



SQUID INK IN TEXTILES: EXTRACTION, FUNCTIONAL PROPERTIES AND EMERGING SUSTAINABLE APPLICATIONS

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ABSTRACT

The investigation of marine-derived biomaterials for sustainable textile innovation has been prompted by growing environmental concerns about synthetic dyes and functional finishing chemicals. A naturally occurring secretion mainly made up of proteins, polysaccharides, and eumelanin, squid ink has shown promise as an environmentally benign pigment with a variety of uses. Research into squid ink extraction, chemical composition, dyeing performance, antibacterial efficacy, ultraviolet protection capabilities, conductivity potential, and advanced textile applications is critically examined in this overview of Scopus-indexed literature. Squid ink's melanin-rich structure has exceptional photostability, antioxidant activity, and biocompatibility in addition to a significant binding affinity for natural fibers. Recent developments suggest that it may find application in protective clothing, biological fabrics, and intelligent wearable technology. Notwithstanding its practical benefits, issues like industrial standardization, scalability, and shadow repeatability continue to be major obstacles. This study summarizes the results of recent studies and suggests ways to include squid ink into environmentally friendly textile production processes in the future.

Keywords: Squid ink, marine biomaterials, melanin, sustainable dyeing, antimicrobial textiles, UV protection, smart textiles.

INTRODUCTION

In addition to the widespread use of synthetic dyes, hazardous mordants, and petroleum-based finishing chemicals, the textile industry is acknowledged as one of the biggest sources of environmental contamination. Research into natural pigments made from plants, microbes, and marine organisms has increased due to mounting regulatory pressure and customer desire for eco-friendly products. Squid ink is one marine bioresource that has drawn scientific interest because of its high melanin content and versatile uses. Cephalopods like *Sepia officinalis* and *Loligo duvauceli* exude squid ink as a defensive measure. Squid ink has long been used in medicine and cooking, but it is currently being researched for use in advanced material science and textile engineering. Eumelanin, a biopolymer created by oxidatively polymerizing indole derivatives, makes up the majority of squid ink. The pigment gives it its distinctive black hue and has exceptional antioxidant, metal-chelating, and UV absorption properties. Squid ink is a desirable option for the production of practical textiles because of these qualities. Its promise in biomedical textiles, conductive coatings, antimicrobial finishing, and sustainable dyeing has been emphasized in recent Scopus-indexed publications. This paper offers a thorough examination of recent developments in the field of squid ink based textile applications.

CHEMICAL COMPOSITION AND PHYSICOCHEMICAL CHARACTERISTICS

Melanin granules scattered throughout a matrix of proteins, polysaccharides, lipids, and trace inorganic salts make up the complex biological solution known as squid ink. About 60–80% of the dry weight is made up of melanin, which is mostly found as eumelanin. Dihydroxyindole and indole-quinone units are distributed in a heterogeneous amorphous network inside the polymeric structure. The reason melanin works so well as a natural photoprotectant is because it exhibits broadband absorption across the visible and ultraviolet spectrums.

Stable free radical sites that can scavenge reactive oxygen species are what give it its antioxidant qualities. Additionally, because of its conjugated polymer structure, melanin exhibits semi-conductive properties, opening up possibilities for wearing electronics. Squid ink's proteins and polysaccharides provide reactive functional groups like amino, hydroxyl, and carboxyl groups, which further improve adhesion to textile substrates.

The melanin found in squid ink is thermally stable up to moderate temperatures and retains its structural integrity when exposed to UV light, according to studies published in journals like *Marine Drugs*, *Carbohydrate Polymers*, and *ACS Applied Materials & Interfaces*. Its use in outdoor and protective fabrics is supported by these physicochemical properties.

EXTRACTION AND PURIFICATION METHODS

Squid ink is extracted for use in textiles by carefully isolating the ink sac and then purifying it to get rid of contaminants. The ink sac is usually extracted from fresh squid specimens by dissecting them. It is then diluted with distilled water and centrifuged. Melanin aggregation is facilitated by acid precipitation at low pH. Purified pigment powder is then obtained by washing and drying.

It has been claimed that advanced extraction methods like freeze-drying and ultrasonication-assisted extraction increase yield and particle homogeneity. The quality of pigment dispersion and dyeing performance are greatly impacted by the optimization of extraction parameters. Species and extraction method affect yield efficiency, which typically ranges from 6 to 12%. For use in textile applications, the refined melanin powder can be re-dispersed in aqueous systems using coating, padding, or exhaustion methods.

