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ALGAL LECTINS AND THEIR POTENTIAL USES

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Abstract

Lectins (hemagglutinins), or carbohydrate-binding proteins, are ubiquitous in nature and play important roles in many biological processes. They bind mono- and oligosaccharides reversibly with high specificity, but are devoid of catalytic activity, and in contrast to antibodies, are not products of an immune response. The erythrocyte agglutination or hemagglutination activity of lectins is a major attribute of these proteins and is used routinely for their detection and characterization. Due to their biochemical and biological properties, lectins attract a great deal of attention in the fields of medicine, molecular biology, biochemistry, and glycobiology. Lectins have been isolated and characterized from marine algae. Many of algal lectins generally have common characteristics of low molecular weight, no divalent cations requirements for their activity, and have an affinity for glycoproteins but not for monosaccharides. These properties imply that they may possess molecular structures and carbohydrate-binding specificities distinct from known lectins from other sources. Recent investigations revealed that algal lectins have the strict binding specificity to some definite oligosaccharide structures and are grouped into several types on the basis of oligosaccharide-binding specificity. Thus, marine algae are promising sources of novel lectin molecules for basic research and application. In spite of the progress made in biochemical characterization of algal lectins, additional information are still needed for a more comprehensive understanding of their molecular structures and possible biological functions for the future applications.

Keywords: lectins, algae, characteristics

1. Introduction

The exploration of marine bio-resources is an indefinite challenge for bio-mining researchers to strengthen the development of marine functional foods, nutra-ceuticals, and associated medicinal benefits (Samarakoon et al., 2014). Nutraceuticals and functional food industries have grown significantly in the last two decades. Nowadays, the consumers paid a great deal of interest towards natural bioactive substances due to the various health benefits of nutraceuticals and/or functional ingredients in food products. The continuous research and investigation on nutraceuticals will prompt another era of foods, which will certainly raise the permeability interface between foods and drugs (Kim et al., 2013).

Marine macro-algae, micro-algae, blue-green algae, invertebrates, vertebrates, and marine-derived microorganisms are valuable sources of active marine nutraceuticals that can contribute to consumers' well-being and play an important role in human health. They offer a lot of source of nutritionally as well as pharmacologically active agents with great chemical diversity and complexity, and potential to produce valuable health or medicinal foods. Moreover, combinations between marine nutraceuticals and novel bioactive substances provide novel pharmaceutically active functional ingredients that would enhance the treatment development of chronic conditions such as tumor malignancy, inflammatory processes, and microbial infections (Kim et al., 2013).

Marine macro-algae or seaweeds are an important group of marine bio-resources with multiple uses that affect the life of humans. They mostly belong to one of three divisions: the Chlorophyta (green algae), the Phaeophyta (brown algae), and the Rhodophyta (red algae). It has been reported that there are about 900 species of green algae, 4000 red algae, and 1500

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brown algae in nature (Khan & Satam, 2003). Industrial utilization of algae is largely confined to phycocolloids and fine biochemicals including carbohydrates, lipids, minerals, and low molecular weight compounds. Moreover, the production of agar, carrageenan, and alginate showed the biggest economic impact since they have attained commercial significance through their uses in various industries that exploit their physical properties such as gelation, water holding capacity, and their ability to emulsify. Green algae such as *Enteromorpha*, *Ulva*, *Caulerpa,* and *Codium* are often consumed as fresh salads or cooked along with rice, and other algae, such as *Porphyra* (nori), *Laminaria* (kombu), and *Undaria* (wakame) are not only used for making fish and meat dishes but also used for soups and side dishes (Khan & Satam, 2003).

Agar, agarose, and carrageenan are among commercially valuable compounds extracted from red algae extensively used in many industries. Agar is widely employed in association with food preparation and in the pharmaceutical industry as a laxative or as an outer cover of capsules. With the emergence of modern molecular biology and genetic engineering, agarose produced from agar is extensively used as a material for electrophoresis in most laboratories all over the world. Carrageenans are generally used for their physical functions in gelation, viscosity, and stabilization of emulsions (for example, foods such as ice cream), suspensions and foams, and control of crystal growth (Chapman, 1970). Furthermore, chemicals from brown algae such as alginic acid, mannitol, laminarin, and fucoidan have also been extracted successfully on a commercial basis. Because alginates can absorb water, have a wide range of viscosity, can readily form gels, and are non-toxic, they have also countless uses in the manufacture of pharmaceuticals, cosmetics, and processed foods (Khan & Satam, 2003).

