines advanced works that use silk fibroin as functional components, as well as the limitations and future directions of silk fibroin-based flexible electronics. The study investigates the use of SF as a wound dressing, its efficacy in both in vitro and in vivo conditions, and its potential uses in the treatment of chronic and acute wounds, including burns. Sponge, hydrogels, nano-fibrous matrices, scaffolds, micro/nanoparticles, and films are all examples of biomaterials containing SF and its derivatives. To offer a thorough grasp of the issue, the study compares SF-based therapies to other natural polymers. This article gives a detailed summary of the current state of development for functional silk protein hydrogel. It discusses the cross-linking processes, characteristics, benefits, and limits of various hydrogels. The article also covers other forms of hydrogels, such as high strength, injectable, self-healing, adhesive, conductive, and 3D printable. The hydrogels' applications in tissue engineering, sustained medication release, wound healing, adhesives, and bioelectronics are discussed. The development opportunities and constraints of silk protein functional hydrogels are also discussed. The study's goal is to contribute to future innovation by encouraging logical design of novel mechanisms and the effective implementation of target applications.

Keywords

Silk Fibroin (SF), 3D Bio-Printing, Hydrogels, Bio-Ink, Bombyx Mori, Flexible Electronics

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1. Introduction

Silk, with its unique hierarchical structure, has extraordinary material characteristics and biological capabilities. It may be utilized to develop high-performance, multifunctional, and biocompatible materials with careful design. Computational modeling has been utilized to better understand silk's mechanical characteristics, anticipate its biomaterial qualities, and devise innovative production methods. Fine-scale modeling, mostly through all-atom and coarse-grained molecular dynamics simulations, offers an in-depth analysis of silk [1]. Silk fibers are unique materials because of their hierarchical structure and biological processes. Their biocompatibility and outstanding mechanical qualities have made them useful in a variety of technological and medicinal applications. Recent computational modeling has brought out the relationship between molecular architecture and emergent characteristics, revealing predictive power in research on novel biomaterials [2]. Silk fibroin (SF), made from Bombyx mori silkworm cocoons, have been used in fabrics and suture materials for decades. It has recently been employed as a wound dressing since it has its beneficial biological and mechanical features, which include mechanical rigidity, flexibility, biocompatibility, biodegradability, water vapor permeability, and mild antibacterial capabilities [3]. SF hydrogels have received much attention due to their assurance, biocompatibility, regulated degradation, and prospective applications in biomedicine and other sectors. However, typical silk protein hydrogels have a basic network structure and a specific function, making them less adaptable to complex surroundings. The creation of functional silk protein hydrogels has created chances to bypass these constraints, and their functional design and prospective uses have sparked global interest. This has sparked greater interest in the creation of silk protein hydrogels [4]. The design and manufacture of hydrogel materials, particularly silk proteins, has piqued attention because to their biological properties and promise in biomedicine. These natural resources may be used in hydrogels, providing value to natural resources while satisfying green production requirements, demonstrating the benefits of the 'asynchronous economization' manufacturing sector. This multidisciplinary approach is critical for a wide range of hydrogel applications [5]. A potential bio-inspired technique entails removing required silk building pieces and reassembling them into functional regenerated silk fibroin (RSF) materials with programmable formats and architectures. This method has good processing and adaptability, making it suitable for a wide range of biological applications. Novel extraction and restoration procedures have been developed to create RSF materials with similar characteristics [6]. Photo cross-linkable biopolymers are prominent in biomedical applications because of their simplicity of production, adaptability, and variety of possibilities. Silk, which is highly biocompatible, minimally immunogenic, and adjustable, has the potential to be a biomaterial in its photo-polymerizable state and mixes with other photo-curable polymers [7]. Bacterial contamination of biomaterials is a global health hazard. The creation of multifunctional biomaterials with antibacterial characteristics is an ongoing objective in biomedical applications. Due to its unusual mechanical characteristics, biocompatibility, adjustable biodegradation, and diverse material forms, SF is an extensively researched natural polymer authorized by the US Food and Drug Administration [8].

2. The Future of Silk: Integrating Technology with Sericulture

Silk fibroin (SF), the major protein that constitutes silkworm silk, has been used in a variety of high-tech applications other than textiles, including biomaterials for drug delivery and tissue engineering. Its superior mechanical features, such as processing capabilities, biological compatibility, predictable biodegradation, and diverse functionalization, have made it a valuable asset [9]. SF, a promising candidate for next-generation flexible electronics, is gaining popularity due to its superior biocompatibility and biodegradability, as well as desirable properties such as adjustable water solubility, optical transmittance, high mechanical robustness, light weight, and ease of processing. These characteristics make SF an important component in the development of biocompatible flexible electronics, particularly wearable and implantable devices, which are frequently absent in other biological materials [10]. SF has emerged as a key material in tissue engineering (TE) during the last two decades, with applications spanning from skeletons to neural regeneration. Due to its flexibility and simplicity of processing, a variety of materials have been developed to meet specific application requirements. Despite extensive research, barely a few fibroin-based medicinal items are employed in healthcare environments [11]. SF has applications in medical sectors including TE, regenerative medicine, medication delivery, and medical devices. Silk chemistry and biomaterial design advancements have resulted in the creation of novel silk-based materials and technologies. Selective chemistries could enhance silk properties involving mechanics, biodegradability, processing capacity, and biological interactions in order to address therapeutic complications [12]. TE is the process of blending cells, scaffold materials, and growth agents to regenerate or replace damaged tissue and organs. SF, a natural protein with outstanding mechanical, biodegradable, and biocompatibility qualities, is a common scaffold material for TE applications. SF may be reconfigured into a variety of material forms, including films, mats, hydrogels, and sponges, utilizing processes such as spin coating, electrospinning, freeze drying, and crosslinking. More sophisticated SF-based scaffolds are being researched employing high-precision methods like micro-patterning and bio-printing [13]. Biocompatibility, mechanical characteristics, biodegradability, as well as security are all reasons why SF is a prominent biomaterial. It was recently created as a medication carrier for cancer treatment, successfully destroying tumor cells with no side effects or drug resistance. However, few trials have been conducted on SF-based anticancer treatment. The evolution of SF-based medication delivery devices is emphasized [14]. Silk-based conductive materials are frequently employed in bio-interface applications that include artificial epidermal sensors, soft bioelectronics, and tissue, cell scaffolds. However, attaining high electrical conductivity, biocompatibility, mechanical robustness, and tissue adhesion without sacrificing other physicochemical qualities remains challenging. These materials require a combination of physicochemical, biological, and mechanical attributes [15]. 3D printing is increasing in popularity in regenerative medicine and tissue engineering due to its capacity to manufacture complex structures with variable mechanical characteristics, degradation rates, and cytocompatibility. However, the absence of bio-inks with these qualities remains an obstacle. SF, on the other hand, has great characteristics and diversity in ink [16]. The 3D bio-printing sector is making great progress, but generating critical-sized synthetic tissue structures remains a long-term aim. Silk fibroin, a natural substance with distinct structural properties, is a potential bio-ink material. Researchers used reverse engineering to enhance shear thinning behavior, printability, cytocompatible gelation, and structural fidelity in 3D bio-printing, focusing on key sources of SF [17]. 3D printing technologies allow for the construction of complicated tissue engineering scaffolds, a significant technological achievement in the tailored biomedical area. Bio-ink, a combination of materials and biological molecules, is used in bio-printing to mimic the extracellular matrix present in live organisms. Due to its exceptional features and versatility, SF may be employed to create complicated structures with variable mechanical properties, degradation rates, and cytocompatibility, making it a significant tool in the clinical setting [18].

