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Review Article

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Progress on Seaweed Polysaccharide: A Review

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Abstract Polysaccharides that widely exist in seaweed have many biological activities such as regulating immunity, anti-tumor, anti-blood lipid and hypoglycemic. They are widely used in a verity of industries. Therefore, the research of seaweed polysaccharide has always been the focus. In this paper, the recent advances in the extraction, separation and purification of seaweed polysaccharides and their biological activities were reviewed. The application of seaweed polysaccharides was described in this paper.

Keywords Seaweed; Polysaccharide; Extraction; Application

Introduction

The vast ocean contains a huge amount of biological resources, and more than 30,000 kinds of algae living in the ocean is a large family of Marine life. With the utilization of seaweed resources, the study of various chemical components and their activities has become the focus of natural products. Seaweed polysaccharides are high polymer carbohydrates formed by same or different sugar groups with a degree of polymerization greater than 10 under the junction of glycoside bonds (generally 1→3 and 1→4 glycoside bonds) [1]. According to their different sources, they can be divided into red algal polysaccharide, green algal polysaccharide, brown algal polysaccharide and so on. They are important components in the plant body, and the main polysaccharides that constitute the basic skeleton of the algal body are cellulose and hemicellulose.

Seaweed polysaccharide has become a research hotspot in the fields of food and cosmetics, due to its various properties such as gel, stability and membranogenesis, as well as antiviral, anticoagulant, anti-tumor, immune regulation and other biological activities [2]. Therefore, this paper summarizes the extraction, isolation, purification and application of seaweed polysaccharides at home and abroad, in order to provide a reference for the further development and utilization of seaweed polysaccharides.

1 Extraction, separation and purification of seaweed polysaccharide

1.1 The extraction of seaweed polysaccharide

The extraction methods of seaweed polysaccharide mainly include solvent extraction method, enzymatic solution extraction method and Physical extraction method [3].

1.1.1 Solvent Extraction Method

According to the solvent type, solvent extraction method can be divided into Water extraction, acid extraction and alkali extraction method [4]. Min et al. [5] extracted seaweed polysaccharide with 80℃, pH7.0 and 10h and its yield could reach 7.8%. Wang et al. [6] added 10 times the volume of 2%Na_2CO_3 solution to the Grateloupia, stirred in 80 C water bath for 3 times/4h, centrifuged and combined the supernatant, adjusted pH with 4 mol/L of hydrochloric

acid to 7~8, rotary evaporation and concentration, precipitated by ethanol and centrifuged, and dried hot alkali to extract polysaccharide. The extraction rate was 15.2%. The alkali extraction that extracted seaweed polysaccharides reduced the polysaccharide activity, while the extraction rate is higher than water formulation [7]. Solvent extraction method is a common extraction method for seaweed polysaccharides. This method is economical and convenient to operate, but it requires multiple extraction, long extraction time, high temperature, and low extraction rate, which limits the large-scale production of seaweed polysaccharides.

1.1.2 Enzymatic solution extraction method

Enzymatic solution extraction method is to use the efficient selective action of enzymes on the cell wall and protein, increase the permeability of the cell wall, make the contents inside outflow, accelerate the release of polysaccharide and other effective components, and improve the extraction rate of polysaccharide. Enzymatic solution extraction method, high extraction rate and mild reaction conditions, includes a single and compound enzyme solution extraction method. In order to reduce the cost and improve the polysaccharide extraction rate, it is particularly important to control the amount of related complex enzymes.

Through single factor experiments and orthogonal experiments, Yang et al. [8] determined that when the amount of compound enzyme added was 480U/g, pectinase: cellulase: xylanase 11:18:11, pH4.5, 59℃, the extraction rate of fucoidan polysaccharide was up to 2.1%. Ren et al. [9] optimized the laminaria polysaccharide extraction process by enzymatic solution extraction method, and determined the extraction process conditions as: enzymatic temperature of 65℃, material ratio of 1:150 (g/mL), pH5.5, add pectase by 0.7% and cellulase by 0.3%, and immersion time of 4h, and the polysaccharide yield was 15.6%. Hardouin et al. [10] extracted ulva polysaccharide by enzymatic solution extraction method, and the results found that compared with blank control, after the treat of enzyme C4 (exo-β-1,3(4)-glucanase), enzyme P1 (a neutral endo-protease (EC 3.4.24.28) and enzyme P2 (a mix of neutral and alkaline endo-proteases (EC 3.4.24.28 /EC 3.4.21.62)), the ulva polysaccharide yield of increased by 60%, 73% and 100%, respectively

Enzymatic solution extraction method can effectively reduce the extraction temperature and time, increase the amount of polysaccharide extraction, and save energy. However, the polysaccharide extraction by enzymatic solution has its limitations and it has high requirements for experimental equipments. At the same time, the enzyme type and concentration, substrate concentration, inhibitor, optimal pH, temperature and other factors should be comprehensively considered.