Moreover, some commercial exploitation of products extracted from algae occurs outside the hydrocolloid industry. In recent years pharmaceutical companies have started looking at marine organisms, including algae, in their search for new drugs and bioactive substances from natural products. These products are also increasingly being used in medical and biochemical research. Among them, lectins or carbohydrate-binding proteins from seaweeds or algae have recently been remarked (Smit, 2004).

2. Lectins

Lectins are naturally occurring proteins and glycoproteins which selectively bind non-covalently to carbohydrate residues. They may be regarded as protein interpreters of the "sugar code" and represent convenient biochemical tools to probe protein-carbohydrate interactions and play some important roles as recognition molecules in cell-cell or cell-matrix interactions. With the completion of genomic sequencing projects, including the human genome, then the focus of many research groups has shifted to interpreting protein expression to gain new understanding about biological processes (Nilsson, 2003). Certainly, proteins are central mediators in cellular processes and perform their duties through interactions with lipids, carbohydrates, small molecules, and other proteins. Therefore, one aspect of functional proteomics is the elucidation of the interactions between proteins and other molecules (Nilsson, 2003).

The term lectin was first proposed by Boyd and Shapleigh in 1954 and is derived from Latin verb 'legere', which means to pick out, choose or select, and refers to the remarkable selectivity and specificity with which lectins recognize and bind to carbohydrate structures (Boyd & Shapleigh, 1954). Brooks et al. (1997) stated that the most widely accepted definition of term 'lectin' is that originally proposed by Goldstein et al. (1980) and adopted by the Nomenclature Committee of the International Union of Biochemistry. This definition states that a lectin is a carbohydrate-binding protein of non-immune origin that agglutinates cells and/or precipitates polysaccharides or glycoconjugates. The definition implies that lectins are:

-Multivalent- two or more sugar binding sites are necessary for them to cross-link cells in agglutination, or polysaccharides/glycoconjugates in precipitation.

-Not antibodies- that their 'non-immune' origin distinguishes them from antibodies.

-Not enzymes- the definition excludes most sugar binding enzymes as they are monovalent, rather than polyvalent. In addition, such enzymes will catalyze the chemical reaction under the right condition so that sugars are modified; this does not happen when lectins bind to carbohydrates.

-Distinct from certain toxins- for example, the toxic A chain of ricin which possesses only one sugar binding site, and acts as an enzyme.

In addition, to qualify as lectins, Rudiger & Gabius (2001) stated that (glyco) proteins have to meet three distinct requirements: a lectin is a (glyco) protein that binds carbohydrate, is distinct from immunoglobulins, and does not biochemically modify the carbohydrates that it binds to. Thus, a simpler definition as stated by Brooks et al. (2002) is that 'lectins are carbohydrate binding proteins other than enzymes or antibodies.'

Lectins, sometimes referred to as hemagglutinins or agglutinins, are glycoproteins with an ability to agglutinate red blood cells (Sharon & Lis, 2003). Various sugars (or glycoconjugates) are present on cell surfaces, and as a result many cells including microbes and yeasts, tumour cells, and erythrocytes are selectively agglutinated by lectins. Cell agglutination of lectins are inhibited by sugars of the same type as those on the surface of the cells being agglutinated (Brooks et al., 1997). They are useful in many research fields including biology, cytology, biochemistry, medicine, and food science (Smit, 2004).

The history of lectin studies has been described by Sharon & Lis (2003) and Brooks et al. (1997, 2002). Stillmark (1888) was the first to describe the activity of lectin (Sharon & Lis, 2003). During work for his doctoral thesis at the University of Tartu in Estonia, he investigated the extracts of seeds from the castor oil plant *Ricinus communis*, a member of the Euphorbiaceae and isolated a toxic protein which he called ricin. Furthermore, he tested the effect of ricin on erythrocytes, liver cells, leukocytes and epithelial cells and noted an agglutination reaction like that seen in clotting.

The most important property of lectins is their ability to bind to carbohydrates and hence agglutinate cells. 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 (Sharon & Lis, 2003).

Most investigators have detected lectins by agglutination experiments (hemagglutination activity assay) using human and animal erythrocytes and/or other cells. This assay was perfomed by two-fold serial dilution method in microtiter V-plate wells and the activity was expressed as titer, the reciprocal of the highest twofold dilution exhibiting positive hemagglutination (Hori et al., 1986a). All lectins have more or less well-defined binding specificities, however, some carbohydrate structures are more common in nature than others. Some lectins, which are specific for commonly occurring carbohydrate structures e.g., *N*-acetylglucosamine (GlcNAc), can therefore agglutinate cells of different blood groups or from several different species. Other lectins are more selective and may preferentially agglutinate cells from a particular animal species or agglutinate erythrocytes of a particular blood group only (Brooks et al., 1997, Varki et al., 1999, Sharon & Lis, 2003).

