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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