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REVIEW ARTICLE

Ulvan from *Ulva lactuca* as A Potential Marine-derived Prebiotic for Functional Foods: A Review

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ABSTRACT
Ulvan, which comes from the green seaweed *Ulva lactuca* as a sulfated polysaccharide, has gained more research interest as a possible marine-based prebiotic. The review aims to evaluate the potential of ulvan derived from *Ulva lactuca* as a marine-based prebiotic by analyzing studies published between 2016 and 2026. Relevant articles were collected from scientific databases focusing on ulvan characteristics, digestibility, fermentation by gut microbiota, and its potential application in functional food products. The research demonstrated through laboratory experiments and animal research that ulvan retains its original form throughout its passage from the upper gastrointestinal tract to the colon, where microbes use ulvan as their fermentation substrate. Experimental results show that the *Lactobacillus* and *Bifidobacterium* bacteria groups demonstrate higher growth rates. Fermentation products like short-chain fatty acids help maintain intestinal balance. Most available evidence comes from experimental and animal studies. The scientific community has not established whether humans show similar reactions because of a lack of thorough clinical research. Research studies show that ulvan has potential to function as a prebiotic, but it has not yet become an established prebiotic component for clinical use. Therefore, ulvan derived from *Ulva lactuca* represents a promising marine-based prebiotic candidate with potential application as a functional food component, although further clinical studies are required.

KEYWORDS: *Functional food, Gut Microbiota, Prebiotic, Ulva lactuca, Ulvan*

Introduction

People in developed nations have been changing their daily routines and their eating patterns as awareness of the relationship between diet and health continues to increase. This shift has contributed to growing consumer interest in functional foods that provide health benefits beyond basic nutrition (Deniz & Sarıta, 2025). Customers today choose their food options because they want to obtain the necessary nutrients which will benefit their health throughout their entire lives. Use of functional foods is increasing as specialized products that can offer health benefits beyond basic nutritional value (Barrientos & Mendoza, 2016; Reque & Brandelli, 2021). This strategy offers better regulation of biomolecular processes and lessened risk for certain degenerative diseases (Klojdova & Stathopoulos, 2022). Prebiotics serve as common elements which researchers link to functional foods because they function as specific food sources that beneficial microorganisms in the body consume to produce health effects (Deehan et al., 2024).

While traditional prebiotic ingredients are largely obtained from terrestrial plants, increasing attention has been directed toward marine resources. Seaweeds serve as an insufficiently studied dietary polysaccharide source because their chemical properties differ from those of terrestrial plant materials. Marine polysaccharides commonly contain sulfate groups, unusual monosaccharide compositions such as rhamnose and uronic acids, and variable molecular weights, which distinguish them from terrestrial plant fibers such as cellulose, inulin, and pectin. These structural differences influence their resistance to digestion and fermentation by gut microbiota, thereby affecting the selective growth of beneficial intestinal microorganisms (Gotteland et al., 2020).

People who eat seaweed stretch their consumption of the green macroalga *Ulva lactuca*, which grows along coastlines, because this seaweed contains various active compounds, and its main polysaccharide exists as ulvan. The main elements that make up ulvan structure include rhamnose, xylose, and uronic acids, while sulfate groups protect the substance from digestive enzyme destruction, which occurs in the upper gastrointestinal tract (Shannon et al., 2021). The human body cannot digest ulvan because the substance maintains its original form until it reaches the colon, which enables bacteria to break it down through fermentation (Charoensiddhi et al., 2022). Specific gut microbiota, including *Bifidobacterium* and *Lactobacillus*, use ulvan as a substrate, leading to the production of short-chain fatty acids such as acetate and propionate. These metabolites lower intestinal pH and create a good environment for beneficial bacteria, thereby promoting microbial balance and inhibiting the growth of harmful microorganisms. Consequently, ulvan consumption may alter the composition of gut microbiota and enhance intestinal health. The controlled fermentation tests showed that beneficial microorganisms *Bifidobacterium* and *Lactobacillus* multiplied their populations while harmful bacteria maintained their existing levels (Seong et al., 2019). According to research, dietary ulvan supplements transform body bacteria while they boost short-chain fatty acid production, which aids in maintaining intestinal balance (Pratap et al., 2022). The scientists have used ulvan in laboratory studies, but also developed synbiotic food systems that include it in yogurt products which help preserve probiotic bacteria during storage (Shalaby & Amin, 2019). Functional food is a rapidly growing topic in nutrition science, as it can be found in all new applications.