Moreover, lectins were used to investigate changes in cell-surface interaction during cell cycle, transformation to malignancy, and other aspects of medical research fields. They were also used in the purification and characterization of saccharides and glycoconjugates contributing significantly to the field of “glycobiology”. Glycobiology is one of the more rapidly growing fields in the natural sciences, with broad relevance to many areas of basic research, biomedicine, and biotechnology. The field includes the chemistry of carbohydrates, the enzymology of glycan formation and degradation, the recognition of glycans by specific proteins (lectins and glycosaminoglycan-

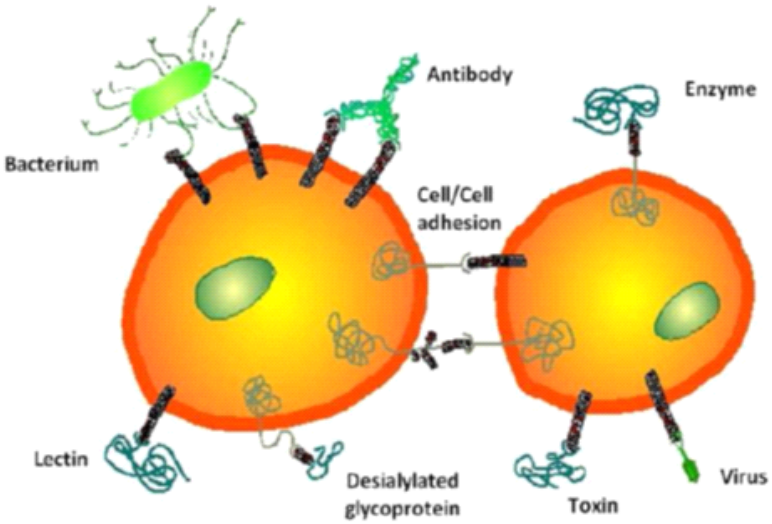

Figure 1. Cell surface of carbohydrates are recognition molecules used in specific binding and interactions among cells, pathogens, and molecules. {Figure adapted from (Magnani & Ernst, 2009)}.

binding proteins), glycan roles in complex biological systems, and their analysis or manipulation by a variety of techniques. Research in glycobiology thus requires a foundation not only in the nomenclature, biosynthesis, structure, chemical synthesis, and functions of glycans, but also in the general disciplines of molecular genetics, protein chemistry, cell biology, developmental biology, physiology, and medicine (Varki et al., 1999, Brooks et al., 2002).

The nominal specificity of a lectin is usually expressed in terms of the simple monosaccharides which best inhibit its effect. This has been most oftenly demonstrated through the inhibition of lectin-mediated cell agglutination. For example, Lima bean (*Phaseolus lunatus*) lectins are reported to be specific for *N*-acetylgalactosamine (GalNAc) because Lima bean lectin-induced hemagglutination of blood group A erythrocytes is most effectively inhibited by the presence of the monosaccharide GalNAc. However, it is extremely important to realize that perceiving a lectin to be specific for a particular monosaccharide is actually an over-simplification. Lectins can combine with monosaccharide moieties and monosaccharide will in turn inhibit lectin-induced agglutination; however the combining site of the lectin is usually far more complex than what is shown in this simple inhibition test. The actual structure recognized by the binding site of the lectin when it combines with its natural ligand is generally larger and more complex than a single monosaccharide. It is thought to involve typically three monosaccharides, terminal and sub-terminal in the oligosaccharide chain, in a particular spatial arrangement and sometimes even involve part of the protein or lipid to which the oligosaccharide is attached. In addition, hydrophobic and electrostatic interactions which are not located at the sugar binding site may also play a role in lectin binding to tissue structures (Brooks et al., 1997, Varki et al., 1999, Sharon & Lis, 2003).

In general, the carbohydrate-binding specificity and molecular structures 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 (Lis & Sharon, 1998, Dodd & Drickmer, 2001). The diversity of lectins on carbohydrate-binding specificity enables them to be used as convenient tools to decode the carbohydrate structures on cell surfaces and in body fluids (Praseptiangga et al., 2012). In addition, recent researches have been directed to the nutritional aspects of lectins because many edible plants, including cereals, vegetables, and fruits contain lectin proteins, and some of them were reported to affect the transport of other food gradients in an intestinal tract model (Sharon & Lis, 2003; Ohno et al., 2006).