1.1.3 Physical extraction method

Physical extraction method mainly breaks cells through physical measures, making the polysaccharide outflow in the cell, thus significantly improving the polysaccharide yield and reducing the extraction time. At present, microwave-assisted extraction method and ultrasonic extraction method are commonly used.

1.1.3.1 Ultrasonic extraction method

Ultrasonic extraction method utilities the cavitation effect, mechanical fragmentation and thermal action produced by ultrasonic high-frequency oscillation to cause cell wall rupture, thus making the seaweed polysaccharides dissolution. The vibration effect of ultrasonic wave accelerates the release and dissolution of intracellular substances, greatly reduce the extraction temperature and time, and improve the extraction efficiency [11].

Dai et al. [12] optimized the ultrasound-assisted extraction process of laminaria sulfate polysaccharide, and the results showed that the ultrasound-assisted extraction process required a short time and a low temperature, which can improve the polysaccharide extraction rate and maintain its biological activity. Wang Huailing et al. [13] extracted Eucheuma geltinae polysaccharide (EGP) for 30min by using single factor investigation and orthogonal experimental method, and the EGP rate was 40.3%, which was 1.4 times that of the traditional hot water extraction.

At the same time, there is also the problem caused by long-term ultrasonic action, molecular degradation of polysaccharides, which destroys the chemical structure of extraction, makes the extracted components more

complex and makes difficult for the subsequent separation [11]. In addition, the mixed noise in the ultrasonic working environment may cause noise pollution.

1.1.3.2 Microwave-assisted extraction method

Microwave-assisted extraction method is the latest extraction technology. Its principle is that under the action of microwave high-frequency alternating electromagnetic field, the polar shock of water molecules inside and outside cells can be caused, resulting in the relaxation of intermolecular hydrogen bonds, cell structure destruction, accelerating the penetration of solvent to the cell and the infiltration of polysaccharide from the cell. Compared with the traditional extraction method, the microwave extraction method can increase the extraction efficiency, reduce the use of energy and solvent, and be more environmentally friendly.

Tang Zhihong et al. [14] extracted Sargassum Fusiforme (Harv.) polysaccharide (SFPS) by microwave method. Under the optimal process, the extraction rate of water-soluble SFPS was 15.58%, 43.3% higher than the hot water extraction method, and the extraction time was 95.37% shorter than that. Yan Zhipeng et al. [15] used the response surface method to optimize the extraction process of seaweed polysaccharide. The study showed that when the temperature was 72℃ and the material-liquid ratio was 1:65, the extraction rate of sargassum horueri polysaccharide reached 12.0%. Rodriguez-Jasso et al. [16] extracted sulfuric polysaccharides (fucoidan) from brown seaweed by microwave assisted extraction and found the optimal process that the pressure was 120psi, the material-liquid ratio was 1:25, and the extraction time was 1min. Yuan et al. [17] optimized the microwave extraction conditions of sulfate polysaccharide (fucoidan) from Ascophyllum nodosum with 120℃ for 15min, and the product yield reached 16.08%.

Microwave extraction method has the characteristics of high heat effect, uniform distribution, high efficiency and energy saving, polysaccharide extraction is thorough and has little loss, but if the relevant parameters are not well controlled, it is easy to destroy the activity of polysaccharide.

The extraction of seaweed polysaccharide by physical reinforcement method can effectively improve the rate of polysaccharide, shorten the extraction time and save resources. However, because ultrasonic, microwave and other equipment are not suitable for mass production, the development of Physical extraction method is limited.

1.2 Separation and purification of Seaweed polysaccharide

1.2.1 removal of impurity

Seaweed crude polysaccharides are often a complex mixture with a wide molecular weight distribution, usually containing protein, pigment, and small molecular sugars, so this complex compound is needed to be separated and purified in order to obtain an ideal active component with high activity.

1.2.1.1 Deproteinization

Organic solvents denature protein. In general, deproteinizationl methods mainly include Sevag method (chloroform - N-butanol method), trichloroacetic acid (TCA) method, enzymatic method. For better results, proteolytic enzymes can also be added, but this method is prone to the loss of polysaccharide [18]. Tricloroacetic acid method has a good effect of deproteinization, but this method has a violent reaction, which will cause some polysaccharide glycoside bond fracture and affect the yield and activity [19]. Tang Zhihong [20] compared the effects of trichloroacetic acid method, Sevag method, enzymatic method and enzyme-Sevag method. The results showed that the effect of enzyme-Sevag method was better, and the removal rate of protein reached 89.73%.

