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SILK COCOON AS A BIOMATERIAL PLATFORM FOR BIOPLASTIC DEVELOPMENT: A REVIEW

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ABSTRACT

The increasing environmental burden associated with petroleum-based plastics has intensified the search for renewable and biodegradable alternatives that also possess adequate engineering performance. Among protein-based biomaterials, silk cocoon has emerged as a promising candidate because it naturally combines silk fibroin as a structural phase and silk sericin as an adhesive and functional phase. Recent studies indicate that silk cocoon can be processed not only into conventional biomedical formats such as films, hydrogels, scaffolds, and coatings, but also into plastic-like materials suitable for sustainable product development. Particularly important advances include direct thermoplastic molding of whole cocoons into rigid biodegradable parts, plasticizer-assisted molding of silk proteins into functional plastics, and sericin-based biodegradable films for packaging applications Direct whole-cocoon molding has been reported as a zero-waste route that avoids pretreatment or extraction and uses shredded cocoons, glycerol plasticizer, and hot pressing at 632 MPa and 145 °C for 15 min to form dense parts with suitable mechanical strength, biodegradability, and hydrophobicity comparable to commercial products . In parallel, sericin–gelatin bioplastic films have shown tensile strength of 27.64 MPa, thickness of 0.072–0.316 mm, and soil-burial degradation of 85% after 14 days, indicating strong potential for disposable packaging applications. This review synthesizes current knowledge on silk cocoon structure, processing routes, material properties, biodegradation pathways, and engineering prospects, and argues that silk cocoon should be regarded as a versatile biomaterial platform for next-generation bioplastics.

KEYWORDS: silk cocoon, fibroin, sericin, bioplastic, biodegradable.

1. INTRODUCTION

Conventional plastics have become essential materials in modern life because of their low cost, durability, and ease of processing. However, their persistence in the environment has created serious ecological consequences, particularly in soil and aquatic systems. This problem has driven interest in bio-based and biodegradable materials that can be processed into functional products without relying on fossil resources. In this context, silk cocoon is attracting increasing attention because it is a naturally occurring protein-based material with hierarchical architecture, biocompatibility, biodegradability, and tunable mechanical performance [1], [2], [3], [4], [5], [6], [7], [8] [5]–[12].

Silk cocoon is primarily composed of silk fibroin and silk sericin. Fibroin serves as the structural protein and is responsible for the remarkable mechanical performance of silk fibers, whereas sericin acts as an adhesive coating and contributes hydrophilicity, biological activity, and interfacial functionality [1][11]. The cocoon contains approximately 75% fibroin and 25% sericin, and conventional processing usually removes sericin through degumming to obtain purified fibroin. However, current research increasingly suggests that both fractions have value for materials design. Fibroin offers strength, toughness, and structural stability, while sericin provides film-forming ability, higher wettability, and easier biodegradability [3], [5], [6], [7], [9].

The transition of silk cocoon from a biomedical and textile material toward a bioplastic feedstock is now supported by several important developments. Silk fibroin has been engineered into recyclable and viscoelastic bioplastic systems [10] [1], whole cocoons have been directly converted into rigid biodegradable plastic parts through thermoplastic molding [11] [3], and sericin from cocoon waste has been combined with fish-gelatin waste to fabricate biodegradable films for packaging[12] [4]. In addition, a broader body of literature on crosslinking, regenerated fibroin processing, whole-cocoon composite formation, coating technologies, and silk-based reinforced systems has provided the scientific foundation needed to understand how silk cocoon may be transformed into plastic-like materials[1], [2], [3], [4], [5], [6], [7], [8], [9], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28]. Accordingly, silk cocoon should no longer be seen merely as a biomedical precursor, but as a renewable material platform with strong potential for bioplastic development.

2. Materials and Methods

This article was prepared as a narrative review using the uploaded peer-reviewed literature related to silk cocoon, silk fibroin, silk sericin, silk-based composites, biodegradable polymers, and bioplastic-oriented processing. The reviewed papers were analyzed through a process–structure–property–application framework. This approach was chosen because the suitability of silk cocoon for bioplastic development depends not only on chemical composition, but also on how processing conditions alter protein secondary structure, densification behavior, water sensitivity, mechanical response, and biodegradation.

