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Prebiotics as Functional Food: The Potentials of Brown Seaweed

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Functional foods, characterised by their ability to provide health benefits beyond basic nutrition, have gained popularity due to their potential to improve general well-being. Prebiotics are non-digestible substances present in food that have the unique ability to support the growth and activity of beneficial bacteria in the gastrointestinal tract. This, in turn, brings about a multitude of health benefits for the individual. Marine macroalgae, also known as seaweeds, are a promising source of renewable biomass that contains a significant quantity of bioactive compounds. *Sargassum* species, which are common among seaweeds, are known for their abundant presence and complex biochemical composition, making them a promising candidate as functional foods. This review article delves into the topic of functional foods and the various prebiotics derived from terrestrial plants, along with the documented health benefits associated with them. Additionally, this article reports on the key bioactive compounds found in brown seaweed that have the potential to be prebiotics. A literature search on the potential health benefits of *Sargassum* species demonstrated in vitro and in animal models was also undertaken.

Keywords: Prebiotic; functional food; brown seaweed; *Sargassum*

I. INTRODUCTION

In recent years, health systems have faced difficulties in effectively handling the management of COVID-19 and other newly developing infectious illnesses, all while ensuring the provision of essential healthcare services on a worldwide level. The World Health Organisation (2023) reported that noncommunicable diseases (NCDs) are responsible for seven out of the top ten leading causes of death. These diseases primarily encompass heart disease, diabetes, cancer, and chronic respiratory illnesses. One of the primary factors contributing to increased risk is the unhealthy eating habits, coupled with a sedentary lifestyle. Additionally, the use of tobacco and excessive alcohol consumption are also significant contributors (Peters *et al.*, 2019). In modern society, there is an increased concern regarding the possible adverse effects of medication. As a result, people are actively seeking new and innovative treatment alternatives, recognising the significance of nutrition as a valuable tool in maintaining good health (Topolska *et al.*, 2021). The majority of people were motivated by the desire to be healthy, which led them to adopt the belief that eating is essential for overall well-being and good health. In recent years, there has been a significant surge in global consumer interest towards functional foods. Consumers tend to seek food that is rich in bioactive compounds and thus provides protection against a range of diseases.

Seaweed, a broad group of marine algae, has a significant amount of bioactive compounds such fatty acids, complex polysaccharides, and carotenoids (Cherry *et al.*, 2019; Peñalver *et al.*, 2020; Rocha *et al.*, 2021). Compounds extracted from seaweeds have been found to possess a range of biological activities, including, antioxidant potential (Wang *et al.*, 2020; Rodrigues-Souza *et al.*, 2022), antibacterial activity (Jun *et al.*, 2018; Nazarudin *et al.*, 2022), anti-viral activity (Sanniyasi *et al.*, 2019; Wei *et al.*, 2022), anti-inflammatory and immunomodulatory

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properties (Pradhan *et al.*, 2023), anti-coagulant activity (Adrien *et al.*, 2019; Manggau *et al.*, 2019), and apoptotic activity (Lee *et al.*, 2021; Agena *et al.*, 2023).

The seaweed plant, in its original state, contains a high amount of polysaccharides and can have a dietary fibre level of up to 75%. This makes it an appropriate candidate for studying its potential as a prebiotic. Various species of seaweeds contain dietary fibres, including soluble fibres. Brown seaweeds contain alginate and fucoidan, red seaweeds contain carrageenan, agar, and porphyrin, and green seaweeds contain ulvan (Tanna & Mishra, 2019; Siddik *et al.*, 2023). The dietary fibres mentioned, such as fucoidan, carrageenan, and alginate, have been found to support the growth of beneficial gut bacteria. These fibres successfully pass through the human digestive system and reach the colon, where they are fermented by the microbiota. Short-chain fatty acids, produced through fermentation, play a crucial role in improving digestion, balancing the immune system, and promoting gut health. Seaweed, with its unique composition, holds great promise as a natural source of prebiotics, offering potential benefits for overall health and well-being.