1.2.1.2 Decolorization

Phenolic compounds are extracted during the extraction of plant polysaccharide, during which they are oxidized into pigments and affect the subsequent total sugar content detection and chromatographic analysis. The common methods of depigmentation of crude polysaccharide have cellulose ion exchange decolorization, oxidation decolorization, and activated carbon decolorization, etc. Oxidation decolorization is to utilize the oxidation characteristics of strong oxide, easy to cause polysaccharide degradation [21]. Activated carbon decolorization

method [22] is the use of activated carbon which has a porous structure, but because the activated carbon adsorb polysaccharide, resulting in polysaccharide loss. Jiang Jun [23] found that compared with activated carbon, the macroporous resin decolorization method had the least polysaccharide lost and the best decolorization effect.

1.2.1.3 Remove small molecule impurities

Dialysis method [24] is a commonly used effective method to remove small molecule impurities. When purifying the polysaccharide, the dialysis bag can be selected according to the molecular weight of the polysaccharide, and dialysis with running water can remove some pigment, inorganic salts and other impurities.

1.2.2 Isolation of seaweed polysaccharide

After purification, seaweed polysaccharide is a mixed polysaccharide, which still needs to separate the mixed polysaccharides with large different molecular weight and molecular structure to obtain the refined polysaccharides with uniform molecular weight. The separation methods of polysaccharides include column chromatography method, graded precipitation method, ultrafiltration membrane separation method, electrophoresis method, etc.

1.2.2.1 Column chromatography method

Column chromatography method, also known as chromatographic separation method, can be divided into cellulose column chromatography, ion exchange column chromatography, gel column chromatography, affinity column chromatography, etc. Among them, Ion exchange column chromatography and gel column chromatography are the most widely used.

Ion exchange column chromatography is suitable for the separation of various acidic and neutral mucopolysaccharide [25], the more common column packing models are DEAE-agarose (DEAE-Sepharose), DEAE-cellulose (DEAE-cellulose) and DEAE-gluan (DEAE-Sephadex) [26]. Gel column chromatography needs to choose appropriate specifications according to the structure of the isolated object and the molecular weight. For relatively large molecular weight, Sephadex G-100 and Sephadex G-200 are commonly used for molecular weight. Ion exchange column chromatography is mainly used to separate the single components of polysaccharides in the crude polysaccharide extract, usually by the gradient elution method.

Gel column chromatography was used to separate or desalinate [27]. Palaniappan et al. [28] extracted Monostroma oxyspermum sulfate polysaccharide by hot water immersion formulation, after anion exchange and gel column chromatography, the resulting sulfate polysaccharide contains 92% carbohydrates. In order to achieve better purification effect, the new packing model DEAE-Sepharose Fast Flow was used in seaweed polysaccharide isolation and purification. Meanwhile, the resin is chemically stable and suitable for performing large amounts of purified [25]. Peng Yongbo et al. [29] used Japanese Kjellmaniellacrassifolia polysaccharide as raw material, purified by DEAE-Sepharose Fast Flow weak anion exchange column chromatography, and obtained 5 components (F-0, F-1, F-2, F-3, F-4). Each separation component was relatively sharp and symmetrical, no tail phenomenon, separation and purification effect is better.

1.2.2.2 Grading precipitation method

The composition structure and molecular weight of polysaccharides are different, and its polarity and the solubility in organic solvents (such as alcohol or ketones) is different. According to this principle, the alcohol concentration can be increased, so that the polysaccharide was separeted and precipitated from large to small precipitation by molecular weight [25]. Tianhua [30] obtained 6 kinds of Gracilaria Chorda Holmes polysaccharides (GCP) by ethanol graded precipitation and found that the yield of GCP20, GCP40 and GCP50 precipitated in 20%, 40%, and 50% ethanol were 25%, 20% and 10%, respectively. This method is simple and easy, the one-time treatment amount is large, the key is to find out the appropriate component of the solvent.

1.2.2.3 Ultrafiltration method

Ultrafiltration method is a more commonly used efficient separation technology in recent years. It takes ultrafiltration membrane with different relative molecular masses as the separation medium, and takes the pressure difference on both sides of the membrane as the driving force to selectively separate polysaccharides with different relative molecular masses. This method has little damage to the bioactive components of polysaccharides.

He Fang et al. [31] separated Pyropiayezoensis polysaccharides (PP) by four ultrafiltration membranes with different trapped molecular weights (MWCO) and obtained five polysaccharides with different molecular weights of PP1 (MW 100K), PP2 (MW: 50~100K), PP3 (MW: 10~50K), PP4 (MW: 5~10K) and PP5 (MW 5K). Liu Hongchao [32] separated Sargassum fusiforme polysaccharides (SFPS) by ultrafiltration technology, and studied in vitro antioxidant activity of the different molecular weight of SFPS. The results showed that different molecular weight of SFPS had strong antioxidant capacity, and the smaller the relative molecular weight of SFPS was, the stronger its free radical scavenging ability was.