The literature was interpreted in four interconnected categories. The first category comprised studies on the fundamental structure and characteristics of silk fibroin and silk sericin, including regenerated silk materials, sericin functionality, silk fibroin sustainability, and cocoon-based biomaterials [1], [2], [3], [4], [5], [6], [7], [8], [9], [14], [20], [23]. The second category included works describing composite or hybridization strategies with chitosan, cellulose, collagen, hydroxyapatite, and related additives that influence strength, barrier performance, and application range [13], [15], [16], [17], [18], [19], [21], [24], [26], [27], [28], [29], [30]. The third category focused on direct and indirect routes for bioplastic processing, including thermoplastic molding, plasticizer-assisted molding, and sericin-based film formation[10], [11], [12], [31], [32], [33], [34], [35], [36]. The fourth category consisted of studies providing environmental or performance context for biodegradable plastics and sustainable packaging development, which helped interpret the broader relevance of silk cocoon-based systems [9], [12], [33], [37], [38], [39], [40]. The review was then synthesized into an IMRAD structure in order to highlight how existing evidence supports the use of silk cocoon as a biomaterial platform for bioplastic engineering.

3. RESULTS

3.1. Fundamental material basis of silk cocoon

The reviewed literature consistently demonstrates that silk cocoon possesses a highly advantageous dual-protein composition. Silk fibroin is repeatedly described as a mechanically robust protein with broad applicability in films, fibers, sponges, hydrogels, scaffolds, and solid biomaterials [1], [2], [4], [7], [8], [14], [23]. Sericin, while less structurally robust, has been shown to provide hydrophilicity, adhesion-promoting behavior, antioxidant activity, and broader functional adaptability in biomedical and bio-based material systems[3], [5], [9], [20]. These complementary roles suggest that the cocoon itself is not merely a fibroin source, but an intrinsic composite system.

A key study on fibroin–sericin composites demonstrated that whole cocoons can be directly converted into fibroin–sericin protein composites, thus avoiding complete separation of the two fractions and shortening the fabrication route. The same work emphasized that this strategy preserves native silk properties while enabling formation of films, sponges, and monoliths from whole cocoon-derived systems. This result is significant because it reframes silk cocoon as a ready-made biomaterial platform that can support both simplified processing and multifunctional material design.

3.2. Regenerated fibroin routes and structural bioplastic potential

Regenerated silk fibroin remains the most established route for engineered silk materials. The literature shows that degummed fibroin can be dissolved, reprocessed, crosslinked, and shaped into dense or porous forms with highly tunable properties [1], [2], [4], [7], [8], [14], [23]. These studies form the scientific basis for understanding how silk fibroin behaves under controlled processing conditions and how structural features such as β-sheet content affect stiffness, toughness, and degradation rate.

Among the most relevant examples for bioplastics is the development of silk fibroin-based dental bioplastic, where fibroin was transformed into a recyclable material with strong viscoelastic behavior and high bio-based carbon content[10]. This study is important because it demonstrates that fibroin is capable of functioning as a high-value bioplastic rather than only as a soft biomedical matrix. Nevertheless, the thermoplastic whole-cocoon study notes that regenerated fibroin processing remains costly and processing-intensive because it requires degumming, dissolution, purification, and freeze drying before conversion into moldable intermediates. Thus, regenerated fibroin routes provide excellent structural control, but may be less favorable for high-volume bioplastic applications than more direct cocoon-based approaches.

3.3. Sericin-based bioplastic film systems

Sericin-oriented processing emerges as a second important route, particularly for biodegradable films and packaging materials. The reviewed sericin literature indicates that sericin can be revalorized from degumming waste and used as a protein-rich, highly polar, biodegradable component in film-forming systems [3], [5], [9], [20]. This route is especially relevant to bioplastics because packaging applications often require flexibility, processability, and environmental degradability rather than very high structural strength.

The most direct evidence comes from the sericin–gelatin bioplastic film study, where sericin extracted from silk cocoon waste and gelatin extracted from fish waste were combined with glycerol, vinegar, starch, sodium hydroxide, and pigment to produce biocomposite films via extrusion. The resulting films exhibited 27.64 MPa tensile strength, 0.072–0.316 mm thickness, and 85% degradation after 14 days in soil burial tests. The study further stated that these materials have potential for packaging, containment, and disposable plastic products. These results demonstrate that sericin, despite being less structurally dominant than fibroin, is a viable raw material for biodegradable plastic films.

3.4. Direct thermoplastic conversion of whole cocoons

The strongest evidence for silk cocoon as a direct bioplastic feedstock comes from thermoplastic molding of whole cocoons. In this route, shredded Bombyx mori cocoons are packed into molds, plasticized with glycerol, and hot pressed to form dense solid parts. The reported process used 632 MPa and 145 °C for 15 min, with glycerol at 1–5 wt% to promote thermoplastic behavior. The molded bars were machinable, more hydrophobic than bamboo toothbrush handles, and had similar density.

