Green Wrap: Seaweed Biofilms Transforming Agricultural Food Packaging

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ABSTRACT

The heavy reliance on petroleum-derived plastics in food packaging has created major environmental problems, notably greenhouse gas emissions and the spread of microplastic pollution. As a sustainable alternative, edible seaweeds, often referred to as "ocean superfoods," are gaining attention. These marine resources are naturally rich in proteins (3–14.5%), polysaccharides, lipids (1–3%), minerals (7–37.5%), vitamins, and other bioactive compounds, making them valuable both as food and as renewable biopolymer sources for post-harvest uses. Key polysaccharides like alginate, carrageenan and agar can be extracted and combined with plasticizers to form biodegradable films using techniques such as casting or extrusion. The resulting films possess favourable mechanical properties (tensile strength ranging from 10.5 to 44 MPa) and can be further enhanced with essential oils to provide antimicrobial and antioxidant functions. These seaweed-derived films are already applied in packaging for fruits, vegetables, dairy, seafood, meat and bakery products, where they help extend shelf life and maintain quality. With their abundance, biodegradability and nutritional benefits, seaweed-based packaging materials represent a sustainable, plastic-free option that supports the principles of a circular economy.

INTRODUCTION

The widespread dependence on petroleum-based plastics for food packaging has intensified environmental challenges, including greenhouse gas emissions and microplastic accumulation. To address this, researchers are turning to seaweed as a renewable, biodegradable and multifunctional resource. According to Said Ali Akbar and Andi Mustari (2024), seaweed-derived polysaccharides such as alginate, carrageenan, and agar can be transformed into biofilms that not only exhibit strong mechanical performance but also provide functional benefits like antimicrobial and antioxidant activity. Likewise, Nesic *et al*. (2024) highlight seaweed's global availability, rapid biomass production and low input requirements, underscoring its value as a sustainable feedstock for bioplastics. Collectively, these studies suggest that seaweed-based biofilms offer a viable pathway toward eco-friendly packaging solutions that support circular economy principles.

Benefits of Seaweed Biofilms in Food Packaging:

Seaweed-based biofilms present a sustainable alternative to conventional plastics, being completely biodegradable and free from microplastic residues (Nesic *et al*., 2024). As a marine crop that requires no freshwater, land, or synthetic fertilizers, seaweed is highly renewable, with global production exceeding 35 million tons annually. Its polysaccharides—such as alginate, carrageenan and agar—are the key components for producing strong, flexible and protective films (Akbar & Mustari, 2024). These films can be further enhanced with natural plant extracts to provide antimicrobial and antioxidant properties, thereby extending the shelf life of packaged foods. Moreover, seaweed cultivation contributes to carbon sequestration, while the films themselves remain free from toxic chemicals, ensuring safe applications in food packaging (Nesic *et al*., 2024).

Manufacturing Process of Seaweed-Derived Packaging Materials:

Food contact materials derived from seaweed are typically produced by isolating polysaccharides such as alginate, carrageenan, agar, fucoidan and ulvan from red, brown and green seaweeds, which act as the main biopolymer sources. To improve flexibility and ease of processing, these polymers are combined with plasticizers like glycerol or sorbitol, or blended with other biobased polymers. The resulting mixtures can be fabricated into thin films, trays, cups or coatings using techniques such as solution casting, extrusion, compression or injection moulding, electrospinning and even 3D printing. Seaweed films are valued for their strong oxygen and grease barrier properties, though their sensitivity to moisture requires further modifications—such as crosslinking, incorporation of nanofillers, or addition of polyphenols—to enhance mechanical strength, stability and water resistance. Furthermore, these films can be functionalized with bioactive agents to impart antioxidant and antimicrobial activity, or with pH-sensitive compounds that enable intelligent packaging applications capable of monitoring food freshness.

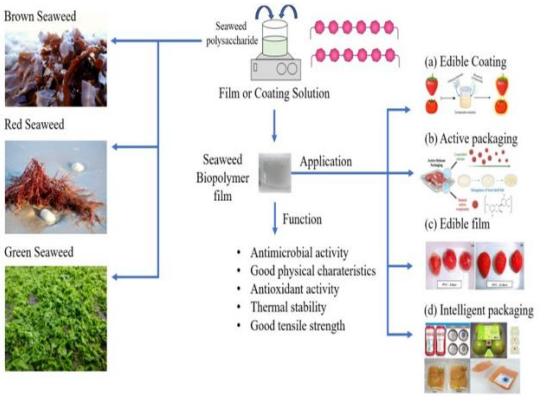

Fig. 1. The process of creating food contact materials using seaweed.

Seaweed-Derived Bioplastics: Current Market Trends:

Seaweed-based packaging has begun to establish a presence in international markets, with numerous startups pioneering innovations in this space. In the UK, companies such as Notpla produce edible pouches and coatings, while Kelpi and FlexSea specialize in films and composite materials and PlantSea develops paper products and pods. Across Asia, Evoware and Biopac in Indonesia are recognized for edible cups, sachets and wraps, whereas Zerocircle in India focuses on creating films and coatings. In the United States, Sway manufactures polybags, Carbonware develops coatings and Loliware is known for seaweed-based drinking straws. Beyond these, firms like Marea in Iceland, Noriware in Switzerland and ULUU in Australia are advancing biodegradable films, tableware, and rigid products. Collectively, these innovators highlight the growing commercial potential of seaweed as a sustainable alternative to conventional plastics.

Fig. 2. Seaweed-based packaging on the market.

Constraints of Seaweed-Based Food Packaging Materials:

While seaweed-based food contact materials present an eco-friendly alternative, they are not without challenges. Their strong hydrophilic nature leads to poor resistance against water vapor and the resulting films often exhibit brittleness, low tensile strength and limited thermal stability (Rani *et al*., 2024). High sensitivity to moisture and vulnerability to microbial degradation further shorten shelf life, while large-scale production through techniques such as extrusion and molding remains costly and less efficient (Gupta & Ahmed, 2023). Moreover, elevated processing expenses and the lack of standardized regulatory frameworks hinder their widespread commercialization when compared with conventional plastics (Rani *et al*., 2024).

CONCLUSION:

Seaweed biopolymers offer a renewable, biodegradable alternative to plastics, with potential for active and intelligent packaging. However, challenges like high hydrophilicity, weak stability, short shelf life, and high costs limit large-scale use (Rani *et al*., 2024; Gupta & Ahmed, 2023). Future efforts should focus on strengthening material properties and developing cost-effective processing, supported by clear regulations, to enable seaweed-based packaging in sustainable food systems.

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