Column chromatography is the most effective method in polysaccharide separation and purification; Graded precipitation method is simple and low cost for large-scale industrial production, but may destroy polysaccharide activity; Ultrafiltration method is an efficient separation technology in recent years, simple equipment and large yield; Salt separation and metal complex method have simple purification effect and small application range; Electrophoresis separation is suitable for microanalysis.

2 Biological Activity of Seaweed Polysaccharide

2.1 Anti-oxidation

Reactive oxygen free radicals, such as superoxide anions and hydroxyl free radicals, are produced by human metabolism or external factors and can destroy macromolecules in the human body, such as cell phospholipid membranes, proteins and DNA. Seaweed polysaccharide can effectively inhibit the formation of reactive oxygen radicals while reducing the lipid peroxide content by increasing the activity of superoxide dismutase [33]. As a natural and pollution-free antioxidant substance, Seaweed polysaccharide is often used as a free radical inhibitor or scavenger, which has a strong application prospect [34].

Mohsind et al. [35] studied the effect of sulfate content on the antioxidant properties of ascophyllan from marine brown alga, performed radical clearance experiments on four polysaccharide fragments with different sulfate content. The results showed that the ability of radical scavenging was positively correlated with sulfate content. Lu et al. [36] analyzed the oxygen free radical absorption capacity (ORAC), 2,2-hydrazine-diammonium salt (ABTS) free radical scavenging capacity and reduction capacity of Laminaria japonica by citric acidextraction, and found that Laminaria japonica polysaccharides had significant antioxidant capacity.

In practical application, the antioxidant activity of seaweed polysaccharide has a certain inhibitory effect on delaying the aging and discoloration after fruits and vegetables are picked, and can also reduce the lipid content of peroxide,

2.2 Antivirus

Viral is a simple structure and harmful for human health by the use of host cell nutrients to multiply. Seaweed polysaccharide has a multi-link, multi-angle antiviral mechanism of action [37]. Hayashi et al. [38] found that polysaccharide of fucoidan from brownalga Undaria pinnatifida has anti-herpes simplex virus (HSV) and its mechanism may be to enhance immune defense function by directly inhibiting virus replication. Some studies have found that sulfated polysaccharide fractions from Gracilaria lemaneiformis could inhibit influenza virus reverse transcriptase activity and prevent the virus from replicating [39].

In addition, seaweed polysaccharide can also improve the resistance to the virus by enhancing the body's immune performance. For example, sulfated galactans isolated from the red seaweed Gracilaria fisheri can improve the activity of phenolic oxidase and superoxide dismutase enzyme in shrimp, and indirectly play a role in resisting the white syndrome virus [40]. This broad spectrum of antiviral properties, its relatively low production cost and low

toxicity, all make that the seaweed polysaccharide have a very broad prospect in the future development of antiviral drugs.

2.3 Immunoregulation

The immune system is an extremely complex physiological system that can protect the human body from foreign pathogens, among which macrophages are an important component of the it. A large number of studies showed that seaweed polysaccharide can regulate body immunity by regulating immune organs and immune cells, stimulating macrophages [41].

HUA et al. [42] treated the thymus and spleen with cyclophosphamide and found that mice were better immunosuppressive at the effect of a concentration of 100mg/kg polysaccharide from Sargassum fusiforme. Kim et al. [43] separated and purified polysaccharides from Enteromorpha proliferae and performed in vitro and in vivo immune tests. The results showed that the purified fraction stimulated the macrophage strain RAW264.7, Significant production of nitric oxide (NO) and a variety of cytokines can be induced by positively regulating mRNA expression. The results of the in vivo experiments showed that there has a significant effect on splenocyte proliferation; Purified fractions significantly increased the secretion of the cytokine IFN-γ and IL-2, While not changing the release of the cytokines IL-4 and IL-5. These in vitro and in vivo results suggested that Sulfate polysaccharides from Enteromorpha proliferae had strong immunostimulatory effects. Chang et al. [44] found that spirulina platensis polysaccharides modulated the immune effect of mouse cells, and the mechanism may be to stimulate the immune cells through regulating the intestinal mucosal system to produce immune factors, thus regulating the immune effect of mice.

2.4 Antitumor

Antitumor is one of the important biological activities of polysaccharides. Polysaccharide can inhibit the growth of tumor in two ways. One is to improve the immune function, regulate the level of cytokines, and then achieve the purpose of inhibiting cancer cells; Polysaccharide has complex spatial structure and diverse biological activities, and it can enhance immune surveillance function, timely identify, kill and remove mutation and damaged cells, prevent tumor occurrence and inhibit tumor growth. Several specific aspects of polysaccharide tumor suppression through immune regulation [45]: ① promoting immune cell activation, ② promoting the secretion of cytokines, ③ promoting the development of immune organs. The other is to directly kill tumor cells, inhibit tumor cell growth and protein synthesis, and realize the killing function of tumor cells [46]. Polysaccharides can stimulate cells, regulate the expression of multiple signal transduction pathways and oncogenes in tumor cells, and alter cell membrane fluidity [47].

