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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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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