II. METHODOLOGY: DATA MINING AND SEARCH STRATEGY

The authors conducted a literature search on Google Scholar using predefined search strategies. Search strings included the terms prebiotics, brown seaweed, and Sargassum. The search was limited to English-language, peer-reviewed original and review articles published between 1975 and 2023. The authors then screened and decided which identified articles to include based on their relevance and quality.

III. FUNCTIONAL FOODS AND PREBIOTICS

The definition of "functional food" varies among different organisations or authors. Functional foods, as defined by Crowe and Francis (2013), are foods that contain physiologically active components that provide health benefits beyond basic nutrition. Functional foods, according to Martirosyan and Pisarski (2017), are foods that are either natural or processed and contain biologically active compounds. These compounds, whether their effects are known or not, have been scientifically demonstrated to offer health advantages for the prevention, management, or treatment of chronic diseases. These foods should be consumed in recommended quantities that are suitable and safe. The functional food industry is an economically sustainable sector of food production that is projected to undergo worldwide expansion in countries including the United States, Japan, Asia Pacific, and the European Union. According to a report by BCC Research (2022), the global market for functional foods and drinks is projected to experience an average annual increase of 8.4% from 2022 to 2027. This growth will result in the market size expanding from $216.4 billion in 2022 to $324.4 billion in 2027. Hence, it is anticipated that industrialised nations would widely adopt functional foods, which are experiencing a surge in popularity.

Prebiotics are defined as food components that are indigestible and have a positive impact on the host by particularly promoting the growth and/or function of certain bacteria in the colon, hence improving the overall health of the host (Gibson & Roberfroid, 1995). The understanding, acceptability, and application of prebiotics have greatly expanded in the disciplines of microbiology, nutrition, biochemistry, and clinical research since they were first introduced.

Prebiotics are widely acknowledged as dietary fibre, even though they do not meet any dietary fibre standards. The criteria for classifying a substance as prebiotics are as follows (Gezer & Okburan, 2021).

a) Prebiotics need to demonstrate resistance to stomach acidity, be resistant to hydrolysis by mammalian enzymes, and not be absorbed in the gastrointestinal tract;

b) Prebiotics should not undergo digestion in the upper gastrointestinal system;

c) Prebiotics need to be fermentable by gut microbiota in the colon;

d) Prebiotics should have beneficial effects on the health of the host;

e) Prebiotics should stimulate the proliferation of beneficial bacteria, particularly lactobacilli and bifidobacterial strains, and,

f) Prebiotics must be capable of withstanding food processing conditions without undergoing alteration.

IV. TYPES OF PREBIOTICS DOCUMENTED

Prebiotics are naturally-occurring compounds found in various diets, including fruits, vegetables, whole grains, and pulses. The type of prebiotic that have been documented are inulin, lactulose, fructo-oligosaccharides (FOS), galacto-oligosaccharides (GOS), xylooligosaccharides (XOS), soy oligosaccharides (SOS), and isomaltose-oligosaccharide (IMO). Nevertheless, the list of potential prebiotics is still expanding.

Fructo-oligosaccharides (FOS), sometimes referred to as oligofructan or oligofructose, are types of dietary fibres that have prebiotic properties and are low in calories. FOS is composed of fructose molecules linked together by β-(2→1) bonds, forming linear chains. FOS is composed of 2 to 9 individual units, while inulin is composed of 10 or more units (Fedewa & Rao, 2014). Enzymes like β-fructofuranosidase or fructosyltransferase use sucrose as a substrate to produce FOS, which is found in several foods such as oats, barley, onions, garlic, bananas, and asparagus (Rahim *et al.*, 2021). FOS stimulates the growth of beneficial bifidobacteria and provides several health benefits, such as inhibiting pathogenic bacteria, reducing cholesterol levels, and aiding in the synthesis of vitamin B complex (Nobre *et al.*, 2022).

