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A Review on Innovative Use of Alginate Based Hydrogel from Brown Algae

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Abstract

This article is based on recent review of alginate-based hydrogel and its application in various fields. Hydrogel are three-dimensional, crosslinked, hydrophilic polymeric networks that can swell in water and absorb significant amounts. When exposes to polyvalent cations such as calcium, it can form gels. Their ability to retain a significant volume of water, while maintaining structural integrity makes them valuable in various applications in fields such as biomedical engineering, pharmaceutical industry, drug delivery, tissue engineering, etc. Alginatea polysaccharide found in brown algae, is extracted from these algae example *Laminaria (Kelps), Macrocystis (Giant Kelp), Sargassum, Ascophyllum (Rockweed), Fucus (Wrack), Saccharina japonica (Kombu)*. Additionally, they are highly beneficial in agriculture, as they enhance soil moisture retention and nutrient delivery, thereby boosting crop yield. Recent application of alginate hydrogels are also being utilized in 3D bioprinting to create complex tissue structure, advancing the field of tissue engineering. Future research aims to develop alginate hydrogels that can deliver drugs in a controlled, sustained, and targeted manner. By combining alginate with naturaland synthetic polymers, as well as bioactive agents, its properties are enhanced. These advanced hydrogels can be used in applications such as dermal tissue regeneration, cancer treatment, and antimicrobial therapies. Futhermore, alginate hydrogels are being explored for environmnental protection, including water remediation and oil spill cleanup. They are also exposed to see increased use in cosmetics and personal care products due to their moisturizing and flim-forming properties. This review article is a collective study on the production and applications of alginate-based hydrogels.

Keywords: Hydrogels, Regenertaive medicine, Sodium alginate, Drug delivery, pharmaceutical, Biomedical engineering

1. INTRODUCTION:

Brown algae constitute a diverse group of algae known for their distinctive coloration, which spans from olive green to lite golden brown. Their size varies from small, thread-like structures to large, intricate seaweed formations. The charcteristicsof brown algae stems from their chromatophores, which contain the golden brown xanthophyll pigment called fucoxanthin. This pigment, along the carotenoids, masks the underlying the chlorophyll c and a, as well as other xanthophylls, resulting in the brownish appearance. Brown algae exhibit a wide range of sizes,from tiny filaments to the largest marine algals species. The majority of the organisms are found inhabiting the intertidal zone [1]. Brown algae serve as a valuable reservoir of biologically active compounds, including proteins,aminoacids, polysaccharides, fatty acids, vitamins , minerals, dietary fiber, sterols, pigments and, polyphenols. In recent years , researchers have shown growing interest in various polysaccharides found in the cell walls of brown algae, particularly laminarins, alginates, and fucoidans. These substances exhibit significant potenial for biological applications across multiple industries such as functional foods, cosmeceuticals and pharmaceuticals [2]. Brown macroalgaes cell walls and intercellular matrix primarly consist of alginate, a polysccharides component. It is a linear polysaccharides composed of two conformational isomer resuides: β-D-mannuronic acid (M) and α-L-guluronic acid (G) connected through 1,4-glycosidic linkages[3]. The molecular chain has an irregualr block layout with varying G-G, M-G and M-M blocks proportions [4]. Brown seaweed is the source of alginate, a substance that has found extensive applications across various industries. Its versatility is evident in its use for immobilization techniques, regenerative medicine, pharmaceutical production, and food processing. In the food sector, alginate serves multiple purposes, including stablization, geltation, thickeneing, and as an edible protective layer for certain food items. Additionally, the textile industry has incorporated alginate into its processes [5]. Commercially, alginate is mainly extracted from brown seaweed sodium soluble alginate. The most commonly used extraction process is the compentional method that implies six steps: pretreatment of the algal biomass, acid treatment , alkaline extraction, precipitation, bleaching and drying [6]. Hydrogels are polymeric networks with a three- dimensional structure, characterized by their crosslinked nature and hydrophilic properties. These materials have the ability to expand in water and retain substantial amounts of it. The polymer chains within hydrogels are interconnected exposed to water. These promising materials have been widely applied in the fields of biotechnology, including drug delivery [7], wound dressing [8], agriculture [9], cosmetics and personal care products [7].