Lectins occur in all classes and families of organisms examined so far. Thus, they are widely distributed in a variety of organisms, from virus to humans, although not necessarily in every genus or species. Many of the better known and most intensively studied lectins are derived from plants. This is in part due to historical reasons, since the search for new lectins by many early workers has focused on plants owing to their original discovery in plant material and their ease of availability. Plant material, especially the seeds of the Leguminosae (=Fabaceae), Euphorbiaceae, and Solanaceae, are enormously rich sources of lectins. However, lectins have subsequently been detected and isolated from diverse sources including viruses, bacteria, fungi, invertebrates, and vertebrates (Sharon & Lis, 2003, Brooks et al., 1997). Lectins were first discovered more than 100 years ago in plants, but they are now known to be present throughout nature.

The most thoroughly investigated lectins have been isolated from plants, particularly of that extracted from members of the Leguminosae family (Teixeira et al., 2012). Legume lectins are a large group of proteins that share a high degree of structural similarity with distinct carbohydrate specificities (Wu et al., 2009, Teixeira et al., 2012). Significant progress has been reached in last few years in understanding the crucial roles of lectins in several biological processes. The importance of lectins as biotechnological tools has been established early in the studies involving its biological application (Teixeira *et al*., 2012). In 1960 a major step in immunology was given in order to determine the role of these proteins on the lymphocytes cell division (Nowell, 1960). It was found that the lectin from the red kidney bean (*Phaseolus vulgaris*), known as phytohemagglutinin (PHA), possesses the ability to stimulate lymphocytes to undergo mitosis (de Oliviera Silva et al., 2011). After these findings, many studies have been performed to evaluate the role of lectins on different models involving the immune response and its products, for instance the stimulation of citokine secretion (Lee et al., 2007), functional activation of monocytic and macrophage-like cells and ROS production by spleen cells (Melo et al., 2010). In addition to immunological studies, recent works have been investigated the influence of lectins in the field of microbiology, since lectins can be considered as valuable tools to verify the role of interaction between the pathogen and carbohydrates present in host cells and its importance to disease development. For instance, it has been proposed that the pathogen *Helicobacter pylori* infected human cells through an interaction involving a lectin (Bennet &

Roberts, 2005). During recent two decades, however, lectins have been isolated and partially characterized from more than 50 species of marine algae (Hori *et al*., 2007).

3. Algal Lectins

With respect to lectins from algae, from surveys of Puerto Rican (Boyd et al., 1966), English (Blunden et al., 1975, 1978; Rogers et al., 1980), Japanese (Hori et al., 1981, 1986a, 1988), Spanish (Fábregas et al., 1985, 1992), United States (Chiles & Bird 1989; Bird et al., 1993), Brazilian (Ainouz & Sampaio 1991; Ainouz et al.,1992; Freitas et al., 1997), and Vietnamese marine algae (Hung et al., 2009), currently, the presence of lectins was analyzed at about 800 algae species (Teixeira et al., 2012).

However, this number is still small, considering that there are thousands of species of marine algae all over the world. Together, the research shows that approximately 60% of the analyzed species show hemagglutination activity (Teixeira et al., 2012). The number of positive species could be higher since in the first screenings the authors used a limited number of red blood cells and without enzyme treated erythrocytes. The improvement in the methodologies of both, extraction, and hemagglutination activity assays could increase the number of positive species. In fact, there appears to be coincidence that the rabbit erythrocytes treated with enzyme (trypsin and/or papain) are most suited for the detection of hemagglutination activity in marine macroalgae (Hori et al., 1988; Ainouz et al., 1992; Teixeira et al., 2012).

The classical methods of purifying algal lectins, include methods such as protein precipitation (using salt or ethanol), liquid chromatography (conventional and/or affinity) and electrophoresis (Sampaio et al., 1999; Sharon & Lis, 2003). Ion exchange chromatography has been effectively used in the purification of algal lectins, mainly in early stages in purification. In this step, the lectins were separated from pigments present in the extracts (Rogers et al., 1988; Ainouz et al., 1995). In the protein extracts, phycobilins are co-extracted with lectins, becoming an undesirable contaminant in the purification process (Rogers et al., 1988).