Xie et al. [48] found that polysaccharides from three diferent matrices (Graciaria Lemaneiformis, Porphyra haitanensis, Coprinus comatus) in a certain proportion had a significant inhibitory effect on cervical cancer cells, and the inhibition rate of 1000 μg/mg compound polysaccharide could reach 76.9%. In addition, polysaccharides extracted from sporophyll of Korean brown seaweed Undaria pinnatifida had a good inhibitory effect on human leading adenoma cells (PC-3), human cervical cancer cells (Hela), human alveolar epithelioma cells (A549), human liver cancer cells (HepG2) and other cell lines.

The formation of tumor cells can also be induced by free radicals in the human body. Due to its antioxidant effect, seaweed polysaccharide can remove free radicals in the body and achieve anti-tumor effect from another way. Therefore, seaweed polysaccharide had great development potential in the pharmaceutical industry or food industry as emerging cancer drugs or functional food products for cancer treatment.

2.5 Lower blood sugar and blood fat

Hypertension, obesity, diabetes and its complications pose important threats to human health, and the development of natural and non-toxic side effects drugs is of great significance for the treatment and prevention of these diseases. Seaweed polysaccharide has a strong water absorption, and it can expand and ferment the feces in the intestine, speed up its operation speed, reduce the absorption of lipid substances and cholesterol by the small intestine, and

reduce blood fat. A lot of studies found that alginate reduced the time food passes through the gut, thus reducing the absorption of fat, sugar and bile salts, and lowering serum cholesterol, blood triglycerides and blood sugar [49].

Jin et al. [50] found that Pyropia yezoensis can effectively reduce triglyceride and total cholesterol levels in hyperlipidemia mice, thus reducing blood lipids. Yang et al. [51] found that Red algae (Gelidium amansii) polysaccharide had good hypoglycemic and blood lipid function, which may be related to its water-soluble fiber. Qian et al. [52] conducted animal experiments on Porphyra yezoensis polysaccharide and randomly divided male rats into three groups, oral high-fat feed, Porphyra yezoensis polysaccharide, and normal fat groups. Porphyra yezoensis treatment of male rats, not only can make plasma triacylglycerol, total cholesterol, plasma LDL cholesterol reduced, also can make the liver weight, triacylglycerol and cholesterol significantly reduced, proved that to a certain degree, the Porphyra yezoensis polysaccharide had high blood lipid activity and was expected to be used in the treatment of hyperlipidemia. Moroney et al. [53] found that polysaccharides from laminarin and fucoidan had significant activity on lowering blood lipid, preventing atherosclerosis, and reducing blood lipid and cholesterol.

3 Application of seaweed polysaccharide

3.1 Application of seaweed polysaccharide in cosmetics

3.1.1 Anti-ultraviolet radiation, antioxidant, and whitening effect

More and more consumers intend to brighten their skin tone through whitening cosmetics. Human skin color is determined by the content and distribution of melanin [54]. Melanin is produced by melanocytes in the basal layer and is transmitted through the dendritic structure of the melanocytes, following the cell up to the epidermal layer. Tyrosinase is the rate-limiting enzyme in this process, so the active components of whitening cosmetics are mainly to inhibit the activity of tyrosase [55]. At the same time, external environmental factors can also affect the skin color. Excessive ultraviolet radiation, free radicals will damage the DNA structure of skin cells, accelerate skin aging, but also act on melanocytes, make cells in a state of hyperactivity, produce more melanin, and result in black skin color [56].

Accordingly, anti-ultraviolet radiation, antioxidant has important significance to maintain skin health. Seaweed polysaccharides have the major role of scavenging free radicals, enhancing antioxidase activity, inhibiting tyrosinase and resisting ultraviolet radiation, and play the role of brightening skin color.

The action mechanisms of seaweed polysaccharide in inhibiting tyrosinase activity are:(1) Competitive inhibition: Seaweed polysaccharides can compete with substrates for the active site of tyrosinase [57]. (2) Non-competitive inhibition: Seaweed polysaccharides can bind to tyrosine residues outside the active center of the enzyme, so that Product of the substrate after binding to the enzyme cannot further transform [58]. (3) Mixed inhibition: Some seaweed polysaccharides can bind to the active site of the enzyme and to amino acid residues outside the active center [59]. Zheng et al. [58] studied the inhibition of sodium alginate on tyrosinase in melanocytes. The results showed that when the polysaccharide concentration was 64 mmol/L, it can have a good inhibitory effect and the inhibition was a mixed inhibition. Ding et al. [60] performed a tyrosinase inhibition experiment on spirulina polysaccharide and found that this inhibition was a reversible hybrid inhibition. Wang et al. [61] investigated the inhibition of fucoidan on tyrosinase and found that it was also a reversible hybrid inhibition, which almost completely inactivates tyrosinase at 25 mg/mL concentrations.