A crucial finding of this study is that the process directly utilizes the whole cocoon without pretreatment or extraction and is explicitly described as a zero-waste route. The same article also demonstrated three biodegradation routes: immersion in protease solution, activation of protease embedded in the molded part, and degradation in planted soil. Morphological changes were observed within three weeks in soil, indicating a practical household degradation pathway. These results show that whole-cocoon thermoplastic molding is already a plausible route for producing rigid biodegradable consumer parts.

3.5. Composite design and material extension

A recurring finding across the broader silk literature is that silk performance can be significantly modified through composite design. The thermoplastic cocoon study showed that cellulose, hydroxyapatite, and chitosan can be directly mixed with shredded cocoon prior to molding, enabling one-step fabrication of structurally integrated bioplastic composites . This observation is consistent with other uploaded works on silk–chitosan laminates, silk fibroin coatings for eco-friendly packaging, nanocellulose-reinforced silk fibers, tough silk-reinforced gels, and silk fibroin–sericin one-pot composite materials [13], [15], [16], [17], [18], [19], [21], [24], [26], [27], [28], [29], [30].

Taken together, these studies indicate that the future of silk cocoon bioplastics is unlikely to depend on neat protein systems alone. Instead, the most promising direction appears to be silk-based biocomposites tailored for specific balances of stiffness, toughness, barrier function, moisture sensitivity, and degradability.

4. DISCUSSION

The results of the reviewed literature indicate that silk cocoon is best understood as a materials platform rather than a single material. Its value lies in the coexistence of fibroin and sericin, which together allow multiple bioplastic pathways. Regenerated fibroin routes are advantageous when high control over molecular structure and performance is needed, especially for high-value or specialty plastics. Sericin-rich routes are better suited to lightweight biodegradable films and packaging systems. Whole-cocoon thermoplastic molding offers the greatest manufacturing promise because it bypasses lengthy regeneration steps and enables direct conversion into rigid parts.

A major scientific theme linking all of these routes is the role of protein secondary structure. In fibroin-dominated systems, β-sheet domains are closely associated with strength, rigidity, and slower degradation, whereas amorphous regions are linked to flexibility and greater water sensitivity [4], [7], [23]. This means that processing variables such as temperature, pressure, plasticizer concentration, solvent history, and annealing route are central to silk bioplastic design. The dental bioplastic study and whole-cocoon thermoplastic study both support this process–structure–property logic, albeit through different manufacturing strategies [10], [11].

Despite the strong promise of silk cocoon, several challenges remain. Water uptake and swelling continue to be important limitations for dense silk bioplastics. The whole-cocoon molding study explicitly notes that water absorption may compromise product quality and mechanical integrity, and suggests coatings or fluorination as possible mitigation routes . Economic competitiveness is another issue. Even though direct cocoon processing is cheaper than regenerated silk solution routes, large-scale commodity replacement will still require further optimization, composite cost reduction, and lifecycle evaluation. The same study estimated the raw material cost of one silk toothbrush handle at approximately USD 0.3 and suggested that direct use of cocoons provides a significant price advantage over regenerated silk systems.

When these findings are viewed together with the uploaded example review article on ecofriendly bioplastics from biowaste, silk cocoon clearly fits within the broader trend of transforming waste-derived or underutilized biological resources into biodegradable plastics with enhanced functionality. The example review emphasizes that sustainable packaging materials depend on biowaste valorization, antimicrobial functionality, and process-property optimization, all of which are directly relevant to silk cocoon-based plastics. Silk cocoon is particularly advantageous because, unlike many generic biowastes, it already possesses a highly organized protein architecture and well-documented processability.

5. CONCLUSION

The reviewed literature supports the conclusion that silk cocoon is a highly promising biomaterial platform for bioplastic development. Its structural protein, silk fibroin, provides strength, stability, and tunable secondary structure, while silk sericin contributes functional surface chemistry, film-forming behavior, and faster biodegradation. Current evidence points to three principal bioplastic routes: regenerated fibroin systems for controlled structural materials, sericin-based films for biodegradable packaging, and direct thermoplastic molding of whole cocoons for rigid consumer products [10], [11], [12], [36].

Among these, direct whole-cocoon thermoplastic molding appears especially promising from an engineering perspective because it is solvent-free, zero-waste, and compatible with composite reinforcement. At the same time, sericin-based formulations offer a realistic route for disposable films, while regenerated fibroin routes remain essential for high-performance and highly tunable bioplastics. Accordingly, silk cocoon should be recognized not only as a biomedical protein source, but also as a renewable and versatile platform for next-generation bioplastic manufacturing.

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