In their investigation, Cummings *et al.* (2001) conducted a randomised, double-blind, placebo-controlled trial to determine the efficiency of FOS in preventing traveller's diarrhoea in healthy individuals who were travelling to countries with a high or medium risk of getting the disease. Participants took 10 gram of inulin or a placebo two weeks prior to the holiday and subsequently continued to eat daily dosages of FOS or a placebo during the entire course of the holiday. While participants reported increased flatulence, the researchers found that ingesting FOS led to a little increase in bowel movements before the trip and considerably improved the feelings of "well-being" during the vacation. However, visiting regions with a high likelihood of infection led to a higher occurrence of diarrhoea. While FOS do provide significant advantages to individuals, they were not enough on their own to prevent catastrophe.

In a study conducted by Parnell and Reimer (2009), overweight and obese adults were examined to explore the impact of FOS supplementation on body weight and levels of satiety hormones. The study was carried out utilising a double-blind, randomised, placebo-controlled design. During a 12-week period, a group of 48 adults with a body mass index (BMI) more than 25kg/m2 were given either 21 g of FOS or a placebo (maltodextrin) per day. According to the data collected, the group that consumed FOS experienced a decrease in body weight of 1.03 ± 0.43 kg, while the control group noticed an increase in body weight of 0.45 ± 0.31 kg. Galacto-oligosaccharides (GOS) consist of oligolactose, oligogalactose, and oligogalactosyllactose. These molecules are primarily found in human milk. Bacterial galactosidases catalyse the synthesis of galactooligosaccharides (GOS) from lactose by forming galactosyl residues connected by β-(1→6) connections and a glucose unit connected by a β-(1→4) bond (Tian *et al.*, 2019). GOS was reported to possess beneficial effects on microbiota found in the intestines of several populations, including healthy persons, the elderly, and infants (Glibowski & Skrzypczak, 2017). Studies have demonstrated that GOS may boost the population of bifidobacteria in the stomach while decreasing the prevalence of detrimental microorganisms (Sierra *et al.*, 2015). Osborn and Sinn's (2013) study found that infants who took in supplement with GOS to FOS with ratio of 9:1 had a lower likelihood of getting eczema. In a study conducted by Brosseau *et al.* (2019), it was demonstrated that a hypoallergenic formula enriched with mixture of GOS and FOS can successfully prevent allergies, such as rhino conjunctivitis and eczema. Tomasello *et al.* (2016) has demonstrated that the addition of GOS and FOS to the diet of neonates promotes the proliferation of lactobacilli and bifidobacteria in their intestines.

Xylooligosaccharides (XOS) are produced from xylose molecules. The primary components of these substances are primarily xylobiose, xylothiose, and xylo-tetraose. They are produced by connecting xylose molecules by β-(1→4) bonds, with a polymerisation degree (DP) ranging from 2 to 10 (Karlsson *et al.*, 2018). XOS has been found in honey, milk, bamboo shoots, vegetables, and fruits that can be fermented by bifidobacteria (Lin *et al.*, 2016). Chemical and/or enzymatic processes can be used to commercially produce XOS from lignocellulosic materials, such as xylan (Aachary & Prapulla, 2011).

XOS has been applied in the food and pharmaceutical industries. The study conducted by Samanta *et al.* (2015) revealed that XOS had no adverse effects on blood glucose levels or pancreatic insulin secretion in individuals with diabetes, suggesting that they are safe to consume. According to the authors, XOS were found to be non-carcinogenic and had the ability to improve mineral absorption in the large intestine. Nam *et al.* (2015) found that XOS can lower the glycemic index of sucrose, potentially aiding in the prevention of overconsumption. In a 6-week randomised controlled trial, a group of 20 healthy persons were given 150 g of porridge per day, coupled with 1.2 g of XOS. The study indicated that this dietary intervention increased the population of beneficial bacteria, specifically bifidobacterium and lactobacilli, in the participants' intestines. The quantity of Clostridium bacteria decreased, while the number of anaerobic bacteria remained unchanged, in comparison to persons who ingested only rice porridge (Lin *et al.*, 2016).