The research community has shown growing interest in ulvan during the last few years, yet its value as a prebiotic component for functional food systems remains under-researched. To establish this connection, scientists must investigate the structural components of the subject and study the biological activities demonstrated through experimentation. The review reports on the current research on *Ulva lactuca* composition and its potential to cause alterations in the gut microbiota for potential applications in food products. The synthesis will create a framework for upcoming research, which will aid in building environmentally friendly marine-derived functional products.

Method

The researchers conducted their literature search through Publish or Perish (PoP) software, which provided access to publications that were available in Scopus and Google Scholar databases. The research considered English and Indonesian articles published between 2019 and 2026. The analysis included only experimental studies that tested ulvan's prebiotic properties, its ability to ferment, and its impact on gut microbiota. The search strategy combined the keywords "Ulva AND prebiotic" and "ulvan AND gut microbiota" with related terms that defined seaweed-derived polysaccharides and their use in functional food products. The inclusion criteria consisted of studies focusing on *Ulva sp.* or ulvan, studies evaluating prebiotic potential, digestibility, fermentation by gut microbiota, and studies reporting in vitro or in vivo experimental results. Only full-text articles published in peer-reviewed scientific journals were included. The exclusion criteria included studies published before 2019, articles not written in English or Indonesian, studies not related to ulvan or *Ulva lactuca*, conference abstracts, editorials, and articles without experimental data. Researchers examined eligible studies which required qualitative examination of bioactive compound characteristics and their associated mechanisms of action, and their experimental results from in vitro and in vivo testing. The researchers organized the results into themes which explained how ulvan could be used in functional food development.

Results and Discussion

Characteristics of Ulvan from *Ulva lactuca* as a Prebiotic Candidate

On account of its vast beneficial effects ulvan, which is a sulfated polysaccharide from green algae, was studied by the investigator (Kidgell et al., 2019). In *Ulva lactuca,* the primary structural polysaccharide ulvan consists of rhamnose, glucuronic acid, and iduronic acid, xylose, and various sulfation levels (Li et al., 2023). Ulvan contains sulfate groups, which differentiate it from most terrestrial plant fibers. Structurally, ulvan is mainly composed of sulfated rhamnose, glucuronic acid, iduronic acid, and xylose, forming repeating disaccharide units such as ulvanobiuronic acid (Kidgell et al., 2019). The presence of sulfate groups and uronic acids contributes to its high solubility, negative charge, and resistance to digestion by human gastrointestinal enzymes (Cindana Mo'o et al., 2020). These physicochemical properties enable ulvan to reach the colon intact, where it can be selectively fermented by beneficial gut microbiota (Charoensiddhi et al., 2022). The extent and manner of distribution of sulfate moieties could influence the interactions with gut microbiota and the subsequent fermentation efficiency of ulvan (Gotteland et al., 2020). These characteristics support the potential of ulvan as a functional food ingredient. The upper gastrointestinal tract cannot break down ulvan, which enables it to reach the colon, where microorganisms digest it. The nutritional value of ulvan increases when its water-binding capacity and gel-forming ability are combined to create food systems that improve both texture and stability. The bioactive properties of ulvan extend beyond its fermentability because it shows both immunomodulatory and antimicrobial effects. These biological activities are mainly attributed to its sulfated polysaccharide structure, including rhamnose, glucuronic acid, and iduronic acid, which contribute to immune stimulation and inhibition of pathogenic microorganisms (Cindana Mo'o et al., 2020). The microbial activity may reduce the growth of harmful bacteria, thereby creating favorable conditions for beneficial lactic acid bacteria such as *Lactobacillus* and *Bifidobacterium*. In addition, the fermentation of ulvan by these bacteria produces short-chain fatty acids that further enhance gut microbial balance and support intestinal health (Gotteland et al., 2020). The combination of these traits with its ability to promote lactic acid bacteria development makes ulvan an ideal ingredient for marine-derived functional foods (Shalaby & Amin, 2019).

Effect of Ulvan on the Growth of Probiotic Bacteria

Ulvan, the principal sulfated polysaccharide obtained from *Ulva lactuca*, has been extensively studied as a marine-derived prebiotic candidate. The gut microbiota ferment the substance after it survives digestive processes in the upper gastrointestinal tract of humans, which meets the main requirements needed to be considered a prebiotic substrate. Table 1 summarizes studies investigating the prebiotic potential of ulvan.