The mechanisms of Anti-UV radiation action of seaweed polysaccharide are as follows: (1) Seaweed polysaccharide can improve the survival rate of skin fibroblasts after being damaged by UV radiation [62]. (2) Seaweed polysaccharide can enhance the body's immunity and resist ultraviolet radiation damage to the immune system [58]. (3) Algae polysaccharide can regulate the metabolic process of skin collagen after UV radiation, and reduce the skin damage of UV radiation [62]. Guo Ziye [63] studied the anti-UV radiation activity of the Ulva prolifera polysaccharide, which showed that 0.5 mg/mL of the Ulva prolifera polysaccharide can significantly protect human skin fibroblasts from ultraviolet radiation damage, and its radiation prevention effect was better than some commercially available sunscreen sprays. Ye et al. [64] studied the activity of porphyra polysaccharide against UV radiation and found that the survival of mouse fibroblasts after UV radiation elevated by 30% at a polysaccharide

concentration of 3.3 μg/mL. Li Jing et al. [65] found that the type I collagen mRNA content with laminarin polysaccharide (5mg/kg) excipients in mice back was twice as high as that in the blank group.

The mechanism of antioxidant action is as follows: (1) Half acetal hydroxyl of seaweed polysaccharide molecules has weak dissociation energy, and can directly provide electron to quench free radical [66] (2) Seaweed polysaccharide can improve antioxidant enzymes to exert antioxidant, such as superoxide dismutase, catalase, glutathione peroxidase enzyme [59,67]. Wang et al. [68] studied the antioxidant effect of enteromorpha prolifera polysaccharide, which showed that 1 mg/mL enteromorpha prolifera polysaccharide solution cleared 62.31%, 28.74% and 78.21% of hydroxyl radicals, superoxide anion and DPPH radicals. Peng et al. [69] performed in vitro antioxidant experiment on Laminaria japonica polysaccharides and found that 1 mg/mL of Laminaria japonica polysaccharide solution cleared 75.20% and 3 mg/mL of it achieved 90.10% of hydroxyl radical.

3.1.2 Moisturize, bacteriostat , and repair the skin barrier

The skin barrier is composed of lipids in human keratinocytes and intercellular spaces, and their organic binding protects skin [70]. On the one hand, it can prevent germs from entering the skin and protect skin health; on the other hand, it can lock up skin moisture and oil to maintain skin water content. When the skin is in an uncomfortable environment or given the wrong care, many skin diseases can be led. Seaweed polysaccharides moisturize, inhibit bacteria, and repair skin barriers, and are widely used in cosmetics.

Seaweed polysaccharide moisturizing mechanisms are as follows: (1) Seaweed polysaccharide molecules contain a large number of hydrophilic groups such as hydroxyl and carboxyl, and they can combine with water molecules in the form of hydrogen bond, so they have good hygroscopic property [71]. (2) Seaweed polysaccharide molecular chain and water molecules can crosslink in space to form a mesh structure, so it has good moisturizing character [72]. Guo Ziye et al. [63] found that compared with glycerol and Qianxiancao loofah water, the polysaccharide from ulva prolifera was better hygroscopic and the Moisturizing of it was similar. Liu Bingyue et al. [72] found that the fucoidan polysaccharide from Sargassum fusiforme solution with quality fraction of 1% was comparable to the glycerol solution with quality fraction of 5%, and through human experiments found that the quality fraction of 5% polysaccharide solution can increase the skin moisture content from 40% to 49%.

The mechanism of action of seaweed polysaccharide to repair the skin barrier is as follows: (1) Algae polysaccharide can induce ERK and JNK phosphorylation and then activate EPK and JNK signaling pathway, promote the proliferation, migration and differentiation of skin keratinocytes [71,73], and accelerate the healing of skin wounds. (2) Algae polysaccharide can promote the proliferation of human skin fibroblasts by activating cell growth factors [74], and increase the extracellular matrix such as hyaluronic acid and collagen fibers, so as to repair the skin barrier. Wang et al. [75] studied the repair effect of sargassum fusiforme polysaccharides on the skin barrier and found that they promoted the proliferation of skin keratinocytes at a concentration range of 5.0 μg/mL to 50 μg/mL, promoted the migration of skin keratinocytes at a concentration range of 2.5 μg/mL to 20 μg/mL, and significantly promoted skin keratinocyte differentiation at 50 μg/mL.