Raffinose, stachyose, and sucrose are soy oligosaccharides (SOS) that consist of various combinations of monosaccharides and disaccharides (Zhou *et al.*, 2012). Soybean seeds and other legumes are the main sources of SOS, which has been approved by the FDA as a well-established prebiotic or generally regarded as a safe component (Chen *et al.*, 2010). Instead of undergoing enzymatic digestion in the stomach or intestines, these oligosaccharides are metabolised by bacteria in the gastrointestinal tract (Švejstil *et al.*, 2015). Multiple studies have demonstrated that SOS has a significant effect in reducing abnormal blood sugar, cholesterol levels, and oxidative stress. In addition, SOS has the ability to effectively suppress potentially hazardous microorganisms, enhance insulin sensitivity, and bolster the immune system, hence reducing the risk of numerous diseases (Liu *et al.*, 2021).

Isomaltose-oligosaccharide, also known as IMO, can be synthesised from maize starch through a sequence of enzymatic processes including α-amylase, β-amylase, and transglucosidase obtained from *Aspergillus niger* (Zhang *et al.*, 2009). The resulting IMO has a degree of polymerization (DP) ranging from 2 to 6. Maize starch was treated with α-amylase, α-glucosidase, and pullulanase enzymes to form IMO. The IMO was then separated into its main components, which include isomaltotriose, isomaltose, and panose (Althubiani *et al.*, 2019). According to the research conducted by Gänzle and Follador (2012), it was found that IMO had a beneficial effect on bifidobacteria and was metabolised by many microorganisms. In a study conducted by Yen *et al.* (2011), healthy adult males were administered a mixture of isomalto-oligosaccharides (IMO) at doses ranging from 10 to 13.5 g/day. This led to the stimulation of bifidobacteria proliferation. The researchers also noted that IMO has been demonstrated to stimulate the proliferation of bifidobacteria in elderly males and females with constipation, at doses of 10 or 13.5 g/day, respectively.

Over the years, both in vitro and in vivo laboratory studies have demonstrated a wide range of possible health advantages associated with IMO. The benefits of consuming these foods include a decreased likelihood of developing cancer, a lower increase in blood sugar levels after eating, a reduction in the amount of triglycerides in the blood, an increase in the presence of beneficial bacteria in the gut such as lactobacilli and bifidobacteria, and the repair of damaged cells in the intestinal lining (Wang *et al.*, 2017).

Although several of the previously stated components are currently sourced from plants found on land, recent study has indicated that polysaccharides and oligosaccharides obtained from marine algae are more resilient to digestion by enzymes in the gastrointestinal tract compared to those that come from plants on land (Han *et al.*, 2019; Seong *et al.*, 2019). Therefore, the compounds obtained from seaweed may exhibit greater level of prebiotic activity.

V. BROWN SEAWEED POLYSACCHARIDES AND THEIR HEALTH BENEFITS

The earth's surface is approximately two-thirds covered by oceans. The oceans harbour and support around 500,000 species, accounting for around 75% of all documented species. Seaweeds, often known as marine algae, inhabit the ocean or brackish water. These algae are commonly referred to as "benthic marine algae", which simply attached algae that live in the sea" (Gomez-Zavaglia *et al.*, 2019). Seaweed, despite being predominantly found in salt water, is also capable of surviving in freshwater (Gomez-Zavaglia *et al.*, 2019).