3. Recommendations

Based on our thorough literature review, we propose the following recommendations for the future.

- Nanotechnology-enabled SF composite films have exceptional antibacterial activity, mechanical characteristics, non-cytotoxicity, cell adhesion, and water and vapor permeability, making them viable wound dressing materials.
- Bio-inspired Science Fiction Biomaterials have the potential to revolutionize material manufacturing by boosting sustainability and environmental friendliness. This might lead to high-performance deliverables that have an impact on both the scientific community and society, possibly influencing future material processing.
- Standardizations are required of modifications in fibroin microstructure over time, yet tunability may not be feasible due to lengthy manufacturing and utilization durations. Chemically cross-linked fibroin is less affected by external circumstances, but further research is needed to maintain the same biological performance as unmodified protein. Tunability may not apply to chemically cross-linked fibroin.
- Integrating diverse strategies for creating synergistic bactericidal action in SFBs is an effective strategy. However, most approaches lack sufficient characterization information and are not yet suitable for clinical use. Future research should concentrate on in vivo investigations, consistent verification test methods, and an understanding of each approach's bactericidal processes in order to improve clinical translation.
- The area of multiscale modeling of natural silks and silk-based biomaterials continues to evolve, offering challenges and opportunities. Effective molecular-to-fiber modeling can help us better understand natural silk fibers while creating beneficial biomaterials.
- SF's exceptional features, including as biocompatibility, tunable biodegradability, water solubility, excellent optical transmittance, mechanical robustness, lightweight, and simplicity of production, make it outstanding for next-generation biocompatible adaptable electronic devices.
- SF is frequently employed as substrates, encapsulating materials, and scaffolds in flexible wearable and implantable electronic devices including electronic skins, bio-absorbable electronics, and therapeutic electronics due to its desirable biological attributes.
- When coupled with 2D nanomaterials, SF has the potential for enhancing bone, cartilage, ligament, and tendon tissue engineering. It has shown promise in lowering the likelihood of scar tissue formation in skin and wounds. However, therapeutic applications are limited, necessitating additional studies for FDA-approved products produced from this biomaterial.

Conclusion

Silk-based materials are transforming several sectors due to its strength, mechanical characteristics, biocompatibility, processing, and modifiability. Bio-inspired indirect building methodologies offer great processing ability and modifiability, satisfying a wide range of biological requirements. This paper discusses common silk building components, with an emphasis on extraction techniques and design strategies for functional RSF biomaterials. Recent breakthroughs in cell material interactions, soft tissue regeneration, and flexible bio-electronic devices emphasize the significance of these methodologies in creating and changing functional RSF biomaterials, hence boosting the high-quality use of natural silk or other biomass materials. SF has enormous potential in a variety of biological applications, including wound healing. Sponge, hydrogels, nano-fibrous matrices, scaffolds, and composite films are examples of recent breakthroughs in SF-based material development. Sponges have a larger porosity, stronger mechanical strength, and faster epithelial cell and collagen deposition. Hydrogels keep burn dressings wet. Nano-fibrous matrix and scaffolds enhance porosity, oxygen permeability, and mechanical characteristics. Electro-spinning is a sophisticated method for creating nano-fibrous mats and scaffolds. SF micro-particles and nano-NPs exhibit distinguishing characteristics such as subcellular size, stability, high carrier capacity, and improved collagen fiber cell development. SF, a natural polymer, is widely employed in biomedical applications because to its superior biocompatibility, outstanding mechanical qualities, regulated biodegradation, and adaptability. Despite its lack of natural antibacterial activity, attempts have been undertaken to improve its antibacterial capabilities. The water-based processing of SF, as well as the existence of numerous functional groups, have allowed SFBs to be functionalized with a variety of antibacterial agents. Furthermore, SF's electron-donating capacity has made it an effective reducing and stabilizing agent for green production of bactericidal nanoparticles, making it easier to create antibacterial SF-based nano-composites. However, bacterial resistance, limited stability, high cost, and possibly cytotoxic consequences remain significant constraints. SF, a well investigated substance in a variety of tissue engineering domains, requires more study to bridge the gap between academic and clinical investigations. This entails extensive standards and regulatory clearances. Researchers should not be discouraged from pursuing pre-market approval, which may have harder standards and a lengthier procedure, but also provides greater confidence in the created medical device.

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Chapter 11

Sericulture 4.0: Sustainable Silk through Modern Technology

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Abstract

This chapter investigates silk fibroin's (SF's) structural characteristics and capacity to produce composites with natural materials including curcumin, keratin, alginate, hydroxyapatite, hyaluronic acid, and cellulose. The study emphasizes silk's compatibility with natural additives due to its high number of polar functional moieties. The combination of silk and natural additives produces synergistic interactions, increasing material application while reducing individual unit restrictions. It also examines the present state and problems of commercializing silk-based biomedical devices. This section discusses current biomedical research on silk nano-biomaterials, with an emphasis on their applications in bio-cargo immobilization, chemo-biosensing, bioimaging, tissue engineering (TE), and regenerative medicine. It also explores the nanoscale attributes of silk, like nano-fluidics for specific blood types. The chapter also covers the limitations and opportunities for transforming silk nano-biomaterial research into affordable, off-the-shelf biomedical alternatives. This article examines at the complicated structure and characteristics of natural silk fibers, as well as their applications in biomedicine and smart fiber technologies. It highlights the application of silk fibers in multifunctional materials due to its mechanical strength, biocompatibility, and biodegradability. The study also discusses their biological applications, which include surgical sutures, TE, and drug delivery systems, as well as current advances in smart fiber applications such as sensing, optical technologies, and energy storage. This article looks at an eco-friendly process of making mulberry spun silk fabric that reduces environmental impact and waste. The silk business pollutes the natural environment by emitting dust, smells, and gasses, resulting in high production costs and material waste. The novel method employs silk waste to minimize carbon emissions, material waste, and energy use. The article examines silk and cotton fibers to see which is more successful in atmospheric deterioration.

Keywords

Silk Fibroin (SF), Biomaterial Engineering, Fiber Bioengineering, Regenerated SF (RSF), Piezopolymer, Piezoelectric, Sericin