Table 1. Summary of studies on ulvan from *Ulva lactuca* and its prebiotic potential.

Study Type	Target Microorganism	Main Findings	Prebiotic Indicators	References
In vitro individual strain fermentation & in vitro human	*Bifidobacterium spp., Lactobacillus spp., Bacteroides spp.*	Ulvan selectively stimulated beneficial bacteria, increasing	Selective fermentation, enhancement of beneficial bacterial	Seong et al. (2019)

fecal batch fermentation		Bifidobacteria (Δ8.5%) and *Lactobacillus* (Δ6.8%), with no observed growth of pathogenic bacteria.	populations, production of acetate and lactate, and generation of short-chain fatty acids (SCFAs)	
In vitro fermentation and functional food application (synbiotic yogurt study)	*L. acidophilus, S. thermophilus, Bifidobacterium spp.*	Ulvan at concentrations of 1–2% increased probiotic viability to 6.4–9.5 log CFU/mL and maintained these levels throughout a 9-day storage period	Increased probiotic survival; enhanced growth; synbiotic functionality	Shalaby & Amin (2019)
In vivo animal study (mouse model)	*Bacteroidia, Bacilli, Clostridia, Verrucomicrobia*	Ulvan supplementation significantly modulated gut microbiota composition and increased specific beneficial bacterial taxa.	Microbiota modulation (no direct SCFA quantification reported)	Pratap et al. (2022)
In vitro gastrointestinal digestion and fecal fermentation model	Human gut microbiota (fecal microbiota model)	Green seaweed polysaccharides, including ulvan-containing fractions, demonstrated resistance to simulated gastrointestinal digestion and influenced gut microbiota composition during in vitro fermentation.	Resistance to digestion in the upper gastrointestinal tract, fermentability by gut microbiota, and modulation of the microbial community structure.	Charoensiddhi et al. (2022)
In vitro study	*Lactobacillus acidophilus, Lactobacillus bulgaricus, Escherichia coli*	Enzymatically produced ulvan oligosaccharides enhanced probiotic growth and inhibited enteric pathogens, exhibiting prebiotic activity comparable to FOS	Probiotic growth stimulation; pathogen suppression; high prebiotic score; selective fermentation	Jagtap et al. (2022)
In vitro study	*Lactobacillus acidophilus and Lactobacillus plantarum*	Ulvan oligosaccharides from *Ulva rigida* enhanced probiotic growth and suppressed pathogenic bacteria	Probiotic growth stimulation; pathogen inhibition; gastrointestinal survival; higher activity than GOS	Krangkratok et al. (2023)

In vivo feeding trial (weaned piglets)	Gut microbiota of piglets (intestinal microbiota)	*Ulva lactuca* supplementation improved gut health and supported beneficial microbial activity in weaned piglets.	Dietary inclusion of ulvan improved gut health parameters and nutrient digestibility; modulation of the intestinal environment was observed	Ribeiro et al. (2024)
In vitro fermentation study	*L. rhamnosus RAL43, L. plantarum RAL25, Lc. lactis SwR14*	Ulvan from *Ulva lactuca* promoted probiotic growth and exhibited prebiotic activity comparable to FOS.	Increased LAB viability; SCFA production; carbohydrate utilization; selective fermentation by probiotics	Rubak et al. (2026)
In vitro fermentation study	Human gut microbiota (fecal microbiota)	Ulvan acted as a fermentable dietary fiber and demonstrated prebiotic potential comparable to inulin	SCFA production; gut microbiota fermentation; modulation of tryptophan metabolism; production of beneficial microbial metabolites	Zonfrillo et al. (2026)

Recent research demonstrates that ulvan promotes the growth of beneficial bacteria, including *Lactobacillus* and *Bifidobacterium*, as shown in in vitro experiments, in vivo animal models, and functional food systems. Ulvan digestion in the upper gastrointestinal tract cannot occur, according to current evidence, because gut microbiota ferments the substance to produce short-chain fatty acids (SCFAs), which promote intestinal health. These SCFAs lower intestinal pH, inhibit pathogenic bacteria, and promote the growth of beneficial microorganisms. In addition, butyrate serves as an energy source for colonocytes and helps maintain intestinal barrier integrity, while acetate and propionate contribute to immune regulation and anti-inflammatory effects. These mechanisms collectively improve gut microbial balance and support intestinal health (Gotteland et al., 2020). The studies demonstrate that gut microbiota composition undergoes substantial changes, yet direct proof of selective fermentation together with permanent SCFA measurement remains scarce for particular experimental setups. Supported by a plethora of data from populations, findings from laboratory or animal work highlight all-important deficiencies in in-depth human clinical trials. Within the boundary of this review, ulvan could best be ascribed as a potential prebiotic, rather than a validated clinical prebiotic.