Mouritsen (2013) categorised macroalgae into three main groups: brown algae (Phaeophyta), green algae (Chlorophyta), and red algae (Rhodophyta). Brown seaweeds, which belong to one of the three kinds of seaweed, typically exhibit a wide size range. This includes the gigantic kelp, which may reach lengths of up to 20 m, as well as smaller species measuring between 30 and 60 cm. Red seaweeds typically have smaller sizes, ranging from a few centimetres to approximately one metre in length. Nevertheless, red seaweeds may not consistently exhibit a red colour; on occasion, they could appear as purple or even brownish red. Green seaweeds, like red seaweeds, also have a small size range (McHugh, 2003). Green algae are abundant in freshwater and terrestrial habitats, while red and brown algae are primarily found in marine environments (Veluchamy & Palaniswamy, 2020). Research indicated that the maritime environment is habitat to 6200 species of red seaweed, 1800 species of green seaweed, and 1800 species of brown seaweed (Pereira, 2021).

Seaweed polysaccharides exhibit species-specific variations, with concentrations ranging from 4% to 76% dry weight (Gullón *et al.*, 2020). In a study conducted by Li *et al.* (2021), it was found that brown seaweed contains polysaccharides that constitute more than 50% of their dry weight. In some species, this percentage can even exceed 70%. Three of the main polysaccharides found in brown seaweed include fucoidans, laminarins, and alginates. Because of their various sources, structure, and physicochemical properties, these brown seaweed polysaccharides have a variety of health-related and pharmacological properties (Lim & Wan Aida, 2017). Several studies have reported positive effects of brown seaweed, including reduced expression of genes associated with diabetes, decreased levels of lipopolysaccharide-binding protein in the blood, increased CAZymes (carbohydrate-active enzymes), decreased activity of faecal bile salt hydrolase, and reduced levels of inflammatory markers in the blood (Lean *et al.*, 2015; Nguyen *et al.*, 2016; Huebbe *et al.*, 2017; Yang *et al.*, 2019). Furthermore, Wang and Cheong (2023) provided further evidence to support the notion that the physicochemical and structural characteristics of brown seaweed polysaccharides play a crucial role in their health-promoting effects.

Alginate

Alginate, also called the salt of alginic acid, is a polymer that dissolves in water. The main source of this substance is brown seaweed species such as *Ascophyllum*, *Durvillaea*, *Lessonia*, *Ecklonia*, *Laminaria*, *Macrocystis*, *Turbinaria*, and *Sargassum*. It is primarily extracted in two forms (sodium or calcium). Alginate consists of linear binary copolymers that connects two acids, β-D-mannuronic acid and α-L-guluronic acid (Khajouei *et al.*, 2018; Bilal & Iqbal, 2019).

Alginate exhibits unique biological and pharmacological properties, along with biocompatibility, non-toxicity, and biodegradability. It also has the ability to remain stable, thicken, and form gels (Peteiro, 2018). Within the food and pharmaceutical industries, their main role was as a gelling agent, stabiliser, and thickening agent (Qin *et al.*, 2018). In addition, alginate is utilised as a food additive to enhance uniformity and durability in various food products such as baked goods, fruits, jellies, jams, ice cream, and mayonnaise. As per the research conducted by Zia *et al.* (2017), alginate has been widely acknowledged for its advantageous properties as a dietary component, particularly its potential anticancer and prebiotic effects. Alginates have found application in the food industry, particularly in product packaging (Rinaudo, 2014).

Bacteroides ovatus, a gut bacterium, is known to ferment alginate (Salyers *et al.*, 1978). Alginate is utilised not only by *B. ovatus*, but also by other gut bacteria. In previous studies conducted by Wang *et al.* (2006) and Ramnani *et al.* (2012), it was discovered that alginate and its low-molecular-weight derivatives have the ability to enhance the growth of *Bifidobacterium* and *Lactobacillus* bacteria within the gastrointestinal tract. In a study conducted by Kuda *et al.* in 2017, it was discovered that depolymerised alginate had the ability to hinder the adhesion and invasion of *Salmonella typhimurium* in both human enterocytes and BALB/c mice.

