Integrating seaweed into aquafeeds: current knowledge and future perspectives

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Abstract. Seaweed has the potential to serve as an alternative to conventional feed ingredients in aquaculture, as it addresses some of the major issues such as fishmeal dependency, disease management, and environmental impact. This review presents recent knowledge on the nutritional and functional benefits of seaweeds (green, red, and brown macroalgae) in aquaculture, highlighting their rich composition of proteins, essential amino acids (EAAs), polyunsaturated fatty acids (PUFAs), antioxidants, and prebiotic polysaccharides. The study demonstrates that dietary seaweed inclusion enhances growth performance, immune response, stress tolerance, and pigmentation in finfish (e.g., Nile tilapia, European seabass), shrimp, and oysters, while also improving gut health and nutrient digestibility. Despite these advantages, challenges such as species-specific efficacy, nutritional variability, and large-scale cultivation barriers persist. Future efforts must focus on standardizing cultivation, developing species-dependent feed formulations, and implementing supportive policies. By bridging the gap between research and industry, this review underscores seaweed's role in advancing eco-friendly aquafeeds to meet the growing demand for sustainable aquatic protein.

Key Words: aquaculture, climate change, fishmeal replacement, immunity, macroalgae, sustainability.

Introduction. Feed costs and disease outbreaks are major threats to sustainable aquaculture practices (Austin 2023; Afewerki et al 2023). The success of aquaculture operations predominantly depends on quality feed and effective disease management. Fish meal, the main component of fish feed, serves as a significant protein source derived from bycatch. However, its high cost and the unpredictability of trash fish supply lead to overharvesting (Güroy et al 2011). Therefore, identifying alternative feed ingredients to supply essential proteins and lipids is imperative. Additionally, the search for ingredients that enhance growth, boost immunity, and improve survivability is ongoing. While some terrestrial plants, such as legumes and oilseeds, have been considered, their use is limited due to antinutritional chemicals, palatability issues, and nutritional imbalances for fish (Bandara, 2018).

Recent research has focused on seaweeds as a promising alternative protein source and functional additive in aquafeeds (Wan et al 2019; Siddik et al 2023). Seaweeds are rich in amino acids, polysaccharides, polyunsaturated fatty acids (PUFAs), antioxidants, vitamins, fibers, and minerals (MacArtain et al 2007; Guedes et al 2015; Radulovich et al 2015; Ismail et al 2017; Chakroborty et al 2025). They provide essential elements such as iodine, potassium, calcium, magnesium, and selenium, which enhance growth, immunity, survival, and flesh quality in aquatic species (Mouritsen 2013; Corino et al 2019). Seaweeds are also available year-round, easy to harvest, and offer sustainability benefits for aquaculture. With their low lipid content (1-5%), primarily composed of PUFAs, and mineral levels up to 20 times higher than those of terrestrial plants, seaweeds are an excellent source of energy, minerals, and protein (Mišurcová et al 2011; Gaillard et al 2018).

The use of seaweed in aquafeeds provides significant benefits to various aquatic species. The green seaweed *Ulva lactuca* demonstrated growth improvement alongside enhanced feed usage and immune function in Nile tilapia *(Oreochromis niloticus)* (Natify et al 2015). The red seaweed *Pterocladia capillacea* improved growth for European seabass *(Dicentrarchus labrax)* fry (Wassef et al 2013) and brown seaweed *Ascophyllum nodosum* showed both antioxidant effects and immune response enhancement for Atlantic salmon *(Salmo salar)* (Van Doan et al 2014). The bioactive substances in seaweed, which include polysaccharides and carotenoids, serve to improve fish pigmentation, which leads to better skin and flesh aesthetics that matter to market demand (Rodríguez-Bernaldo et al 2010). Additionally, seaweed's fiber and prebiotic effects improve gut health and nutrient digestibility, particularly in herbivorous and omnivorous species (Pereira et al 2012). Beyond its nutritional benefits, seaweed farming supports environmental sustainability by absorbing CO_2, mitigating climate change, and reducing reliance on fishmeal, thereby alleviating pressure on wild fish stocks (Buschmann et al 2017). These multifaceted impacts make seaweed a promising and sustainable alternative for enhancing aquaculture productivity and environmental health.