2. DIFFERENT METHODS OF EXTRACTION OF ALGINATE FROM BROWN ALGAE:

2.1 CONVENTIONAL ALKALINE EXTRACTION:

This examination explores the chemical and physical characteristics of alginates their various uses and the conventional technique for obtaining alginate from brown algae seaweed. Additionally, it outlines multiple phases in the direct industrial process of extracting alginate, which involves acidification, alkaline extraction, solid-liquid separation, precipitation, conversion to the specified salt form, drying, and milling [10]. The most prevalent method for obtaining sodium alginate is the conventional alkaline extraction technique, which employs alkaline solution like sodium carbonate. This method converts the water-insoluble mixed alginic acid salts found in the algal cell wall matrix into water-soluble salts, mainly sodium alginate under alkaline conditions. The extraction process generally consist of three main stages: pre-extraction, neturalization, and precipitation/purification. This detailed approach addresses various elements of alginate, such as its sources, extraction techinque, classifications, significant properties, and uses [4]. The approach to refining the conditions for alkali treatment in alginate extraction was outlined through several alkaline processing stages. Numerous extraction trials were performed, modifying parameters like Na_2CO_3 concentration, temperatures (T1 and T2), and time periods (t1 and t2). This process clarified the properties of the resulting alginates, focusing on aspects such as their yield, molecular weight, and viscosity[12].

2.2MICROWAVE-ASSISTED EXTRACTION:

In 2024, the aim of the research conducted by scholars from multiple universities in South Korea is to enhance the efficiency of sodium alginate extraction through the use of microwave-assisted extraction (MAE). The extraction temperature was carefully controlled with the help of onboard sensors that are part of the devices built-in reaction control system [13]. Microwave technology has been effectively employed in previous studies for the extraction of carbohydrates from both agricultural residues and marine algae. Nonetheless, there was a lack of research specifically addressing the application of this method for obtaining alginate from brown seaweeds. This study aimed to determine the optimal operational parameters for microwave-assisted extraction such as temperature, power settings, duration of exposure and the ratio of solvent to biomass. The focus of the investigation was on how these factors influenced the extraction yield (EY) and uronic acid content (UA) of sodium alginate. The main objectives of the study were to measure and analyze the EY and UA of sodium alginate, as well as to assess the impact of varying temperature, microwave power, extraction time and solvent-to-biomass ratio on these metrics [14]. An extensive summary of different extraction methods, physical and chemical properties, and biomedical uses of alginates was provided [10]. To obtain alginate and its related parameters, a 14-position carousel was incorporated into the MARS-X 1500 W Microwave Accelerated Reaction System for Extraction and Digestion (CEM, Mathews, NC, USA). The microwave-assisted extraction (MAE) apparatus was set up with the following configurations: a moderate stirring speed, complete magnetron power, a 10-minute heating ramp, and a 20-minute extraction period at 100°C. Samples of brown algae were placed in extraction vessels within the MAE system, with each vessel fitted with magnetic stirrers. The microwave unit was equipped with a sensor to monitor potential solvent leaks, while temperature and pressure were continuously recorded in a designated control vessel throughout the extraction process. The entire procedure was performed according to the specified operational parameters [15].

2.3 ULTRA SOUND ASSISTED EXTRACTION:

This study investigated the use of ultrasound-assisted extraction (UAE) for retrieving alginate from the leftover material post-fucoidan extraction. The goal was to develop an environmentally friendly technique for extracting alginate from brown seaweed. The focus of the research was on the large-scale extraction of fucoidan, a significant biomolecule, from the seaweed species *Fucus vesiculosus*. The procedure involved drying and grinding the seaweed, followed by treatment with a proprietary green extraction solvent at 80°C for two hours under controlled conditions. After this step, the mixture was filtered to separate the residue from the liquid extract. The resulting byproduct was dried and set aside for further research, aimed at comparing UAE with traditional extraction methods for alginate recovery from the residual material generated in the large-scale production of fucoidan from *Fucus vesiculosus*. Additionally, the study explored the effects of various ultrasound amplitudes and sonication times on the yield of crude alginate, the percentage of alginate, and the molecular weight (Mw) [16]. The environmentally friendly ultrasonic technique was employed to extract sodium alginate from waste *Sargassum* seaweed. The goal of the team was to create this sustainable method for real-world applications, which were discussed [17].

2.4 ENZYME ASSISTED EXTRACTION METHOD:

Research on the enzyme-assisted extraction of alginate from *Fucus vesiculosus* beach wrack offers a beneficial method for acquiring sodium alginate. The scientists utilized commercial mixtures of cellulase and proteases to break down the cell walls of *Fucus vesiculosus*, investigating how the type of enzyme, its activity, and the duration of extraction influenced alginate yields, molecular weight distribution, functional groups, and purity. This eco-friendly method is considered effective for the commercial extraction of sodium alginate [18].

3. DIFFERENT METHODS OF HYDROGEL FABRICATION:

3.1 IONIC CROSSLINKING:

Different methods of crosslinking for biomedical hydrogels are investigated, including physical, chemical, and light-activated techniques. These methods are recognized for their applications in fields like wound healing, drug delivery, and the creations of engineered tissues. The research emphasizes the importance of advanced crosslinking methods in progressing the biomedical industry [19]. The development and production of biocompatible hydrogels with improved mechanical strength for biomedical purposes, along with a discussion on the progress made in the creation of hydrogels from sodium alginate.