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1. Introduction

Silk, sometimes known as the "queen of textiles," is a sustainable biopolymer with exceptional biocompatibility, adjustable degradability, mechanical resilience, and simplicity of processing. Recent study into its nano-scale characteristics has broadened its biological uses, emphasizing its distinct role in biomaterial engineering [1]. Recent advances in silk materials have created new prospects for sustainable green energy, acting as an environmentally benign alternative to existing energy harvesters and storage devices. Silk-based energy sources are viewed as novel possibilities for flexible human-integrated applications because to their biocompatibility, biodegradability, and appealing features as a result of natural protein composition, modification methods, large-scale green manufacturing, and advanced fabrication processes [2]. Natural silk fibers are attractive for biomedical applications and smart fiber technology because of their ease of use, high mechanical qualities, varied functional groups, controlled structure, and exceptional biocompatibility. These fibers provide environmental sustainability, biocompatibility, and biodegradability, making them indispensable in modern materials science and technology, promoting the development of next-generation smart materials [3]. Due to the complexities of human lifestyles, there is a rising demand for functionalized textile materials. Nonetheless, the production processes have a detrimental environmental impact. A potential alternative is bio-mimicry, which employs chemical-intensive applications to transmit natural capabilities. While it shows promise for sustainable manufacturing, it must minimize hazardous chemical use and boost structural uses to obtain long-term results [4]. The silk textile industry's life cycle assessment (LCA), from extraction to fiber lifetime, aids in quantifying resource depletion and minimizing environmental consequences. The industrial sector contributes significantly to environmental damage. Spun silk is a type of silk that recycles waste materials at various stages. However, the spun silk sector faces significant challenges such as environmental pollution, low production efficiency, material waste, and energy exploitation [5]. Researchers are looking for greener technologies and materials due to the detrimental impacts of synthetic materials and chemicals on the environment and individuals. Silk fibroin (SF) is attracting scientific attention because to its exceptional toughness, tensile strength, biodegradability, Young's modulus, functional groups, simplicity of processing, and biocompatibility. Combining SF with natural materials might provide an alternative to chemical-based treatment methods, resulting in extensive study into silk-based biomaterials [6]. While textile production and processing processes offer desired features including stretch and moisture control, they also contribute to greenhouse gas emissions, micro-plastic contamination, and hazardous wastewater. Green alternatives, such as fiber bioengineering at the nano, micro, and macro-scales, can enhance the environmental effect and technical performance of textile materials, opening the path for a circular, sustainable economy [7]. Spun silk is a high-quality textile material with a high added value, made mostly from mulberry and non-mulberry silk waste, as well as eri silkworm cocoons. Due to market diversity, modern spinning processes are replacing traditional hand spinning. Mill spinning involves complex machinery and is employed to produce fine count silk yarn. This environmentally friendly technique is popular with ethical customers and has enormous research possibilities. Only a few commercial machinery are available for special silk spinning units [8]. Insects and arachnids create silky proteinic fiber with distinctive qualities including resistance, elasticity, stickiness, and toughness. Because of its low density, degradability, and adaptability, this fiber offers biomaterial application promise. Electro-spinning enables the development of nano-metric-scale nonwoven mats with unparalleled pore size and structure. Silk scaffolds are used in regenerative medicine, medication delivery, decontamination, and filtration. Silk is made by the silkworm Bombyx mori and the spiders Aranea diadematus and Nephila Clavipes [9].

2. Sustainable Silk through Modern Technology

Silk fibroin (SF), which is generated by the Bombyx mori L. silkworm, is an important biomaterial owing to its biocompatibility with humans, high mechanical strength, biodegradability, and physiologically active characteristics. SF has been employed in a variety of experiments to create sponges, hydrogels, nano-spheres, and films, resulting in important advances in tissue engineering and cancer treatment. Genetic engineering has also improved the characteristics of SF-derived biomaterials [10]. Natural silk fiber from the Bombyx mori silkworm is a premium raw material in the textile industry as well as a medical suture due to its great strength and flexibility. Regenerated SF (RSF), a protein derived from cocoons, has recently acquired popularity due to its simplicity of processing, improved biocompatibility, regulated biodegradation, and versatility of functionalization. This has resulted in substantial attempts to convert silk fibroin into sophisticated materials for biomedical uses, flexible optics, electronics, and filtration [11]. The usage of biologically based materials and their incorporation into living technologies may create a business opportunity for natural biopolymers. Biopolymers incorporated into implantable devices or in vitro chips for electrophysiological recording of brain cells are in increasing demand for neurological applications and neuroscience research. Bombyx Mori produces silk fibroin, a natural protein biopolymer that has uses in organic photonics, electronics, and optoelectronics. The development of silk-based material interfaces and devices aimed at bidirectional communication with brain cells is being evaluated [12]. Silk biomaterials, including particles, coatings, and assemblies, are distinct materials with diverse sizes and dimensions. These multi-scale SF materials offer adjustable architectures, outstanding mechanical characteristics, and biocompatibility, making them indispensable for biomedical and drug delivery applications. In addition to their adjustable architectures and great biocompatibility, they can be beneficial in a variety of applications [13]. SF holds promise a new generation of soft bioelectronics due to its excellent biocompatibility, tailorable biodegradability, and an impressive set of mechanical properties. Silk's adaptability in numerous material forms enables integration with implanted sensors and electronics. Currently, silk has dominated the development of resorbable surfaces for in vivo applications. However, the development of non-transient water-stable silk bio-electronics necessitates multidisciplinary methodologies for non-resorbable packaging. This intersection of demand, know-how, and potential influence on implantable applications demonstrates the enormous potential of silk in bionic relationships [14]. Silk, a natural proteinaceous substance made from fibroin and sericin, has been utilized in interior design and architecture. Researchers are combining silk's active qualities into SF to improve uniformity, paint strength, coatability, and portability. Plasma therapy can also enhance silk characteristics more quickly, resulting in active silk with attributes suited for both new and established fields. Various plasma treatments can yield active silk, which has potential in interior design and architecture [15]. The increased demand for wearable healthcare monitoring devices requires bioelectronics production that is sustainable. Green electronics seeks to replace inorganic battery-powered devices with organic, biodegradable solutions. Silk, a green material with adjustable biodegradability and flexibility, is being investigated for its usage in functional electronics due to its inherent piezoelectricity. This idea is gaining traction in the scientific and industrial communities [16]. Wearable piezoelectric sensors depends heavily on the biosafety and sustainability of inorganic perovskites and organic piezopolymers. Because of its biocompatibility and adjustable characteristics, SF is an appealing option. However, its natural piezoelectricity is minimal, limiting its practical sensing applications. SF sensors can detect joint bending and muscle movements in people, making them appropriate for wearable bio-electronics applications [17]. Piezoelectric materials derived from biological sources are rapidly being investigated because to their biocompatibility, sustainability, and capacity to adjust features through chemical modification and genetic engineering. Silk, a bio-piezopolymer generated from silkworm glands, has been intensively explored for its piezoelectric characteristics. A thorough material characterization technique was performed to evaluate the performance of a thin film produced from a silk-Aloe vera composite solution. The composite material increased piezoelectric properties, had high surface uniformity and crystallinity, and was employed in pressure sensors [18]. The expanding population and disposable goods trend, notably in the textiles sector, exacerbates the worldwide oversupply dilemma. Demand for quick fashion is strong, resulting in the depletion of non-renewable feedstocks and strain on natural fiber supply. To remedy this, we should look at our history for sustainable textile production methods. Research on regenerated protein fibers reveals the resource potential of food waste, however current manufacturing processes provide obstacles for a circular economy owing to hazardous waste creation [19]. Inadequate waste water treatment in businesses, agriculture, and homes poses a serious hazard to the ecology and human health. Traditional materials have been employed to eliminate contaminants and repurpose water resources. However, due to post-use degradation hurdles and environmental compatibility issues, natural biopolymers such as silk protein have gained popularity for their environmental friendliness, low carbon emissions, biodegradability, sustainability, and biocompatibility [20].

3. Recommendations

Based on our thorough literature review, we propose the following recommendations for the future.

- Despite substantial advances in SF-based materials, large-scale SF synthesis and nano-structure control remained significant challenges. The majority of SF materials-processing procedures are laborious and solvent bulky, and increasing hierarchical structure control for particular applications continues to be an issue.
- SF, a biomaterial that has made major advances to tissue engineering, is additionally employed in cancer treatment as a coating agent for lung and breast cancer. Molecular engineering has been exploited to improve SF for biological purposes.
- The polymer's promise for healthcare disciplines is apparent, with its increasing exposure and electro-spinning technology anticipated to inspire an abundance of initiatives in the future.
- Silk research, involving electro spinning, has resulted in nano-metric scale spinning mats for building scaffolds with precise topographies or complex embedments. However, producing an electrospinning dope from fibroin is problematic because to the gathering and handling of natural silk, which is difficult for unfarmable spiders, or regeneration using genetically engineered vectors.
- Spideroin is an innovative biopolymer with high strength, elasticity, biocompatibility, durability, and low density that competes with high-performance materials. Its distinct profile and capacity to conduct novel behaviors such as super-contraction and water-tailoring distinguish it as a one-of-a-kind and outstanding material.
- The availability of protein feedstock for textile goods, notably milk manufacturing, must be carefully considered owing to possible valorisation back into the food sector. This creates environmental, sociological, and economic concerns that must be extensively investigated in order to establish the best avenues for valorisation while balancing human nutrition and lowering the environmental effect of accelerating fashion.