Despite growing interest in seaweed-based aquafeeds, critical knowledge gaps persist. Research conducted so far lacks standardized commercial inclusion levels, together with insufficient knowledge about long-term physiological impacts and significant variations in seaweed nutritional content. The combination of high variability in seaweed composition with economic and scalability issues prevents the regular and broad adoption of seaweed in aquafeeds. This review addresses these gaps by systematically evaluating the nutritional efficacy of green, red, and brown seaweeds as feed ingredients for finfish, shrimp, and oysters. Furthermore, it analyzes the functional roles of seaweed-derived bioactive compounds in promoting growth, immune function, and stress resilience, summarizing species-specific inclusion thresholds. Research from around the world between 2010 and 2025 has been analyzed in this review to provide practical insights for researchers, feed manufacturers, and policymakers to advance the integration of seaweeds in environmentally responsible aquaculture systems.

Material and Method. This review specifically examines the potential of seaweed as an ingredient in aquafeeds, focusing on its types, habitat, and nutritional composition. A systematic search of scholarly literature was carried out using the Google Scholar, ScienceDirect, Scopus, and Web of Science, targeting English-language publications and including the title, abstract, and keywords fields (TITLE-ABS-KEY). The primary search term employed was combined with various pertinent keywords, including "seaweed", "aqua feed", "fish feed", "shrimp feed", "oyster feed", "aquaculture", "nutritional composition", "feed additives", "fish meal", "green seaweed", "brown seaweed" and "red seaweed".

The growth input was calculated using the specific growth rate (SGR) and the percentage of weight gain (%WG). The feed utilization and digestibility were determined by the feed conversion ratio (FCR). Immunity was assessed based on haematological parameters and the fish's response to pathogen exposure. The survival rate (SR%) was measured by the live fish after the experiment.

The results were evaluated based on the performance of seaweed incorporating feed relative to the control treatment. After retrieving results from Scopus and Web of Science databases, duplicate papers were initially eliminated. Subsequently, a preliminary screening process was conducted based on a careful examination of titles and abstracts, with articles deemed irrelevant to the specified topics of interest being excluded. The methodological approach and exclusion criteria are delineated in Figure 1. To ensure the reliability and credibility of the included studies, a quality assessment was conducted on all selected studies. This assessment involved a general evaluation of potential risks of bias, considering factors such as study design, methodology, and reporting. Studies with significant methodological concerns were excluded from the final analysis to maintain the overall quality of the review.