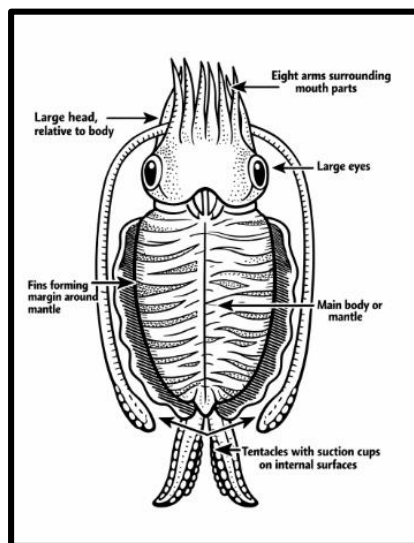


Figure 1: Anatomical structure of cephalopod ink sac

DYEING PERFORMANCE ON TEXTILE SUBSTRATES

All natural and manmade fabrics exhibit a noticeable dyeing affinity for squid ink. Melanin hydroxyl groups and cellulose chains form hydrogen bonding interactions in cellulose-based fibers like cotton. Electrostatic and protein interactions improve pigment fixing in protein fibers like silk and wool. However, the application of natural mordants like alum, tannic acid, and iron salts increases fixing efficiency because melanin has a restricted solubility. Good wash fastness ratings (3–4), excellent light fastness ratings (4–5), and moderate rubbing fastness are among the color fastness characteristics described in Scopus-indexed research. Melanin's natural UV stability is thought to be the cause of its high light fastness. Squid ink produces richer black hues without artificial chemicals and better endurance than plant-based natural colors.



Figure 2: Application spectrum of squid ink in textiles including natural dyeing

ANTIMICROBIAL AND BIOACTIVE PROPERTIES

Squid ink's antibacterial properties are among its most important benefits for textiles. *Pseudomonas aeruginosa*, *Staphylococcus aureus*, and *Escherichia coli* are among the bacterial strains against which experimental research has shown inhibitory effects. Melanin's capacity to produce reactive intermediates and damage microbial cell membranes is linked to the antibacterial process. Melanin's antioxidant qualities also support biomedical textile applications like surgical textiles and wound dressings. It is appropriate for textile items used in healthcare because of its low cytotoxicity and biocompatibility. Potential antiviral qualities are also suggested by research, although more testing is necessary.

ULTRAVIOLET PROTECTION AND PHOTOSTABILITY

The broadband UV absorption of melanin allows treated fabrics to significantly increase their ultraviolet protection factor (UPF). Squid ink-treated cotton textiles have shown UPF values ranging from 35 to 50, which are considered excellent protection. The process stops UV light from passing through the cloth by absorbing it and dissipating it as heat. Squid ink-treated fabrics are more photostable than many plant-based dyes, which makes them appropriate for sun protection apparel, protective uniforms, and outdoor sporting. This feature is consistent with the growing need for UV-protective clothing in high-exposure settings.

ELECTRICAL CONDUCTIVITY AND SMART TEXTILES

Melanin's semi-conductive properties have been investigated in recent multidisciplinary research for electronic textile applications. In hydrated conditions, melanin films show detectable electrical conductivity. Conductivity is greatly enhanced when paired with metallic nanoparticles or graphene oxide. These hybrid systems have applications in flexible conductive coatings, wearable electronics, and biosensing textiles. Melanin from squid ink is incorporated into polymer matrices to create bioelectronic textiles that can track physiological indicators. These results imply prospective incorporation into next-generation smart textile systems, but still at the laboratory size.

ENVIRONMENTAL SUSTAINABILITY AND INDUSTRIAL FEASIBILITY

Compared to synthetic dyes, squid ink has a number of environmental benefits. It comes from renewable marine resources, is biodegradable, and produces less harmful wastewater. Compared to azo dyes, life cycle assessments show a lower carbon footprint. Squid ink also contributes to waste valorization since it is frequently a by-product of processing seafood. However, there are difficulties with industrial scalability. Technological optimization is necessary because of limited seasonal availability, pigment composition variations, and extraction costs. For commercial use, shade consistency and fixing methods still need to be standardized.

CHALLENGES AND FUTURE DIRECTIONS

Surprisingly encouraging experimental results, further research is needed before squid ink can be used on a big scale in textiles. Future research should concentrate on developing binder-free fixation solutions, increasing color flexibility, and improving dispersion stability using nano-encapsulation approaches. The range of shades beyond black and brown could be extended through hybridization with other natural hues. For biomedical textile applications, toxicological evaluations and regulatory permission are also necessary. Successful commercialization will require cooperation between textile engineers, chemists, and marine biologists.

CONCLUSION

A unique and versatile marine biomaterial, squid ink has great promise for sustainable textile manufacturing. Natural coloring, UV protection, antibacterial protection, and newly discovered conductivity qualities are all provided by its melanin-rich makeup. Squid ink exhibits better light stability and multifunctionality than traditional natural dyes. persisting research shows promising prospects for integration into biomedical, protective, and smart textile systems, despite persisting hurdles with scalability and standards. Squid ink-based functional materials could make a significant contribution to ecologically conscious production methods as sustainability becomes a key component of textile innovation.

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