- Ethical and local textile sourcing, rather than outsourcing, improves environmental benefits, gives businesses more control over manufacturing, and increases worker well-being, hence minimizing the need for outsourcing.
- Waste streams can lower fermentative bio-fabrication costs, but understanding the unpredictability of waste stream inputs and the repeatability of bio-based fiber processing is critical for moving the circular economy forward.

Conclusion

Fibroin, an ancient natural fiber with outstanding strength and flexibility, has a distinct structure, according to research. This semi-crystalline long chain of amino acids is very resilient to strain pressures and can adapt to a variety of situations. Spider silk is the most inspirational of the three, known for its biocompatibility, availability, and simplicity of manipulation, whereas silkworm silk is praised for its biocompatibility. SF-based materials are appealing biomaterials because of their distinct structure, low weight, outstanding mechanical capabilities, flexibility, optical transparency, thermal stability, biocompatibility, controlled biodegradability, variety in material format design, and mild aqueous processing. Green technology for extracting and fabricating reverse-engineered SF have been developed for medicinal, electrical, optical, and filtration use. Bio nanotechnology, including nano-imprinting, patterning, restricted alignment, and 3D printing, can help to accelerate the development of SF-based materials for a variety of applications. SF, a protein produced by B. mori, is a primary structural component of silk and possesses unique qualities such as biocompatibility with human beings, mechanical properties, and biodegradability. Its promise in medicine has resulted in breakthroughs in biomaterials including scaffolds and nanoparticles. SF's properties may be regulated and reconstructed using a variety of ways, and it has earned recognition as a green material due to its promise in a variety of applications. For enhanced environmental performance and circularity, the work advises reusing waste and byproduct streams, creating efficient fiber processing, employing perfluorinated, formaldehyde, and metal-free chemicals, and recycling solvents. Renewable energy sources should also be employed to make bio-fabricated textile fibers. Step-by-step improvements should be supported by a third-party LCA, which should be incorporated into environmental performance measures and industry certifications. The study describes a composite bio piezopolymer that incorporates silk fibroin solution and Aloe vera extracts, resulting in enhanced performance and homogeneity. This composite may be a viable alternative to traditional piezoelectric materials, as evidenced by the fabrication and characterization of a pressure sensor. Thin films might be employed in transducers, energy harvesters, and self-powered systems, proving their practicality.

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Chapter 12

Silk and Technology: The Rise of Sericulture 4.0

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Abstract

This study examines current advancements in microencapsulation technology for the use of silk fibers. It defines the fundamental concept and technology, discusses the adhesion between microcapsules and Silk fibroin (SF), and highlights the application and impact of microencapsulation technology in SFs. It also covers the possible obstacles and opportunities for microencapsulation technology in natural SFs. SF produced by B. mori silkworm cocoons may be blended with other biomaterials to create biopolymer composites. Recombinant DNA technique enables genetic control over silks. Silk proteins may be converted hydrogels, films, sponges, and electrospun carpets, among other materials. These environmentally friendly materials offer sustainability and adaptability in specific applications. Controlled-release systems, degradable devices, and tissue engineering have been the focus of recent bio-nanotechnology advances in silk-based materials' manufacture and functionalization techniques. Because of their unique structure and high nitrogen content, silk materials can be transformed into naturally nitrogen-doped and electrically conductive carbon materials. Soft electronics applications for these materials include textile electronics, bio-resorbable electronics, ultra-conformal bioelectronics, transient electronics, epidermal electronics, flexible transistors, resistive switching memory devices, and conformal biosensors. A variety of technological formats for functional soft electronics, including bio-resorbable electronics, ultra-conformal bioelectronics, transient electronics, epidermal electronics, textile electronics, conformal biosensors, and flexible semiconductors, are made possible by silk fibers, textiles, and re-engineered silk materials. The study explores new scaffold design techniques that employ SF, a natural polymer, and indirect 3D-bioprinting technology. The scaffolds are bio-compatible and have adjustable mechanical strength, which can be regulated by adjusting the SF content. The approach produces flexible scaffolds, which makes them excellent for bio-engineering soft and musculo-skeletal tissues, and the solvent may be modified for controlling the entire procedure.

Keywords

Silkworm Silk, Bio-Inspired Spinning, Sericultural Regions, Tri-Boelectric Nano-Generators

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1. Introduction

Silkworm silk, renowned for its lightweight, high strength, flexibility, and luster, has been used for thousands of years in the textile business. It is a desirable biomedical material because to its non-immunogenicity, biodegradability, and biocompatibility. Silk medical devices used in reconstructive surgery and sutures have FDA approval. Silkworm silk has drawn attention to electronics and photonics due of the increasing need for biodegradable and implantable medical devices [1]. Natural protein-based biomaterials called silks have been artificially created for usage in consumer goods, devices, and biomedical engineering. Silk is now a viable biomaterial for tissue engineering, drug delivery, and biodegradable medical devices because to bio-inspired spinning and advanced biopolymer processing [2]. Because of its mechanical properties, biocompatibility, and biodegradability, silk, a protein-based biomaterial, has potential for use in biomedical applications. Improvements in methods for treating silk have resulted in functional biomaterials, however the majority are natural silk proteins with minor chemical modification. Creating silk-based fine compounds with specific functionalities might broaden silk materials' applicability, particularly in biomedical domains [3]. Spider and silkworm silks are significant materials in materials science because of their exceptional mechanical qualities and potential for biologically useful composites. The study of raw silks and silk-based composites while managing processing conditions is critical for advances in silk usefulness. An interdisciplinary approach is required while researching silk and its by-products [4]. As the global use of wearables develops, researchers are looking at the bio-mimetic possibilities of natural fibers such as spider silk. These fibers, made from proteins in a water solvent, outperform synthetic fibers and may be tailored to certain ecological circumstances. However, obstacles include restoring mechanical performance, increasing production, lowering silk manufacturing costs, comprehending silk genome sequences, and developing precise artificial spinning techniques [5]. The potential health-related uses of soft bioelectronics have piqued the curiosity of material scientists, electrical engineers, and biomedical scientists. Silk, an ancient natural biopolymer, has distinct advantages such as biocompatibility, programmable biodegradability, processing capacity in a variety of material shapes, and large-scale sustainable manufacturing. Silk has been developed into sophisticated materials such as silk fibers, textiles, nano-fibers, films, hydrogels, and aerogels during the last decade thanks to advances in material processing techniques and research [6]. Silkworm strain genetic stocks have been conserved in public research centers for millennia, ensuring that sericultural regions retain diverse genotype collections. Most regions continue to raise silkworms for cocoon manufacture. Mori-culture is required since the Because mulberry leaves are the only food source for larvae, organizations dedicated to preserving B. mori genetic resources also preserve collections of mulberry germplasm [7].