Only 31 lectins from Rhodophyceae and 17 lectins from Chlorophyceae were isolated and characterized up to now (Teixeira et al., 2012). The virtual absence of lectins purified from brown algae (Phaeophyceae) is particularly due to the amount of polyphenols present in plants. It is known that polyphenols are released in extraction and that these compounds and their oxidation products, quinones, bind tightly to proteins causing a false hemagglutination (Blunden et al., 1986; Rogers et al., 1986). Even with the increase in the publications related to algal lectins, biochemical and structural information on algal lectins is limited and from only a few species, and hence the functional and phylogenetic classification of these lectins remains unclear.

Some examples of algal lectins are hypnins A-D in *Hypnea japonica* (Hori et al., 1986b, 2000), *Hypnea musciformis* (Nagano et al., 2002), *Hypnea cervicornis* (Nagano et al., 2005) *Eucheuma serra* (Kawakubo et al., 1997, 1999, Hori et al., 2007), *Eucheuma denticulatum* (Hung et al., 2014) *Enteromorpha prolifera* (Ambrosio et al., 2003), *Ptilota plumosa* (Rogers et al., 1977, 1980, Sampaio et al., 2002), *Ptilota filicina* (Sampaio et al, 1998), *Ulva lactuca* (Sampaio *et al.*, 1998), *Gracilaria verrucosa* (Kakita et al., 1999), *Gracilaria burso-pastoris* (Okamoto et al., 1990) *Gracilaria tikvahiae* (Chiles & Bird, 1990), *Bryothamnion seaforthii* and *Bryothamnion triquertum* (Ainouz et al., 1995; Calvete et al., 2000; Pinto et al., 2009), *Boodlea coacta* (Hori et al., 1986c) and a hemagglutinin in *Codium barbatum* (Praseptiangga et al., 2012).

These 'algae-specific' lectins show novel carbohydrate-binding specificity and molecular structures including those specific for high-mannose *N*-glycans (Boyd et al., 1997, Bokesch et al., 2003, Bewley et al., 2004, Mori et al., 2005, Hori et al., 2007, Sato et al., 2007, Hung et al., 2011,Sato et al., 2011a, Sato et al., 2011b, Hung et al., 2014) and core (α1-6) fucosylated *N*-glycans (Hori et al., 2000, Okuyama et al., 2009). They also show some interesting biological activities, including anticarcinogenic (Fukuda et al., 2006) and antiviral activities (Boyd et al., 1997, Bokesch et al., 2003, Bewley et al., 2004, Mori et al., 2005, Sato et al., 2007, Sato et al., 2011a, Sato et al., 2011b). Their antiviral activities are specially remarkable because they inhibit *in vitro* infection of immunodeficiency virus (HIV-1) and influenza virus with half-maximal effective concentration (EC_{50}) in the low nanomolar to picomolar ranges through their binding with viral envelope glycoproteins (Ziolkowska et al., 2006, Li et al., 2008).

Many algal lectins, especially from red algae, share some common characteristics of low-molecular weight, monomeric forms, thermostability, and divalent cation-independent hemagglutination, and having affinity only for glycoproteins but not for monosaccharides (Hori et al., 1990, Rogers & Hori, 1993). These properties of algal lectins are dissimilar to most of land plant lectins that have affinity for monosaccharides and consist of oligomeric forms (Van Damme et al., 1998). However, some monosaccharide-binding lectins have been reported from several species of green algae belonging to the

genera *Enteromorpha* (Ambrosio et al., 2003), *Ulva* (Sampaio et al., 1998b, Wang et al., 2004), and *Codium* (Rogers et al., 1986, Fabregas et al., 1988, Alvarez-Hernandez et al., 1999).

Among the lectins from *Codium*, those from *C. fragile* ssp. *tomentosoides* (Rogers et al., 1986), *C. fragile* ssp. *atlanticum* (Rogers et al., 1986), *C. tomentosum* (Fabregas et al., 1988), and *C. giraffa* (Alvarez-Hernandez et al., 1999) are commonly specific GalNAc and/or *N*-acetylglucosamine (GlcNAc) and consist of oligomeric forms, except for a monomeric lectin from *C. giraffa*. Recently, interestingly, *C. barbatum* lectin (CBA) showed a different hemagglutination-inhibition profile from those of GalNAc-specific lectins so far isolated from other species belonging to the same *Codium* genus (Rogers et al., 1986, Fabregas et al., 1988, Alvarez-Hernandez et al., 1999) as the activity of CBA was not inhibited by GalNAc and/or GlcNAc (Praseptiangga et al., 2012). CBA was therefore the first example that has no affinity for monosaccharides among the known *Codium* lectins (Praseptiangga et al., 2012). Its activity was inhibited by Porcine Thyroglobulin (PTG) and the inhibitory activity was remarkably enhanced with asialo-PTG, suggesting that the branched sugar moiety of PTG was responsible for inhibition (Praseptiangga et al., 2012). As the first example among *Codium* lectins, the primary structure of CBA has been elucidated by a combination of ESI-MS, Edman degradation, and cDNA cloning. CBA consisted of a SS-linked homodimer of a 9257 Da subunit and contained a total of 14 half-cystines involved in disulfide linkages. During *in silico* searches for amino acid sequences, no significant similar proteins were found, including lectins. Thus, the amino acid sequence of CBA was distinct from land plant lectins, and also from monosaccharide-binding lectins from other green algae, indicating that CBA was a novel lectin (Praseptiangga et al., 2012).