Alginate is a highly viscous polysaccharide with a significant molecular weight. It has the remarkable ability to form gellike substances inside the stomach, resulting in the postponement of emptying the foods residues in the stomach. This property of alginate has been found to increase satiety and improve glycaemic control (Piras & Smith, 2020; Guo *et al.*, 2020). Gastric emptying postponement allows nutrients to remain in the stomach for a longer duration, resulting in increased absorption in the digestive tract and gut. Furthermore, alginate's capacity to undergo gelation enables it to build a shielding coat on the wall of intestine, resulting in a reduction of inflammation and enhancement of barrier function for the intestinal (Agüero *et al.*, 2017).

Fucoidan

Fucoidan, or sulfated fucans, is a polysaccharide that consists mainly of L-fucose with sulphate ester groups, along with a few other monosaccharides. In a study conducted by Lahrsen *et al.* (2018), it was discovered that the composition of the brown seaweed *Fucus vesiculosus* consisted of 84% fucose, 7.3% galactose, 6% xylose, and 2% mannose. The polysaccharides found in brown algae have molecular weights ranging from 7 to 2300 kDa. These polysaccharides make from 4 to 10% of the dry weight of the algae. The biological activity of fucoidans has been extensively studied in relation to factors such as molecular weight, monosaccharide composition, chemical composition, sulfation degree, location of sulphate groups, and glycosidic linkages (Sanjeewa *et al.*, 2017; Dobrinčić *et al.*, 2020; Li *et al.*, 2021; Ramos-de-la-Peña *et al.*, 2022).

Fucoidan is a major component of the cell walls of brown seaweed, commonly found in species such as *Ascophyllum nodosum*, *Cladosiphon okamuranus*, *Sargassum*, *Ecklonia cava*, and *Undaria pinnatifida* (Bilal & Iqbal, 2019). Fucoidan exhibits potent pharmacological effects that are intricately linked to its molecular weight, sulphate amount, place, along with various structural characteristics (Zhang *et al.*, 2020). According to a study conducted by You *et al.* (2020), fucoidan was found to be more viscous than laminarin, which can be attributed to its higher molecular weight. The viscosity of the substance varied based on its concentration and the degree of sulfation. In a study conducted by Shang *et al.* (2018), it was discovered that fucoidan has the potential to enhance gut health and alleviate intestinal dysbiosis, in contrast to alginate. Fucoidan is not easily broken down by the microbes in our intestines, but it does have the ability to change the composition of gut bacteria and their ability to ferment, which can be beneficial for the host.

Laminarin

Laminarin, commonly referred to as laminaran or leucosin, is the primary storage glucan present in brown seaweeds. The hydrophilic and hydrophobic forms of it can be found in *Saccharina* and *Laminaria* species (Yao *et al.*, 2023). According to Kadam *et al.* (2015), brown algae have been shown to contain as much as 35% laminarin when measured on a dry basis. Laminarin is a polysaccharide made up of β-glucans that are connected by (1→3) and (1→6) glycosidic links. The specific ratios of these linkages might vary depending on the species, environment, season of harvest, and the methods of extraction (Rioux *et al.*, 2010). Laminarin has a low ability to form gels and does not have substantial thickening abilities (Custódio *et al.*, 2016).

The usual molecular weight of laminarin is around 4 to 5 kilodaltons (kDa), which is lower than that of other polysaccharides (Custódio *et al.*, 2016). In addition, because of its low viscosity, gut microorganisms were able to digest laminarin more easily (Bäckhed *et al.*, 2005). Kuda *et al.* (2009) found that laminarin obtained from seaweeds stimulated the growth of *Lactobacillus* and *Bifidobacterium* species in the stomach. The gut microbiota metabolised laminarin through fermentation, resulting in the production of microbial metabolites, specifically short-chain fatty acids (SCFAs). These SCFAs have the potential to improve the absorption of minerals and the nutrition metabolism within the colon (Alexander *et al.*, 2019).