2. Silk and Technology: The Rise of Sericulture 4.0

A biodegradable protein that is kind to the skin is called silk fibroin (SF). biocompatible, and has minimal immunogenicity. It has limits in terms of water filtration, antimicrobial capabilities, and conductivity. It is not appropriate for sensors or tri-boelectric nano-generators that lack conductivity. The mechanical and anti-inflammatory characteristics of SF are important in tissue engineering for wound healing. Physical and chemical adjustments might improve SF characteristics and broaden its applications [8]. SF is adaptable and may be treated into a number of shapes for applications including tissue engineering, drug delivery, and bio-device substrates. Fabrication improvements have permitted the combination of silk fibroin with other nano-materials for particular uses such antibacterial qualities, UV light resistance, cell imaging, and sensing. The increasing prevalence of wearable and intelligent gadgets has led to the usage of silk fibroin as an active component in optical and electrical equipment [9]. A flexible sensing platform based on SF films is being developed for environmental and health monitoring, anti-counterfeiting, and stealth applications. The gadget has a high humidity responsiveness, flexibility, and noncontact capabilities, sensing human health indicators like as breathing, voice, and fingertip movement. The bionic structure can function as a color humidity indicator, with visible color shifts, reversibility, and stability [10]. Natural polymers are used as biomaterials for tissue engineered scaffolds due to their biocompatibility. However, creating 3D scaffolds with enough mechanical strength remains difficult. Despite advancements in 3D-bioprinting technology, scaffold production with natural polymers with customizable mechanical characteristics remains a difficulty [11]. The ability of 3D bio-printing methods, including inkjet, laser, and extrusion bio-printing, to produce sophisticated arrangements that allow for precise control over the structure and suspension of cells. It emphasizes the use of silk as a bio-ink for producing bio-printed implants via 3D bio-printing due to its favorable properties [12]. Recent advances in 3D printing technologies, as well as the use of a wide range of functional materials and devices for various biomedical applications have been developed as a result of using silk as an ink for biocompatible constructs. This makes silk a perfect option for adaption to various 3D printing processes. [13]. Water is an essential connection between biological and technological systems, yet its high surface tension makes production at the bio-nano interface difficult. SF, a surfactant, may be utilized to process nanoscale devices using water. In terms of regulating the interfacial energy between hydrophobic surfaces and water-based solutions, it outperforms commercial surfactants and expands surface coverage. This results from silk's amphiphilic character and adapts to a variety of substrates [14]. Microencapsulation technique improves the value and distinctive functionalities of SF functional finishing by encasing finishing chemicals and specific functional ingredients in polymer film-forming materials. These microcapsules preserve the functional components and can only be ruptured or released during processing or usage when exposed to external circumstances such as pressure, friction, or temperature. This procedure permits microcapsules to be released via the diffusion action of the microcapsule shell [15].

3. Recommendations

Based on our thorough literature review, we propose the following recommendations for the future.

- The diversity of silk products has resulted in a growing demand for multi-functional adhesives, which have higher performance requirements. Adhesives are presently being developed for modified, reactive, multifunctional, nanometer, and other uses in new energy, energy conservation, green environmental protection, and expanding sectors.
- Regenerated silk fibroin mesoscopic doping solves issues with chemical stability, low water and temperature resistance, and high brittleness. while retaining biocompatibility and biodegradability. This novel technique may be employed for human display of the electronic skin Since many parts of the human body can serve as carriers for displays, display technology on the human body is revolutionary.
- The SF nanocomposite scaffold is intended to enhance mechanical performance, allowing for optimal cell response in tests of both static and dynamic cell culture, as well as to resolve the tension between the mechanical and deteriorating properties of porous scaffolds and their porous structure.

- It is essential to replace non-biodegradable micro-plastics with biodegradable alternatives is widespread in numerous sectors. However, rigorous performance constraints and large-scale production make it difficult to substitute micro-plastic polymers with circular ones.
- Silk, a sustainable polymer, is a potential material for future use and serves as a paradigm for sustainable polymer technology. Crosslinking and plasticization techniques provide new avenues for studying the interaction between science, structure, and degradation kinetics.
- The demand for soft, flexible substrates for on-skin electronic devices and sensors has fueled substantial development in the silk plasticization area. This brings up opportunities in domains such as implantable bioelectronics, soft robotics, bionics, and human-machine interfaces. It has also increased our understanding of structural changes and silk self-assembly, allowing us to build 3D and porous silk materials.

Conclusion

Since 2010, fresh developments in microcapsule technology have emerged, including electro-spinning and electrospray, which provide great efficiency, excellent release, and stability. However, commercial applications are hampered by poor throughput. These difficulties will be remedied when materials and equipment mature and continue to innovate. Silk items are getting more intelligent, with materials that clean, wear, and mend themselves. As researchers get a better grasp of microcapsule technology, more high-value and commercial items will emerge, ushering in the era of silk intelligence. Covalent crosslinking has enabled silk to interact with current production technologies like as 3D printing and photolithography, allowing it to be processed into intricate 2D and 3D patterns. This is required for optical, electrical, and photonic devices, as well as human tissue replication for biomedical purposes. However, the processing of unmodified silk into complex patterns and 3D structures is an emerging technology, and understanding the dynamic changes in electrically crosslinked silk over time remains challenging. Silk-based protein materials are becoming more popular for Bio-inks for 3D printing because they are immunologically tolerant, flexible, mechanically sound, cytocompatible, and biodegradable under control. The study investigates the silk's adaptability to several printing processes, concentrating on creating precise two-dimensional structures. While VP offers complex structures and great resolution, ME is frequently used due to its material flexibility but low resolution and form fidelity. On the other hand, silk-based printing materials for the VP process are quite limited. The study highlights the silk's adaptability to a range of printing processes.

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Chapter 13

Revolutionizing Sericulture: From Mulberry to Market with Technology

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Abstract

Mulberry, a deciduous woody perennial tree, is native to the northern and southern hemispheres. It is found at altitudes ranging from sea level to 4000 meters. However, mulberry is facing challenges as a result of global warming, industrialization, and urbanization. To carry on cultivating and provide income for rural people, contemporary biotechnological methods must be exploited to generate novel varieties with increased productivity and adaptability. This chapter discusses mulberry origins, distribution, taxonomic position, genetic resource characterization, growing strategies, biotechnology advancements, and molecular biology applications. Mulberry, a plant with numerous sustainable attributes, is cultivated for its economic value and sustainability. It is primarily used in the sericulture industry for silkworm feeding, enhancing the manufacturing of raw silk for commercial use. To ensure environmental safety, mulberry is also used in the food, beverage, cosmetic, and pharmaceutical industries. Mulberry continues to be a crucial crop plant for economic growth and a sustainable future despite its many advantages, making it an essential resource for rural economies. Silk reeling machines are used throughout Africa, Europe, Central Asia, and the Near East to manufacture raw silk and handcrafted goods.These machines include standard wheel machines, enhanced two-end reeling machines, direct multi-end reeling machines, and multi-end reeling machines with compact reels. Some primitive machines need a lot of effort and may be replaced with contemporary ones that are specifically built for the cottage industry without a large expenditure. This study investigates the feasibility of vertical farming techniques such as hydroponic, aero-ponic, and aqua-ponic systems for mulberry propagation in controlled conditions. These techniques can boost protein content in meals and extract physiologically beneficial components for phyto-therapy. However, these approaches need the availability of space and irrigation, both of which vertical farming systems can readily provide. The objective of this article is to assess their application to sustainable and safer agriculture methods.