Modulation of Gut Microbiota and Metabolite Production

Research shows that ulvan enhances probiotic bacteria, but its effect on the gut bacterial ecosystems renders independent research outcomes. Animal-based studies indicate that green algal polysaccharide supplements, which contain ulvan, produce microbiome changes by increasing beneficial species while decreasing dangerous species (Gotteland et al., 2020). The research conducted on piglets demonstrated that ulvan dietary supplements improve intestinal health while increasing nutrient absorption, which results in better gut health (Ribeiro et al., 2024). The intestinal microbiome can break down ulvan to produce short-chain fatty acids (SCFAs), with acetate and propionate as the main products (Deehan et al., 2024). Studies on piglets have demonstrated that intestinal health benefits from ulvan dietary supplements which also improve nutrient absorption through enhanced intestinal function. Microbial fermentation generates SCFA, which researchers use to measure prebiotic effects because SCFA production shows active fermentation processes (Koh et al., 2016). The fermentability of ulvan shows variability because its fermentability depends on three factors, which include its molecular weight, sulfation level, and monosaccharide composition (Kidgell et al., 2019). The substance's biological properties differ because of its geographical origin and extraction techniques. The available research shows that microbiota modulation can occur, but most studies use controlled laboratory environments and animal testing methods. Human clinical trials which follow proper research design show limited evidence, which creates a need for more research before making final judgments. Currently, scientific investigations have demonstrated that microbiota modulation can affect human microbiota.

Ulvan in the Context of the Current Prebiotic Definition

The definition of prebiotics has evolved since the 2017 ISAPP consensus, which defined prebiotics as "a substrate that is selectively utilized by host microorganisms conferring a health benefit" (Gibson et al., 2017). The Global Prebiotic Association established that proof of measurable health outcomes must precede the classification of any substance as a prebiotic (Deehan et al., 2024). Reflection on ulvan in the light of these parameters appears somewhat inadequate in reinforcing the ailing indicia at the cost of lagging behind the urged appropriate recommendations. The experimental results show that ulvan remains undigested in the upper gastrointestinal tract while specific gut microbiota bacteria can digest it. The properties of this material that in total correspond with the necessary basic requirements for a good prebiotic substrate (Gotteland et al., 2020). Human direct health advantages which receive clinical proof still lack sufficient evidence. The reported effects which include changes in microbial composition and higher production of short-chain fatty acids, come from in vitro systems or animal models (Shannon et al., 2021). Researchers should classify ulvan as a promising prebiotic candidate because it has not yet been proven to function as a prebiotic ingredient. Therefore, according to the current prebiotic definition, ulvan meets several criteria of prebiotics, including resistance to digestion and selective fermentation by gut microbiota. However, the lack of clinical evidence in humans indicates that ulvan should currently be classified as a potential prebiotic candidate rather than a confirmed prebiotic.

Implications of Ulvan as a Functional Food Ingredient

The assembly of operational food systems with ulvan as a key ingredient needs to solve several problems which include both their operational requirements and their strategic needs. The marine biomass *Ulva lactuca* exists in large quantities which permits its farming under monitored environments, thus making it a suitable material for sustainable manufacturing. Resource usage follows the principles of Blue Economy considering that it puts sustainable methodologies in place for the management and valuation of marine resources. The technological properties of ulvan enable its hydrophilic and gel-forming abilities to enhance the texture, viscosity, and structural stability of products. The functional properties of these materials enable their use in both dairy-based systems and plant-based and new food products.

Scientists have discovered that the combination of ulvan and probiotic strains produces an ability which extends bacterial survival during both storage and their journey through the digestive system because ulvan serves as an essential supporting material for synbiotic systems (Krangkratok et al., 2023). The addition of 1-2% ulvan to yogurt systems resulted in better survival rates of *Lactobacillus acidophilus*, *Streptococcus thermophilus*, and *Bifidobacterium* spp. The bacteria showed counts between 6.4 and 9.5 log CFU/mL during fresh testing and after nine days of refrigeration at 7 ± 1˚C (Shalaby & Amin, 2019). The results show that ulvan functions as an ingredient in synbiotic dairy products, which can be used to create products across all functional beverage and plant-based product categories.