VI. SEAWEED SARGASSUM AS POTENTIAL PREBIOTIC SOURCE

Lorem *Sargassum* is a highly diverse genus of brown seaweed, consisting of around 400 distinct species. It belongs to the Sargassaceae family, Fucales order, Cyclosporeae subclass, and Phaeophyceae class (Mattio and Payri, 2011). According to De Wreede (1976), *Sargassum* sp. grows prolifically at the hottest time of the year in temperate regions and during the coolest time of the year in tropical regions. Yeong and Wong (2013) stated that the growth of *Sargassum* sp. changes significantly depending on the geographical region and the reef ecology. Two investigations were carried out to examine the seasonal growth of *S. polycystum* in two different geographical areas: Visakhapatnam, situated on the East Coast of India (Rao & Rao, 2002), and Port Dickson, located in Malaysia (Yeong and Wong, 2013). According to the findings of Rao and Rao (2002), *S. polycystum* was found to flourish in large quantities throughout the winter season, specifically from November to January in India. Nevertheless, in Malaysia, there was a significant proliferation of *S. polycystum* throughout the period of June to July in the year (Yeong & Wong, 2013).

People in Indonesia and Thailand consume *S. polycystum* as part of their daily diet. Scientists conducted an analysis of the nutrient composition in *S. polycystum* and discovered that it possesses a significantly larger amount of dietary fibre (about 55% more) in comparison to plants that grow on land. Furthermore, it has been scientifically demonstrated that *S. polycystum* possesses a greater concentration of minerals in comparison to typical vegetables and fruits. The seaweed contains minerals such as calcium, sodium, potassium, and magnesium (Suhaila *et al*., 2013).

Sargassum species have been extensively studied for their ability to produce a wide range of metabolites with various therapeutic properties. These metabolites include terpenoids, polysaccharides, polyphenols, sargaquinoic acids, sargachromenol, plastoquinones, steroids, glycerides, and other compounds. Due to its numerous pharmacological properties, it has been classified as a therapeutic food of the 21st century (Yande *et al*., 2014). Furthermore, studies have been carried out to reveal its additional pharmacological features. For example, *S. polycystum* contains an iodine component that helps in the treatment of goitre. Furthermore, scientific research has demonstrated that *S. polycystum* possesses several therapeutic properties, including the treatment of diabetes, obesity, arteriosclerosis, and other illnesses (Brown *et al*., 2014).

In a study conducted by Rodrigues *et al.* (2016), an *in vitro* fermentation process was carried out using fresh faeces from three healthy donors and extracts from *Sargassum multicum* (1% w/v) for a duration of 24 hours. Their research demonstrated a decrease in levels of *Clostridium coccoides* and *Eubacterium rectale*, while *Bacteroides* and *Prevotella* showed an increase. In addition, the production of lactic acid and SCFA was found to be higher compared to the negative controls.

In a study conducted by Nagappan *et al.* (2017), the researchers showcased the potential of *S. siliquosum* and *S. polycystum*, two plant species found in Malaysia, to mitigate risk factors linked to cardiovascular diseases. These plants were found to effectively inhibit ACE, α-amylase, and α-glucosidase enzymes. Additionally, there is a potential for fucoxanthin-rich-fractions (FRF) to exhibit antioxidant properties at low concentrations.

In their study, Fu *et al.* (2018) conducted a 48-hour *in vitro* fermentation using *Sargassum thunbergii*. The data revealed a significant increase in the population of beneficial bacteria, with a rise from 17% to 28%. At the same time, there was a decrease in a specific group of harmful *Firmicutes*, which dropped from 75% to 64%. The *Proteobacteria* and *Actinobacteria* showed no noticeable changes. After 24 hours of incubation, there was an observed increase in the abundance of *Lactobacillus*, *Bifidobacterium*, *Roseburia*, *Parasutterella*, and *Fusicatenibacter*. Following another 48 hours, there was a subsequent rise in *Faecalibacterium* and *Coprococcus*.