Keywords

Mulberry, Commercial Raw Silk, Genetic Engineering, Soil-Mulberry-Silkworm System, Medicinal Plant, Black Mulberry, White Mulberry Fruit

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1. Introduction

Mulberry, a perennial, resilient plant, is grown around the world in temperate, tropical, and subtropical climates. Traditional breeding can increase leaf output and quality, which has a direct influence on cocoon production and economy. In sericulture practices, traditional breeding. Techniques have shown promising results in creating superior mulberry cultivars that are more resilient to drought, low temperatures, salinity, soil alkalinity, and pests and diseases, and that have higher leaf yields and better leaf quality [1]. A hardy, woody tree species, mulberry is mostly planted for the sericulture industry, which boosts rural economies. Its leaves are used to make raw silk for commercial purposes and to feed silkworms. For commercial uses, the quality and quantity of mulberry crops have significantly risen thanks to modern biotechnology techniques. Using technologies such as micro-propagation, in vitro tissue culture, callus culture, protoplast integration, marker-assisted selection, and genetic engineering, stress-tolerant mulberry varieties have been created, which have led to optimal leaf production and an excellent financial reward [2]. Mulberry, a plant with several advantages, has established itself as an important asset in a range of sectors, including sericulture, food production, pharmaceuticals, and preservation of the environment. Its unused elements can be utilized for nutrition, phytotherapy, and the extraction of physiologically active chemicals. However, the plant's distinct characteristics necessitate availability of space and water supply, which can be readily fulfilled by vertical farming technologies such as hydroponic, aeroponic, and aquaponic systems. These strategies will assist the plant overcome its limitations and maximize its potential for growth [3]. A nursery is a controlled environment for juvenile cuttings until they are ready to be transplanted into the field. The primary purpose is to generate enough high-quality seedlings to fulfill consumer demands. Using both conventional and new strategies for mulberry sapling development, including Mini clonal Technology, has shown economically viable, with Mini clonal Technology outperforming traditional propagation methods [4]. Silkworm rearing and mulberry cultivation are essential elements of Asian agriculture that support long-term development, economic expansion, and cultural preservation. In addressing heavy metal (HM) contamination, the soil-mulberry-silkworm system (SMSS) has social, environmental, and economic ramifications.HM tolerance is determined by development phases and contamination levels in mulberry and silkworm products [5]. Mulberry trees are critical for raising the silkworm Bombyx mori, giving employment and foreign cash in nations including Asian country. Mulberry trees have greatly increased crop quality and leaf output because of their high heterozygosity, which results from their out-breeding reproductive system. Conventional breeding has greatly advanced, whereas modern biotechnology technologies have not advanced as much [6]. Mulberry is a hardy perennial plant of to the genus Morus and family Moraceae. It is reasonably resistant to environmental stresses such heavy metals, waterlogging, and drought. Bombyx mori, the silkworm that makes silk thread, is fed mulberry leaves. Mulberry trees have greatly increased crop quality and leaf output because of their high heterozygosity, which results from their out-breeding reproductive system. Conventional breeding has greatly advanced, whereas modern biotechnology technologies have not advanced as much [6]. Mulberry is a hardy perennial plant of to the genus Morus and family Moraceae. It is reasonably resistant to environmental stresses such heavy metals, waterlogging, and drought. Bombyx mori, the silkworm that makes silk thread, is fed mulberry leaves. Mulberry trees can thrive in a variety of climates and soil conditions, and their significance in mitigating desertification, preserving water and soil, and managing salty land has rekindled attention [7]. Silk is a luxury material used in a variety of items, including robes, bedding, and gowns. Mulberry silk, which comes from the Mulberry silkworm, is the costliest silk. Silk production costs have grown as a result of the advent of synthetic textures like as polyester. Silk-noils, a type of short fiber, are generated by carding, combing, and spinning. Rotor spinning now provides considerable economic advantages for producing mulberry silk-noil, cotton, and polyester blended fibers [8].

2. From Mulberry to Market with Technology

The businesses aims to identify high-quality fruit mulberry varieties by gathering resources, developing gardens, and evaluating their characteristics. They intend to develop a mulberry material basis based on green food standards while also researching high-output green farming technologies. They prefer to utilize mulberry fruit to make industrial goods including juice, wine, sauce, and pigment. Mulberry industrialization is the outcome of their plan to combine production, sales, processing, and cultivation into an organic whole. [9]. Over the last decade, there has been an increase in interest in herbal or plant-based diabetic treatment options. Mulberry, a medicinal plant, has been examined for its anti-diabetic potential. In experimental animals and people, several sections of the plant, including as the leaf, root, fruit, and branches, have demonstrated substantial hypoglycemic and antidiabetic properties. The sequencing of the mulberry genome is expected to increase our understanding of the gene architectures and metabolic pathways involved in the mulberry's antidiabetic components [10]. Growing silkworms, feeding animals, and producing delicious fruit that is full of health-promoting components like sugar, carbohydrates, alkaloids, vitamins, lipids, minerals, amino acids, carotenoids, flavonoids, and antioxidants are all made possible by mulberries, a valuable economic resource. The bark of the root and stem has a high phenolic content and is astringent, anthelmintic, and purgative. Mulberries can be cultivated as trees, tall bushes, and short bushes in environments that receive rain and irrigation. They can also be reproduced through grafting, seedlings, stem cuttings, saplings, and seedlings. [11]. **Figure 1** below demonstrates the path of the silk from seed to market. Mulberry, recognized for its medicinal benefits, is extremely perishable due to its high moisture content. This raises sustainability concerns, like food waste and an increased carbon impact. Mulberry vinegar is a biotechnological solution that converts a perishable raw material into a stable product by fermenting it with a mixture of acids, sugar, and crushed mulberries. However, heat-intensive processing, which results in energy and environmental inefficiencies, is occasionally a part of older approaches [12]. Because mulberry leaves are pleasant and easy for ruminants to digest, they can also be used as a feed ingredient for non-ruminants. They provide 15-35% protein, depending on the species, and are used as supplements for dairy cattle, goats, sheep, rabbits, and pigs. Mulberry fodder has more protein than Napier grass hasn't been able to boost milk production. Whereas ruminant production uses cottonseed and canola meal, non-ruminant production uses fishmeal and soybean meal [13]. Since ancient times, black mulberry (Morus nigra) has been utilized as a traditional remedy because of its high nutritional value and physiologically active ingredients. Its components include vitamins, proteins, minerals, anthocyanin, polysaccharides, and quercetin. Extracts from these fruits have shown to be antibacterial, anti-Alzheimer's, anti-tumor, and anticancer. However, research on the therapeutic properties of this fruit is minimal, needing more research to determine its possible health benefits [14]. The white mulberry fruit is renowned for its health advantages and nutritional importance. It is a healthy snack that may be eaten either fresh or dry. This fruit's classification is inconsistent, nevertheless. A machine vision system that blends artificial intelligence and image processing was developed to address this. The system uses support vector machine classifiers and artificial neural networks to categorize data as either high or low quality. This novel technique may tremendously benefit stakeholders in the mulberry business [15]. Mulberry fruits are high in glucose, phenols, flavonoids, organic acids, tannins, vitamins, iron, potassium, and calcium. They are utilized as a medicinal plant to promote human health by extracting biologically active substances from its leaves, stems, and roots. To retain mulberry's beneficial characteristics in confiture manufacture, each technical process is examined step by step, with crucial control points dictated by temperature regimes and variations in soluble solid content [16]. The demand for health-promoting items has grown as people become more aware of the benefits of a healthy lifestyle. Ohmic heating, a new sterilizing method, is being used to sterilize indigenous berry-like fruits in Indonesia, including mulberry, bignay, and jambolana. These fruits have a high potential as raw materials for juice companies. A fixed ohmic heating system was constructed and tested on these fruit juices to determine their suitability [17].

Figure 1. Path of Silk from Mulberry to Market

3. Recommendations

Based on our thorough literature review, we propose the following recommendations for the future of the various Mulberry market domains.