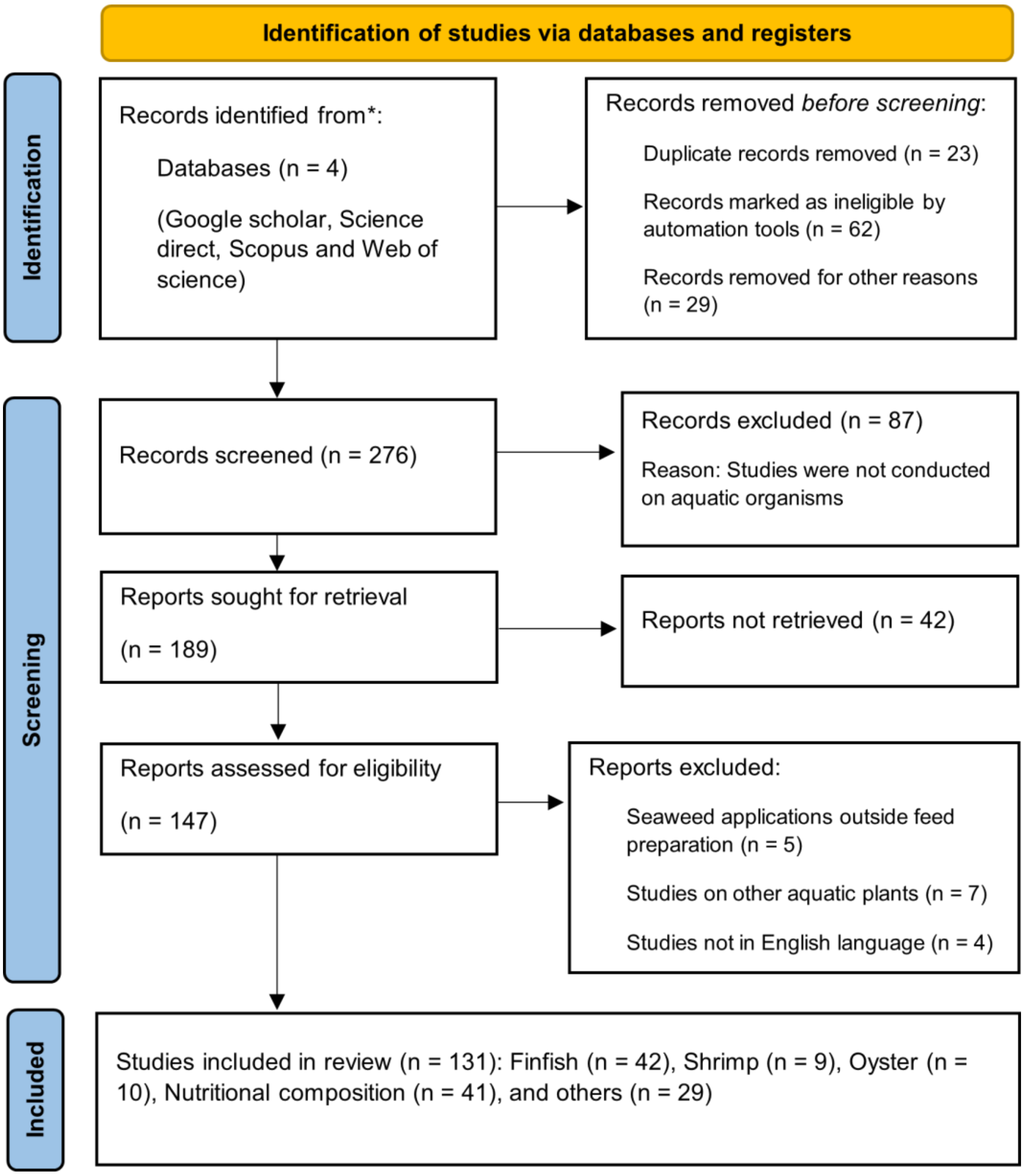


Figure 1. Data collection and inclusion flowchart for systematic reviews.

Seaweed**: **types, nutritional composition and production. Seaweed encompasses thousands of macroscopic, multicellular marine algae species that are photosynthetic organisms and form the foundation of the marine food chain. Human interaction with seaweed dates back to the New Stone Age (Erlandson et al 2015), with the earliest documented use by humans occurring approximately 1,700 years ago in China (Yang et al 2017). In recent years, seaweeds have been considered significant for fish diet (Siddik et al 2023; Chakroborty et al 2025). Seaweed production has grown significantly over the years, driven by advancements in the identification and cultivation of various species (Figure 2). Globally, there are an estimated 12,000 species of seaweed, which are classified into three main taxonomic groups: Rhodophyta (red), Chlorophyta (green), and Phaeophyta (brown) (Guiry & Guiry 2022). However, only about 27 seaweed species are cultivated worldwide, with a strong focus on a few key species. In 2019, five genera - *Laminaria*, *Saccharina*, *Undaria*, *Eucheuma/Kappaphycus*, and *Gracilaria* - accounted for more than 95% of the world's total seaweed cultivation production (Zhang et al 2022).