The functional food industry faces multiple obstacles to the practical use of ulvan because research has shown its health benefits, yet commercial application requires further validation (Cherry et al., 2019; Kidgell et al., 2019; Cindana Mo'o et al., 2020). The main issue arises from the chemical composition of the substance, which shows different patterns based on its geographic location and the time of year when it was collected (Kidgell et al., 2019). The extraction methods lead to different structural outcomes, which in turn impact the biological performance of the extracted materials. Methods used in extraction procedures should aim at achieving consistent functional outputs through continuous finetunements (Rahimi et al., 2016). Fully safeguarded assessments are necessary for a well-rounded safety evaluation before ulvans can be considered in line with the principles of prebiotic potential. Food label claims to health benefits now need to provide explicit proof of benefits before regulatory bodies will accept their use (Deehan et al., 2024; Gibson et al., 2017). Consuming seaweeds, which are full of essential nutrients, is not very widespread because their effects are changed in the context of the client's available foods (Cherry et al., 2019). The study found that ulvan functions as a useful marine natural product because its complete market potential needs both clinical research validation and human testing under controlled conditions.

Study Limitations and Future Research Directions

Ulvan, the principal sulfated polysaccharide obtained from *Ulva lactuca*, has been extensively studied as a marine-derived prebiotic candidate. The gut microbiota ferment the substance after The lack of adequately designed human clinical trials is a considerable stumbling block for the research literature. The existing scientific research depends primarily on two sources which include in vitro fermentation models and animal testing. In vitro fermentation models commonly involve human fecal batch culture systems that simulate colonic conditions to evaluate microbial growth and short-chain fatty acid production. Meanwhile, animal testing is typically conducted using rodent models, such as mice or rats, to assess changes in gut microbiota composition, intestinal health, and metabolic responses following ulvan consumption. Scientific methods provide essential knowledge about biological processes, yet they fall short of producing an accurate reproduction of the complete human gut microbiome, which shows different patterns of existence across various human populations. The researchers must perform additional human studies to establish the precise link between ulvan and its prebiotic functions because this data will help them determine safe dosage levels and evaluate its extended safety (Deniz & Sarıta, 2025; Filomena et al., 2016). The extraction process needs standardization, which should include structural assessment because molecular weight, sulfation degree, and monosaccharide composition differences result in varying fermentability and biological response patterns (Cindana Mo’o & Rat, 2020). The research needs to include both controlled clinical trials and studies that examine microbiota-host interactions, together with formulation research that develops functional food products from research findings.

Conclusion

The polysaccharide ulvan, extracted from *Ulva lactuca*, demonstrates a couple of characteristics congruent with the requirement of an apt prebiotic from marine origins. The research conducted during the last ten years proves that ulvan remains undigested in the upper digestive system while certain gut bacteria can ferment it. Fermentation gives double health benefits by augmenting extra helpful bacteria as well as the production of short-chain fatty acids, which are beneficial to the health of the gut. Scientific knowledge at present exists because researchers studied laboratory experiments and animal models, yet human clinical trials produced minimal evidence. The evaluation procedure needs three particular elements which evaluate chemical composition changes under various environmental conditions through different extraction methods, while they tackle the problem of missing established dosage standards. The approval process for ulvan as a functional food ingredient with prebiotic benefits requires human testing and development of superior methods to assess its structural and functional characteristics.

Supporting Information

Extra data about the study material can be obtained through the request process.

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Declaration of Generative AI

The authors used AI language tools to improve their manuscript writing by achieving better grammatical accuracy and clearer writing. The authors created and assessed all scientific concepts, data analysis methods, and study outcomes. These contents are solely the responsibility of the authors.

Conflict of Interest

The authors agree that there is no conflict of interest related to this manuscript.

Author Contributions

Cepi Permana managed project development through his literature research, together with data analysis work and manuscript writing. Muhamad Rifai contributed to the development of the manuscript through discussion and literature evaluation. Alberta Rika Pratiwi and Dyah Wulandari served as thesis supervisors, performed supervisory duties through his manuscript assessment work, which he used to give final publication permission. The authors completed their final manuscript review and approval process while taking full responsibility for all project work.

Ethical Statement

The study conducted was more of a literature review than direct experimentation with human or animal subjects. Thus, it does not require ethical standard approval of the APA.

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