3.2 Freeze thawing method:

A simple and efficient technique for creating sodium alginate hydrogels is the freeze-thaw method. This process consists of dissolving sodium alginate in water and then subjecting it to multiple freeze and thaw cycles. The outcome is a three-dimensional network of interconnected polymers that is utilized in numerous biomedical applications. These applications encompass injectable formulations, scaffolds for tissue engineering, drug delivery systems, and materials for wound care [20].

3.3 Chemical crosslinking:

Innovative approaches for creating hydrogels employ both chemical and physical cross-linking techniques. Scientists have evaluated the advantages and disadvantages of each method, highlighting recent advancements in natural and synthetic crosslinking agents that improve the mechanical properties of hydrogels and controlled drug release profiles. The research emphasized the significance of employing non-toxic and biodegradable crosslinking agents, particularly in biomedical applications such as drug delivery systems, tissue engineering, and medical devices [21]. Investigations into the comparative analysis of chemical crosslinking reactions and the uses of bio-based hydrogels, as well as the creation of hydrogels from sodium alginate are examined. It offers a summary of the different production methods for bio-based hydrogels, highlighting new chemical functional groups and various crosslinking techniques, while also discussing their uses in drug delivery, wastewater management, and agricultural applications [22].

3.4 Electrospinning:

The production of flexible nanofilaments using the core-shell electrospinning technique. These nanofilaments, with adjustable mechanical properties and the ability to deform, were inspired by the structure of long DNA chains, making them suitable for biomedical applications, such as drug delivery and microfluidics. The fabrication process involved core-solution polymerization following electrospinning. Researchers outlined the mechanical properties of these nanofilaments using AFM nanoindentation tests [23].

4. Biomedical application:

4.1 Drug delivery system:

The thorough examination of studies on various biopolymers, including chitosan, alginate, starch, cellulose, albumin, silk fibroin, and collagen, was conducted. It investigated the different methods for the preparation, analysis, and application of these biopolymers within drug delivery systems. The review emphasized the potential of biopolymers to establish effective and biocompatible drug delivery systems, while also addressing the advantages and drawbacks related to their use. The article provided an overview of the current state of biopolymer research in drug delivery applications, exploring recent advancements and possible future paths in this field of research[24].

4.2 Tissue engineering:

The alginate's outstanding properties for use in tissue engineering, including its biocompatibility, gelation capabilities, non-toxicity, and biodegradability. Alginate-based hydrogel scaffolds are utilized to facilitate cellular growth, contributing to tissue repair, bone injury recovery, cartilage regeneration, and new bone formation [25].

4.3 Wound dressing:

The characteristics of hydrogel-based wound dressings include conductivity, adhesion, antibacterial efficacy, hemostatic properties, stimulation of angiogenesis, antioxidant capabilities, anti-inflammatory effects, and self-healing abilities [26]. An analysis was conducted to assess how different concentrations of lauric acid affect the mechanical and physical properties of chitosan-alginate hydrogels, aiming to enhance their performance as wound dressing materials. The research utilized commercially accessible chitosan obtained from crab shells, alginate extracted from *Sargassum* species, and lauric acid derived from palm starch. The findings indicated that a 4% concentration of lauric acid yielded the best results, generating a hydrogel with ideal mechanical characteristics, such as tensile strength and elongation at break. [8]. In 2023 highlights the beneficial effects of hydrogel-based wound dressings. These dressings have demonstrated the ability to enhance the healing process and reduce pain across various wound categories, including skin trauma, diabetic foot ulcers, and second-degree burns. Importantly, no major side effects were observed with the application of these dressings [27].

4.4 Environmental application:

In 2022, hydrogels gained prominence for their application in environmental remediation, particularly due to their exceptional absorption capabilities. Their significance was notably highlighted in the fields of water purification and oil spill cleanup, showcasing their role in preserving water resources and promoting eco-friendly practices [28].

5. Conclusion:

Hydrogels derived from brown algae present a promising option for biomedical uses, providing an ideal mix of biocompatibility, biodegradability, and safety. They can create gels under mild conditions without the need for harmful chemicals, which makes them appropriate for medical applications. Being sourced from renewable brown algae ensures that alginates are both sustainable and environmentally friendly.

6. FUTURE PERSPECTIVES:

The incorporation of carotenoids into these hydrogels creates exciting opportunities for a range of biomedical uses. By encapsulating carotenoids, their stability and bio availability are improved, allowing for controlled release and prolonged efficacy in nutritional supplements and pharmaceuticals. The fusion of alginates and carotenoids promotes sustainability and environmental friendliness, making them appealing for the development of Eco-conscious products across various industries. In terms of skincare and wound care, hydrogels rich in carotenoids offer antioxidant properties. In the food sector, functional foods enriched with carotenoids improve their nutritional profile. This innovation effectively utilizes the natural advantages of both components, resulting in advanced and sustainable products that can make a significant difference in everyday life.

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