- To accomplish the Sustainable Development Goals for global food security, innovative technologies and techniques to strengthen sericulture are required. It might be beneficial to switch from traditional sericulture to alternative systems that are less impacted by climate, pesticides, and water consumption, such as indoor hydroponics, aquaponics, and aeroponics.
- Black mulberry, which is high in nutraceutical components, has a variety of pharmacological qualities, including antibacterial, anti-tumor, anti-diabetic, brain damage prevention, anticancer, and Alzheimer's activity. Additionally, it has therapeutic and preventive benefits on the kidneys, liver, gastrointestinal tract, and central nervous system.
- Mulberry should be utilized in a variety of industries, including environmental safety, medicines, cosmetics, and food & beverage. To enhance genetics, it is critical to acquire and capitalize on un-adapted species, applying modern genomic tools like transgenic technology, and integrate traditional breeding approaches.
- Mulberries have an ecological influence that preserves soil and water, prevents desertification, manages salty and alkaline terrain, and protects sand forests. with a focus on recovering heavy metals in soil because to its widespread distribution, high biomass, established root system, and adaptability.
- Environmental impact assessments can encourage environmentally friendly activities by concentrating on energy efficiency and waste reduction. Microbial dynamics research can improve safety standards for non-thermal fermentation, and researching synergistic combinations of non-thermal methods can result in considerable efficiency and quality advantages.
- By computing the benefit-cost ratio and net revenue, the study ascertains the financial sustainability and feasibility of mulberry nurseries. demonstrating that commercial nurseries using mini clonal technology are extremely lucrative after the second harvest.

Conclusion

The Catalytic Development Programme (CDP), which the Indian government has suggested, aims to establish sericulture clusters in rural and tribal areas. The goal of providing quality mulberry seedlings at a cheaper cost. The program's goal is to give self-employment possibilities to entrepreneurs and jobless adolescents. The study assesses the feasibility of mulberry nursery operations by comparing net revenue and benefit cost ratios for nurseries employing traditional and innovative sapling production methods. An SVM and ANN classifier-based machine vision method was created to evaluate the quality of dried white mulberry samples. The samples' high and low quality were determined by precisely grading them. ANN classifier performed better than the other two. The creation of an opto-electromechanical system for industrial and real-time use should be the focus of future research. allowing for the automated grading of mulberry or comparable fruits based on appearance, soundness, and maturity. Mulberry is an important medicinal plant with bioactive qualities, and many researchers have discovered mulberry-based products with favorable biological benefits. Oxidative stress is a key cause of heart disease and cancer. Mulberry's high antioxidant activity may aid in the treatment of various disorders. It also inhibits lipid build-up in hyper-lipidemia-related disorders by promoting lipolysis and inhibiting lipid synthesis. Mulberry is also a unique food source for B. mori, making it ideal for year-round cultivation in locations with restricted resources owing to cold weather, soil, or land. Mulberry is therefore an effective preventive medication for fatty liver conditions.

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Chapter 14

Silk Farms of the Future: The Impact of Sericulture 4.0

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Abstract

Resources for natural fiber are abundant in Asian nations, but they have not yet been fully utilized. In terms of pleasant national demand, there was a yearly difference of millions between 2014 and 2020. Enhancing economic potential and utilization requires a comprehensive analysis. The study aimed to demonstrate the economic advantages, technological processing, and availability of natural fibers. National R&D groups, government policymakers, and academic institutions working together are critical for producing national bio-products based on home innovation and advancing the circular economy. Sericulture, meaning the art of silk manufacturing, is a complicated enterprise with important economic, social, and environmental implications. It all begins with mulberry agriculture, which includes silkworm rearing and fabric weaving. Sericulture provides long-term employment opportunities, particularly in rural regions where over 60 percent of the workforce is female. Mulberry agriculture and silkworm rearing are profitable investments, making this a significant business. Silkworm Bombyx mori L. needs nourishment to grow, and premium mulberry leaves are needed for the best cocoon creation. Applying manures and bio-fertilizers after pruning can boost leaf production and enhance mulberry quality while preserving soil fertility. Bio-fertilizers, which contain live microorganisms, colonize the rhizosphere and stimulate growth by boosting the host plant's primary nutrition source. They are renewable plant nutrition sources that may be used in conjunction with chemical fertilizers. Mulberries require main nutrients from organic manures and bio-fertilizers, since organic manures promote soil microflora proliferation and supplement the crop with minor nutrients such as NPK. The interior micro-structure of cultivated and wild silkworm cocoons is investigated in this work via means of X-ray micro computed tomography (XCT). According to the statistics, fiber percentages first decrease as fiber widths increase from the inner to the outside layer. Because of the cocoon's modest diameter, the fibers in different layers are more aligned. which is advantageous for biomaterial development. The findings emphasize the relevance of knowing the interior microstructure of silkworm cocoons for biomaterial development.

Keywords

Sericulture, Natural Silk Fiber, Muga Silkworm, Silkworms, Bombyx Mori

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1. Introduction

Sericulture is a sustainable agricultural strategy that helps rural communities by minimizing forest strain and improving soil conservation. It burns mulberry twigs and branches as fuel, lessening the need on forests. Despite its potential, mulberry production accounts for just a small proportion of arable land. Sericulture activities are being expanded, notably in upland regions and among landless households, as part of efforts to promote inclusive growth and rural expansion [1]. Natural silk fiber is gaining popularity as a possible material for multifunctional intelligent biomaterials. Its success in the fashion sector, particularly in ecologically friendly production, is driving its research into smart biomaterials for a variety of applications, including medicines, health, electronics, and optical fibers. Natural color dyeing of silk yarn with fixators and mordants has been the focus of recent research on silk fiber as a multipurpose smart biomaterial and raw material for textiles and fashion [2]. A wide range of industries, including automotive, aerospace, construction, bio packaging, textiles, biomedical applications, and military vehicles, can benefit from the renewable and biodegradable nature of natural fibers. It takes the right technological and social strategies to increase their applicability. The most promising natural fibers for domestic items can be selected with the aid of an integrated management system by using digital data on potential and associated technical methods. [3]. The Muga silkworm, a semi-domesticated species, is distinguished by its golden-yellow color and has been produced for millennia by numerous ethnic and tribal groups. This mono race, which has minimal genetic diversity, is raised in open conditions and is vulnerable to a variety of illnesses, pests, and predators. Unpredictable weather, natural disasters, disease outbreaks, and natural enemies have all had a substantial impact on muga silk output. To increase productivity, it is critical to understand the elements influencing this silkworm [4]. Hand reeled silk yarns are categorized based on physical attributes like weight, color, and circumference. Nowadays, certified inspectors select pieces at random and assess uniformity, which can be time-consuming and unreliable owing to the inspectors' expertise. To remedy this, an optical sensor device known as “Silk Check” was built to identify hand reeled silk strands, calculating their length and linear mass density in real time and precisely categorizing them into the appropriate agricultural category [5]. Silkworms are sensitive to environmental conditions; thus their rearing is focused on developing high-quality cocoons with a high silk content. Larval growth and cocoon crop quality are significantly impacted by temperature, humidity, light, and air. The quality of the leaf supply and rearing practices including feeding, cleaning, and spacing are additional elements that affect raising activities. A bad environment has a negative impact on silkworm growth, and behavior varies depending on the stage of development [6]. New low-risk control strategies and chemical pesticides, including nano-pesticides, have to be developed in response to the expanding environmental and health concerns. Given the rapid advancement of nanomaterials, a deeper comprehension of their toxicity to non-target organisms is vital. Using chitosan, silver, and zinc oxide nanoparticles, a study on Eri silkworms discovered that higher concentrations increased corrected larval mortality while lowering length, girth, and cocoon weight [7].