Chamidah (2018) used *Sargassum crassifolium* for evaluating the prebiotic index of two crude laminaran compounds – laminaran acid extract (LAE) and laminaran modified extract (LME). Their findings indicated that the total sugar content of LAE was 9.075%, which was greater than the sugar content of LME, which was 7.355%. The prebiotic index values for LAE and LME were 1.29 and 2.10, respectively. Therefore, the author concluded that laminaran extract, specifically LME, has the potential to be considered as a prebiotic candidate.

Praveen *et al.* (2019) examined the use of *S. wightii* in MRS broth for *in vitro* fermentation. They evaluated the prebiotic score and antioxidant activity by comparing the growth of *Salmonella typhimurium* and *L. plantarum*. Based on the study findings, it was observed that the prebiotic activity score showed a positive trend, indicating a preference for the growth of *L. plantarum* over the pathogen *S. typhimurium* in a specific manner. Specifically, the prebiotic had a significant impact on the development of *L. plantarum*, increasing it by 1.42 times compared to *S. typhymurium*.

In their study, Nazarudin *et al.* (2020) evaluated the prebiotic properties of *S. polycystum* as a dietary supplement for Asia sea bass fingerlings. The fish were fed with four different food formulations of powdered seaweed. Their research demonstrated that fish fed with feed supplemented with 1.5% and 3.0% seaweed performed better than the control group in terms of survival rate, feed consumption, efficiency, and growth performance.

In a recent study, Nazarudin *et al.* (2021) conducted an evaluation of the chemical, nutrient, and physicochemical characteristics of *Sargassum polycystum* C. Agardh. The samples were collected from Port Dickson in Peninsular Malaysia. Upon analysis, it was determined that the *S. polycystum* exhibited an 8.65 ± 1.06% protein content, 3.42 ± 0.01% fat content, 36.55 ± 1.09% carbohydrate content, and 2.75 ± 0.58% total dietary fibre content on a dry weight basis. Furthermore, the *S. polycystum* contained the following mineral contents, such as, sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), iron (Fe) and other minor minerals. The total carotenoid, chlorophyll a and b, and their respective were also found in *S. polycystum*. The amino acid composition was determined to be 74.90 ± 1.45%. The investigation has identified fucose, mannose, galactose, xylose, and rhamnose as the primary components of *S. polycystum* fibre, alongside several secondary metabolites. The physicochemical characteristics of S. polycystum, such as its ability to swell and retain water, closely resemble those of various fiber-rich products available in the market. Their research indicates that *S. polycystum* could potentially be a suitable choice for human consumption as a functional food source.

Ghanavati *et al.* (2022) examined the structural and functional characteristics of the water-soluble polysaccharide *Sargassum illicifolium* (WSPSI), which was obtained using hot water extraction. Their research demonstrated that WSPSI has the potential to be utilised as a unique and natural ingredient in the development of functional foods. The extract proved to be beneficial in improving the growth and viability of the probiotic bacterium *Lactobacillus casei* (ATCC 39392). Furthermore, the extract also exhibits significant antioxidant properties. Furthermore, the extract demonstrated inhibitory action against the pathogen *Salmonella typhimurium* (ATCC 14028).

VII. CONCLUSION

Functional foods, namely those that include prebiotics, have a crucial role in promoting health and preventing illness. Seaweed-derived prebiotics, specifically from the *Sargassum* species, offer significant health benefits owing to their abundant nutritional content and bioactive compounds. Incorporating seaweed-derived prebiotics into one's diet can improve gut health, stimulate the immune system, and provide a range of additional health benefits. Ongoing research and advancement in this field may lead to the development of innovative functional food that improve overall well-being.

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