Alhalgal polysaccharide has a broad spectrum of antibacterial activity, its antibacterial mechanism is mainly to bind to the protein receptor on the bacterial cell membrane, destroy the phospholipids, proteins, fatty acids on the bacterial membrane, and enhance the clearance of lysozyme to bacteria [74]. Chen Haixiu et al. [75] conducted antibacterial experiments on the low molecular weight fucoidan polysaccharide, which showed that the polysaccharide had good antibacterial property, and its molecular weight below 6kDa at a concentration of 8.00 mg/mL could inhibit the growth of E. coli.. Gao Yujie et al. [76] conducted an antibacterial test on enteromorpha polysaccharide and found that the concentration of enteromorpha polysaccharide of 6.80 mg/mL will inhibit the growth of E. coli and S. aureus, while the required concentration of the polysaccharide after selenization modification for inhibiting these two bacteria was only 1.70 mg/mL, which indicated that the antibacterial performance was better after selenization modification

3.2 Application of seaweed polysaccharide in the food industry

Seaweed polysaccharide is widely used in the processing of beverages, meat products, candy and other food because of its good solubility, thickening effect, gelation and stability, etc. At the same time, seaweed polysaccharide can be made into edible food film. In addition, seaweed polysaccharide is also widely used in the preservation of food coating film.

3.2.1 Drink

Seaweed polysaccharide has a variety of physiological activities such as lowering blood sugar, lowering blood lipid and regulating immunity. Besides, Seaweed polysaccharide contains algal glycans, alginate and other substances, which can cover gastric mucosa and reduce the gastric damage of alkaloids in tea [78]. Therefore, adding it to the beverage can play a good health care role.

Lin Wenting et al. [79] developed energy drinks with enteromorpha prolifera polysaccharide as the main raw material, hawthorn, wolfberry and other auxiliary materials. The results showed that the drink had a good regulation of glucose and lipid metabolism in typeII diabetic rats. Wu Xiaoqing et al. [80] mixed the laminarin polysaccharide concentrate extracted by compound enzyme method with Tieguanyin tea powder and licorice, and determined the best seaweed tea formula.

In the process of beverage production, it is easy to observe material suspension, stratification and precipitation. Therefore, maintaining the stability of drinks is an important step. As a natural polymer compound, seaweed polysaccharide is hydrophilic, high viscosity, flocculation and other characteristics, which is a good clarifying agent. Sun Yonglin et al. [81] studied effects of different vegetable clarifing agents on clarification and stability of lentinula edodes-grape wine. The results showed that sodium alginate can be used as a clarification agent for lentinula edodes-grape wine. Li Cong et al. [82] found that sodium alginate can stabilize the foam in beer, thus increasing the light transmittance and stability, and extending the shelf life.

Seaweed polysaccharide is a kind of natural hydrophilic colloid and has good emulsifying, thickening suspension. It can increase the particle settling speed in the system, also can improve the protein mesh structure and interface adsorption performance, significantly improve the stability of turbid liquid system. Adding a certain amount of sodium alginate to the cocoa milk and fruit yogurt can increase the thickening feeling and prevent the particles from sinking. Li Jinli [83] studied the effect of various polysaccharides as a peanut milk thickenert, and found the best stable effect of xanthan gum, carrageenan and sodium alginate.

3.2.2 Meat Product

Adding seaweed polysaccharide to meat products can not only improve the quality of meat products, but also increase the water retention and tenility of meat products, and reduce the loss of nutrients and flavor substances. Gao Xueqin [84] added carrageenan and soybean protein isolate to the pork products, which improved water retention, oil retention, qualitative structure and sensory indicators of the pork products to different degrees.

3.2.2.1 Water retention agent

The water retention of meat products not only affects the quality and taste of meat products, but also plays an important role in economic benefits. The study showed that seaweed polysaccharide was added to meat products as water retention to effectively prevent water loss, reduce cost and improve economic benefits. Song Lei et al. [85] found that the trehalose formulation of composite cryoprotectant can effectively improve the water retention of frozen chicken meatballs. Wang Qidong et al. [86] developed Spanish mackerel surimi by extracting sodium alginate from Sargassum horneri, and found that the mass structure characteristics of it was better than that of Traditional kelp alginate sodium Spanish mackerel millet.

3.2.2.2 Fat substitute

High fat and high cholesterol in meat products are harmful to health. Seaweed polysaccharide has good biological activities such as lowering blood sugar and blood lipid, which can hinder the absorption of cholesterol by human

body, so it can be used to make healthy, low-fat fat substitutes. Fan Suqin et al. [87] studied the influence of different commercial compound sodium alginate products on the tecture of fat substitution. The results showed that fat substitute with desired appearance and texture could be obtained by adding sodium alginate gel I at 2.5% and then stirring for 20-30 min. Tan Wenying et al. [88] prepared a functional composite fat substitute with excellent water retention, oil retention and emulsification stability with sucrose polyester and sodium alginate as the main raw materials.

