Development of Seaweed-based Biopolymers for Edible Films and Lectins

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Abstract. Marine macroalgae (seaweeds) as one of important groups of biopolymers play an important role in human life. Biopolymers have been studied regarding their film-forming properties to produce edible films intended as food packaging and active ingredient carriers. Edible film, a thin layer or which is an integral part of food and can be eaten together with, have been used to avoid food quality deterioration due to physico-chemical changes, texture changes, or chemical reactions. Film-forming materials can be utilized individually or as mixed composite blends. Proteins and polysaccharides used for their mechanical and structural properties, and hydrophobic substances (lipids, essential oils, and emulsifiers) to provide good moisture barrier properties. In addition, bioactive substances from marine natural products, including seaweeds, have been explored for being used in the fields of medicine, food science, pharmaceutical science, biochemistry, and glycobiology. Among them, lectins or carbohydrate-binding proteins from seaweeds have recently been remarked. Lectins (hemagglutinins) are widely distributed in nature and also good candidates in such prospecting of seaweeds. They are useful as convenient tools to discriminate differences in carbohydrate structures and reveal various biological activities through binding and interacting to carbohydrates, suggesting that they are promising candidates for medicinal and clinical application.

1. Introduction
Marine macroalgae, better known as seaweeds, are an important group of marine bio-resources with multiple uses that affect the life of humans [1]. Indonesia, a tropical country with 5.8 million km square of marine waters and 95.181 km of coastlines, is one of nation with the greatest marine biodiversity in the world and one of global players in seaweed production [2-4]. Indonesia is increasingly focusing on in-country processing of the raw materials [2], since an approximately 8.6 % algae of the whole species in the world are found in Indonesia [3,4]. Indonesian ocean has a large variety of biota, including 782 algae species [5]. The production of seaweed-based biopolymers such as agar, carrageenan, and alginate showed the huge economic impact through their application in various industries, including food industries that exploit their physical properties such as gelation, water holding capacity, and their ability to emulsify [1,6]. Industrial utilization of algae is largely confined to phycocolloids and fine biochemicals including carbohydrates, proteins, lipids, minerals, and low molecular weight compounds [1,6,7]. However, in recent years algae have attracted a great deal of interest in the search for bioactive compounds to develop new drugs and healthy foods. Among them, lectins or carbohydrate-binding proteins from algae have begun to receive much attention [1,7].
Moreover, the use of renewable resources, including seaweed-based biopolymers to produce biopolymer films and coatings has gained significance with the increasing of consumers concern on high-quality and long-shelf-life-products and their awareness of environmental issues. Petrochemical-based plastics packaging put a serious problems on the environment since the material’s inability to biodegrade [8-12]. Therefore, research works related to the use of biopolymers has emerged as an alternative, due to their biodegradability. In the development of edible and biodegradable materials, seaweed-based biopolymers such as carrageenans and alginates are among the most important biopolymers due to their great abundance and processability [11,12]. Thus, the utilization of seaweed-based biopolymers for edible films and lectins in a perspective of food and health applications is studied in this current article.

2. Edible Films

Biopolymers have been studied regarding their film-forming properties to produce edible films and coatings intended as food packaging [8-10]. Edibility and biodegradability are the most beneficial properties of edible films and coatings. Edibility of films and coatings could be achieved if films and coatings components including biopolymers, plasticizers, and other additives be food grade ingredients. Meanwhile, all the processes and equipment should be acceptable for food processing [13,14]. Further, the toxicity and environmental safety must be evaluated by standard analytical procedures to claim biodegradability of films and coatings [13,14].

Edible film, a thin layer made of edible material which can be placed on or between food components or which is an integral part of food and can be eaten together with [8,10,13], while an edible coating is a thin layer of edible material formed as a coating on a food product [13,15]. The main difference between these two food systems is that the edible coating is applied in liquid form on the food, usually by immersing the product in the solution of edible material, and edible film is first molded as solid sheets, then applied as a wrapping for food products [13,16]. Edible films and coatings have been used to avoid food quality deterioration due to physico-chemical changes, texture changes, or chemical reactions. Moreover, the protective barrier of edible film can be formulated to prevent the transfer of moisture, gases, flavor, and therefore to maintain or improve food quality and to increase shelf life of food products [8,17]. Different biopolymers have been used in the development of edible film and coatings, such as proteins, lipids, and polysaccharides [8,10,17]. Among these biopolymers, seaweed-based biopolymers such as alginates and carrageenans have been frequently used in recent years due to their good barrier properties to oxygen, carbon dioxide, and lipids as well as their great mechanical properties (tensile strength and elongation at break). Various edible films and coatings from alginates and carrageenans have been reviewed, including productions and properties of these films [13].