2. Silk Farms of the Future: The Impact of Sericulture 4.0

Silkworms have attracted people throughout the world for millennia owing of the by-products of transformation. Although industrialization and illness worries have caused a reduction, some factors still promote their existence. Proteins are the most abundant nutrition in silkworm rearing. Other nutrients are present, including as fatty acids, vitamins, minerals, and polyphenols. The amino acids metabolized by larvae and pupae in mulberry leaves, together with their amino acid composition, give silkworm by-products great nutritional potential, equivalent to or superior than fish meal and other aquaculture-specific feed products [8]. Silk is a fiber-like material composed of fibroin and sericin (SER) proteins derived from silkworm cocoons. Glycine, serine, aspartic acid, and threonine are among the amino acids that make up these proteins. SER, which can be made in a number of ways, is used in hydrogels, films, and sponges for a range of biological applications. It is perfect for cell proliferation, tissue engineering, and skin tissue regeneration because of its moisturizing, anti-inflammatory, antioxidant, and mitogenic properties [9]. The performance of local complex and simple silkworm hybrids was assessed using reproductive, biological, productive, and technical indices. The findings revealed that these hybrids outperformed control varieties, showing a great potential for silk production. Local silkworm hybrids produced more and higher-quality cocoons than international counterparts. The essay recommends expanding the volume of preparation for industrial cocoon manufacturing due to their superior performance compared to international counterparts [10]. A microfluidic method has been developed to create biological fibers from easily accessible proteins such collagen, milk, bovine serum albumin, chicken, quail, and goose eggs. High tensile strength and toughness comparable to regenerated silkworm or recombinant spider silks are produced by the crosslinking action and double-drawn treatment that follow spinning. These fibers are also utilized to suture rat and minipig models [11]. The researchers indicated that cocoon fiber widths rose from the inner to outer layers, although fiber percentages decreased at first. The fibers were better aligned with the cocoon's small diameter, with Antheraea mylitta fibers displaying the highest alignment. The fractal dimension of domestic cocoons was less than that of wild cocoons, which had higher breaking energy, initial modulus, and maximum strength. The breaking energy and peak strength of Antheraea pernyi are higher than those of Antheraea mylitta [12]. Silkworm productivity and health depend on the gut microbiota, and sericulture depends on both. SrRNA sequencing was used to examine the impact of three diets on silkworm gut microbiomes: a diet consisting only of mulberry leaves, a diet consisting solely of artificial feed, and a gradual transition from artificial feed to mulberry leaves. The findings demonstrated that the microbial diversity of the various groups varied significantly [13]. The pathogenicity of Antheraea proylei nucleo-polyhedrovirus (AnprNPV), a major impediment to oak tasar sericulture output. Transmission electron micrographs show single rod-shaped entities and occlusion-derived viruses enveloped in many envelopes. The virus exhibits tissue tropism and multiplies in all silkworm developmental stages, demonstrating its capacity to dispersed across an individual's lifespan. The potential host range for infections has been expanded by the cross-infectivity of the baculovirus identified from infected A. proylei in other wild silkworm species [14]. Since ancient times, the domestic silkworm Bombyx mori has been used to generate silk. Today, it is used to mass-produce recombinant bioactive proteins in the textile and pharmaceutical industries. Silkworms are also used for food and to cure human diseases. The purpose is to look into the biophysical and chemical features of edible silkworms in order to assess their therapeutic and nutritional potential [15]. Eri silkworm is a polyphagous worm that feeds on over host plants. However, not all food plants are appropriate for Eri silkworm rearing, with castor, kesseru, cassava, borkesseru, borpat, and payam being more suited for commercial Ericulture. Varieties and genotypes have a substantial influence on Ericulture production and profitability. The primary purpose of Eri host plant enhancement is to create perennial plants with non-bloomy red varieties, lower anti-nutrient content in cassava leaves, boost rooting power in borpat, make dwarf plants for pruning, and improve leaf production and tolerance to a variety of climatic situations [16]. Mulberry plants can benefit from the use of manures and bio-fertilizers following pruning, which increases leaf output and quality while without reducing soil fertility. Biofertilizers, which include live microorganisms, colonize the rhizosphere and boost the plant's primary nutrition sources. They are a renewable supply of plant nutrients that may be used with chemical fertilizers. Bulky organic manures stimulate soil microflora growth while also supplementing the crop with minor nutrients like NPK [17].

3. Recommendations

Based on our thorough literature, we propose the following recommendations for the future.

- It is possible to make better use of natural fibers in a range of applications by considering their basic characteristics and the relevant technologies. An integrated management system may aid in the selection of potential natural fibers for national goods, while cooperation among national R&D agencies, government policymakers, and university institutions are critical to the circular economy.
- Silkworms, a fascinating species across the world, have been employed for millennia owing to its byproducts. Despite reduction owing to industrialization and disease concerns, reasons to keep it alive include the abundance of protein found in silkworm rearing, like mulberry leaves and silk.
- A study of silkworm gut microbiota composition and functional capability demonstrated exceptional adaptation and resistance to dietary changes. Key microbial taxa, including Methylobacteriaceae, Weissella, and Lactobacillus, were shown to be differently enriched among food groups, paving the door for targeted therapies to improve silkworm health and production.
- Cooperative silkworm rearing necessitates technical expertise, which many rural farmers lack. Poor upbringing might result in crop failures and illnesses in later instars. Furthermore, many rearers cannot afford the essential equipment for ideal circumstances. To solve these challenges, cooperative raising has been created to give technical help and optimal settings, and rearing is carried out until the second or third molt.
- Researchers discovered substantial declines in fiber and average pore area in core rings for three cocoon species, with B.mori displaying greater reductions than wild cocoons. Additionally, the fiber intersection density is greatly decreased, in contrast to wild cocoons, which first diminish and then increase along the direction of the cocoon's thickness. The fibers of A. mylitta exhibit the highest fiber orientation, while the fibers of other layers of cocoons align more toward the small diameter of the cocoons.
- Both domestic and wild cocoons show notable fractal characteristics, according to the researchers. Although wild cocoons had relatively stable fractal dimension values, suggesting that B. mori's structure was more optimized from outer to inner layers, B. mori's fractal dimension was significantly reduced along the thickness direction.
- New technology should be developed to help muga silkworms live and avoid extinction. This unique asset represents our rich history and social identity, and a silk revolution is required to preserve it.

Conclusion

The study indicated that mulberry leaves treated with vermin-compost Azospirillum had a good effect on silkworm larval duration. This is due to the fact that earthworms promote microbial breakdown of organic debris, which releases nutrients to the mulberry tree. This has a direct impact on the quality of the leaves, improving their palatability and acceptability, boosting silkworm feeding efficiency, and resulting in higher cocoon yields. To assess the physical quality of hand-reeled silk yarn in real time, an optical sensor system has been put into place. The apparatus evaluates the uniformity of color variance, diameter, and denier, transforming an analog manual process into a digital one for Sericulture 4.0. The system combines mechanics and basic optical metrology to provide quick operation and ease of application. Farmers and associated peoples encounter several problems when cultivating silkworms, notably for Muga silk, which is a heritage product. Scientific research is required to understand the causes of muga silkworms and their silk output. Proper indoor rearing strategies for domesticating larvae are critical because they are extremely susceptible to climatic and environmental changes. Seridiversity and its utilization have the ability to enhance rural socioeconomic situations while also becoming a favoured industry in the Indian subcontinent. India's huge biological resources provide opportunities for development, but conservation systems must be strengthened urgently. Popularizing new technology among farmers is critical for widespread acceptance, which will change transforming the old-fashioned cottage industry into a modern, high-tech industrial endeavor. In order to change India's reputation as a traditional cottage industry to one of a modern, high-tech industrial activity, research and development should be primarily focused on poverty reduction and sustainable socioeconomic development.

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