3.2.2.3 Binder

Binders can effectively improve the quality and taste of meat products, and extend the shelf life. Seaweed polysaccharide gel has high performance, and added it to meat products can change its structure, increase viscosity and improve the taste of meat products. Seaweed polysaccharide is added to the recombinant meat to utilize its gel structure thus changing the muscle tissue, adipose tissue and connective tissue distribution of the meat to make it taste better [89]. In addition, seaweed polysaccharide also has a bonding effect on canned meat, which can enhance the forming ability of canned meat and maintain a stable curing ability after high temperature sterilization, so as to improve the quality of canned food.

3.2.3 Candy

Seaweed polysaccharide added to the candy can act as a stabilizer. Seaweed polysaccharide added to the transparent fruit fudge can improve the transparency of the candy. Adding seaweed polysaccharide to the general hard sugar can make the candy uniform and smooth. Pan et al. [90] prepared beef fudge with gelatin, agar and carrageenan as the main compound gel agent. Agarose, fig fructose, marshmallow and other products are added a certain amount of agar to enhance the gel.

3.2.3.1 Jelly sweet

Jelly sweet are mainly made from food glue and starch syrup through specific processes. Seaweed polysaccharide can be used to make gel fudge because of the gel characteristics, which is one of the main accessories of fudge. Jelly sweet with Seaweed polysaccharide as auxiliary material is brittle and transparent, with high water content and long shelf life, which is better than starch gel fudge. Tian Qiying et al. [91] added agarose powder to the fudge formula with agar as the coagulant, and developed a new fudge product with moderate taste and better chewing ability. In the actual production, various colloids can be combined to improve the quality and taste of the fudge. Bai Xu [92] used agar and carrageenan compound to make ginger and citrus peel soft candy, the product has a unique flavor and smooth taste.

3.2.3.2 Candy additives

Candy is a daily consumer product, but a large amount of sugar is easy to cause blood sugar to increase. Adding seaweed polysaccharide to the ingredients of candy can prevent blood sugar to rise to a certain extent. Seaweed polysaccharides have good gel performance,and added it to agarose, fig fructose, marshmallows and other products can play the role of a stabilizer, effectively enhance the product gel performance. Chen Xiangzhi [93] made cretots with compound glue and gelatin respectively, and studied its properties respectively. The results showed that the antideformation ability of compound glue of cretots was better.

3.2.4 Food packing

3.2.4.1 Edibility film

Seaweed polysaccharides have good film formation and can be used to make edible films. Calcium alginate can be mixed with other natural polymers to make edible films, which can improve the calcium alginate gel properties [94]. Jia Xiaoyun et al. [95] prepared a prulandaccharide-sodium alginate composite antibiofilm with antibacterial capability, which can effectively extend the shelf life of fresh meat to 16d. Seaweed polysaccharide edible films can also reduce the oil content of fried foods and make them healthier. Studies showed that seaweed polysaccharide

composite coating with different solutions (containing 2% seaweed polysaccharide, 0.4% chitosan, 0.2% konjac gluancan) used for pepper coating preservation [96]. Nima et al. [97] found that alginate - based edible coating preservation solution (12.98g/L sodium alginate +0.25g / L sunflower oil + 11.6g/L glycerol + 3g / L lemon refined oil) significantly inhibited the activity of microorganisms.

3.2.4.2 Apply film to keep fresh

Seaweed polysaccharides are hydrophilic colloids, but they can cross-link with metal ions to form a mesh structure, limiting the free movement of polymer structure while inhibiting water flow, thus reducing the water solubility of seaweed membrane. Zhao Shan et al. [98] found that using penyllactic acid- sodium alginate as sweet cherry fresh packaging material can reduce the loss of water and nutrients in sweet cherries and prolong the storage time. Jiang et al. [99] used alginate/nano-Ag coating to keep mushrooms fresh, and its preservation effect is better. Different polysaccharide composite coating film can improve the transparency, air permeability and water retention of the film through high polymer action, which is more conducive to coating film preservation.

3.2.5 Other aspects

Seaweed polysaccharides can be used in the production of foods such as chewing tablets, jellies, ice cream and vegetables. Wang Jiaying et al. [100] combined low melting point agar with other food colloids to make jelly. The results showed that the jelly produced by low melting point agar was similar to industrial jelly in terms of sensory and structural properties. Used in ice cream production, Seaweed polysaccharide can reduce its ice crystal precipitation, improve viscosity and expansion rate, and improve its taste and state. Seaweed polysaccharide can also be used as a pesticide residue degradation agent in vegetable production, which can effectively improve the safety of vegetable production.

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