Film-forming materials can be utilized individually or as mixed composite blends. Proteins and polysaccharides used for their mechanical and structural properties, and hydrophobic substances (lipids, essential oils, and emulsifiers) to provide good moisture barrier properties [8,13]. Hydrophilic or hydrophobic materials can be used in film-forming materials, but in order to maintain edibility, merely water or ethanol could be used as solvent during processing. Other components can also be added into the materials matrix to enhance its functionality, including those that can improve or modify the basic functionality of the material (plasticizers, crosslinking agents, reinforcements, and emulsifiers) and those that intend to improve the quality, stability, and safety of packaged foods (antioxidants, antimicrobial compounds, nutraceuticals, flavors, and/or color agents) [18]. Edible films and coatings showed promising systems to be employed as active ingredient carriers, however, the mechanisms of deterioration of each food and the mode of action of each package should be understood and related in order to assess a successful application of these materials as food packaging [18].
3. Lectins

Lectins are naturally occurring proteins and glycoproteins of non-immune origin which selectively bind non-covalently to carbohydrate residues and able to agglutinate cells and/or precipitates polysaccharides or glycoconjugates. They play some important roles as recognition molecules in cell-cell or cell-matrix interactions and may be regarded as valuable biochemical tools to probe protein-carbohydrate interactions since they can interpret the ‘sugar code’ [1,19]. They are not only useful in many research fields including glycomics, but they are promising candidates for medicinal and clinical application [1,19]. The ability to bind to carbohydrates and hence agglutinate cells is the most important property of lectins. Agglutination is due to the fact that the lectin has at least two binding sites and it is therefore able to crosslink cells through its interaction with carbohydrates on the cell membrane [20]. In general, the molecular structures and carbohydrate-binding specificity of lectins are diverse and dependent on the organisms from which they originate, although lectins are classified into several families based on amino acid sequences of carbohydrate-recognition domains, some of which are also evolutionarily conserved [1, 21-24].

Lectins occur in all classes and families of organisms, including in algae (seaweed). Recently, the presence of lectins was analyzed at about 800 algae species [1,25]. In comparison to other lectins, some characteristics patterns of algal lectins are becoming apparent. For example, many algal lectins have some common characteristics of low-molecular weight that are much smaller than those derived from land plants [26,27]. This feature may make algal lectins more suitable in drug targeting and/or drug delivery system because the smaller molecules may be expected to be less antigenic than the larger land plant lectins. Before such uses can be envisaged, however, further information is required on the precise specificity of the small glycoprotein-binding algal lectins and their primary structure [28,29]. Furthermore, lectins showing anti-HIV and anti-influenza virus activity have been recently discovered from cyanobacteria, bacteria and eukaryotic macroalgae. These lectins are promised to be a new antiviral agent because their inhibiting activities are extremely strong compared to those of lectins from other biological groups [30]. A red alga Griffithsia sp. [31] as well as the cyanobacteria (blue-green algae) such as Nostoc ellipsosporum [32], Schytomena varium [33] and Microcystis viridis [34], OAA from Oscillatoria agardhii NIES-240 [29,35,36], PFL from Pseudomonas fluorescens Pf0-1 [37], MBHA from Myxococcus xanthus [38], BOA from Burkholderia oklahomensis [39], KAA-2 from Kappaphycus alvarezi [40], BCA from Boodlea coacta [41] and ESA-2 from Eucheuma serra [42] are examples of this lectin family [30]. All of these lectins share binding specificity for high-mannose N-glycans and have commonly two or four tandem repeats consisting of highly conserved sequences, which may lead to subtle difference in the degree of inhibiting activities, suggesting that this lectin family may become a novel class of antiviral compounds for application [30]. Moreover, EDA from Eucheuma denticulatum [43] and KSA-2 from Kappaphycus striatum [30] showing antibacterial activities, suggesting that algal lectins could be useful as antibacterial reagents and they also showed antiviral activities that might be indicate to become a candidate for a functional food ingredients that can prevent virus infection in the future. Thus, marine algae should be expected as sources of novel lectin molecules for basic research and future application in the fields of medicine, food science, pharmaceutical science, biochemistry, and glycobiology.

4. Conclusion

Edible films and coatings have been received considerable attention over the last years due to their possibility to use as edible packaging materials over synthetic ones and to reduce environmental pollution. They are promising systems to be used as active ingredient carries, since such films can be carrier of antioxidants, antimicrobials, nutraceuticals, and flavoring agents or other additives to improve the mechanical integrity, handling, and quality of food products. Among biopolymers, seaweed-based biopolymers (alginites and carrageenans) have been paid a great of interest in recent years due to their good barrier properties as well as mechanical properties. Furthermore, algal or seaweed-based industry has promising prospects to be more developed in Indonesia. Marine-derived nutraceuticals, including from marine algae (seaweeds), are alternative sources for ingredients that play an important role in
human health and nutrition. Algal (seaweed) lectins, a potential algal-derivative product, could be more intensively studied, because there is no report on lectins from Indonesian marine algae (seaweeds) up to now. Hopefully, novel lectins from Indonesian marine algae with specificities distinct from other sources will be found and applied as convenient tools to contribute greatly to the era of glycomics-based biomarker investigations.

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