Furthermore, novel lectins showing strong anti-HIV activity have recently been discovered from a red alga *Griffithsia sp*. (Mori et al., 2005) as well as the cyanobacteria (blue-green algae) such as *Nostoc ellipsosporum* (Boyd et al., 1997), *Schytonema varium* (Bokesch et al., 2003) and *Microcystis viridis* (Williams et al., 2005). The HIV inhibiting lectins from algae commonly showed the high mannose-binding nature, which was critical for their antiviral activities (Botos et al., 2002, Botos & Wlodawer, 2003). Hori et al. (2007) reported that in the continuous studies on algal lectins, it is found that there exists a new family of lectins in lower organisms such as marine red algae belonging to the genera, *Solieria, Eucheuma* and *Gracilaria,* and a freshwater *cyanobacterium* (blue-green alga) (Sato et al., 2000, Sato et al., 2009). The lectins of this family shared both the similar N-terminal amino acid sequences and hemagglutination profiles which are inhibited by high-mannose *N*-linked glycans, in addition to other intrinsic characteristics common to many macroalgal lectins mentioned above. Additionally, their *N*-terminal sequences also resembled well to that of a hemagglutinin (MBHA) from a soil myxobacterium, *Myxococcus xanthus* (Romeo et al., 1986), suggesting that the lectins belonging to this family may be widely distributed in lower organisms. Thus, marine algae should be expected as sources of novel lectin molecules for basic research and application, for instance, they are also applicable as convenient tools in the field of glycomics because they can discriminate the difference among carbohydrate structures.

4. Prospects for Algal Lectins Research 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 or seaweed-based industry has promising prospects to be developed in Indonesia, since Indonesia is a tropical country with the highest marine biodiversity in the world. Indonesian ocean has a large variety of biota, including algal species and hundred thousands of other macro and micro biota which are not known yet (Fajarningsih, 2011). Thus, it gives great opportunities and challenges for many researchers in the world, particularly Indonesian researchers to explore the potential utilization of Indonesian marine resources. Recent intensive studies on marine natural products have demonstrated that algae are sources of bioactive compounds. Among them, algal lectins have recently been remarked. Moreover, the recently discovered anti-HIV and anti-influenza virus lectins from cyanobacteria (blue-green algae) and macroalgae are promised as a new antiviral agent because their inhibiting activities are extremely strong compared to those of lectins from other biological groups (Hung et al, 2015). Despite disparity in physicochemical and biochemical characteristics, lectins from different sources essentially exhibit common biological activities. Lectins are a subject of intense investigations. As more lectins are isolated and further studies are conducted on the biological activities and mechanisms of action of lectins, the production of lectins can be improved and new applications of lectins can be found (Lam & Ng, 2011). Algal lectins are one of the potential algal-derivative products that could be more intensively studied. In spite of the progress made in the biochemical characterization of lectins from marine algae, additional information are still needed for a more

comprehensive understanding of their properties, structures, and possible biological functions. Therefore, research on algal lectins, starting from the screening of Indonesian marine algae towards the lectins purification and characterization, have been conducting by a collaborative research framework between Sebelas Maret University (UNS) Surakarta, Republic of Indonesia, and the Research and Development Center for Marine and Fisheries Product Processing and Biotechnology, Republic of Indonesia. It is hoped that this research collaboration would become initial steps for the development of algal lectins research in Indonesia, since there is no report on lectins from Indonesian marine algae (seaweeds) up to now. Discovery of novel lectins isolated from Indonesian marine algae, and further research and development towards the potential application of algal lectins will open great opportunities to contribute and strengthen the development of marine-derived nutra-ceuticals and associated medicinal benefits.

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