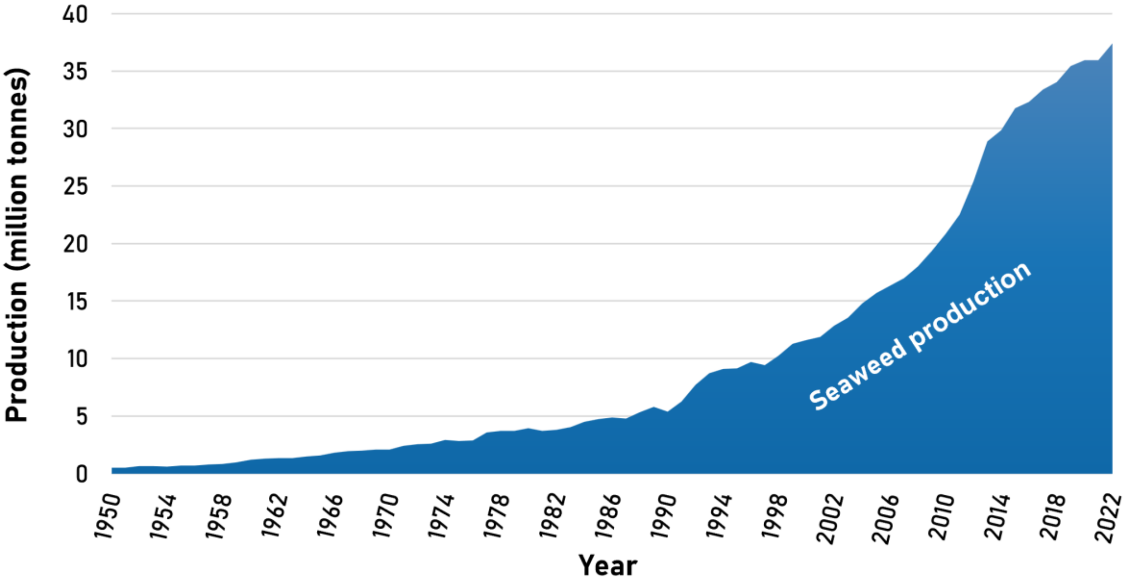
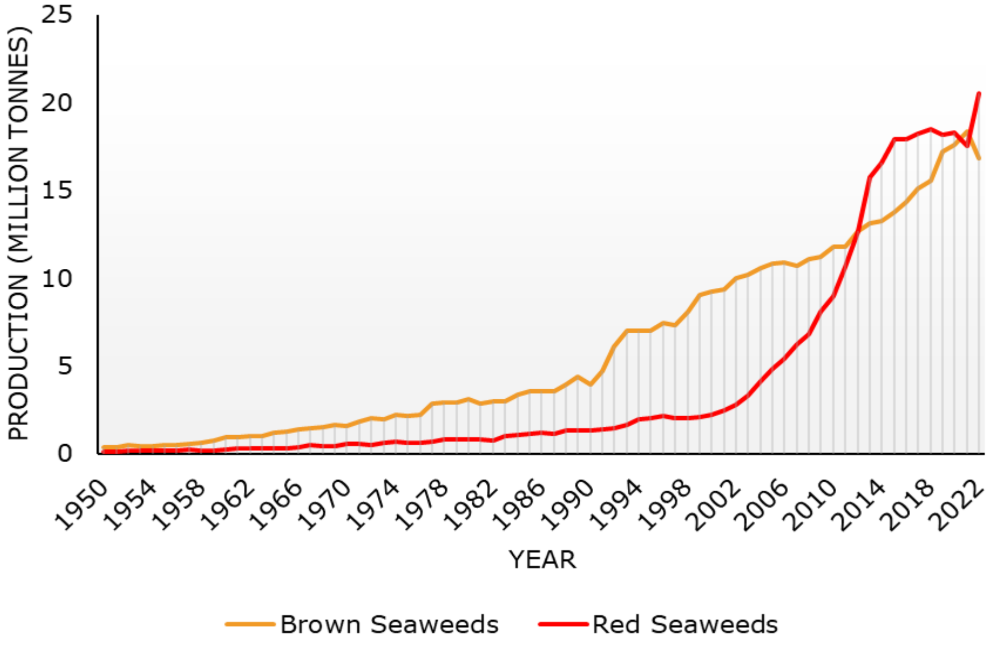


Figure 2. Seaweed production (1950-2022) all over the world (FAO 2024).

Green seaweeds*.*The principal genera include *Ulva*, *Codium*, *Chaetomorpha*, and *Cladophora* (Corino et al 2019). This algae belong to the Ulvophyceae class (phylum Chlorophyta). *Ulva*, found in brackish water (mainly in estuaries), is one of the most known genera of green seaweeds. Being filled with minerals, proteins, and vitamins, these species are very appealing to study at a nutritional level (Jamal et al 2017). *Ulva* is relatively rich in proteins and insoluble dietary fibers (glucans) and soluble fibers and has potential as an alternative source of proteins for animal feeding (Corino et al 2019) (Table 1). While the production of green seaweed is on the rise, it remains comparatively lower than that of the other two groups in last decade(Figure 3).

(a)



(b)

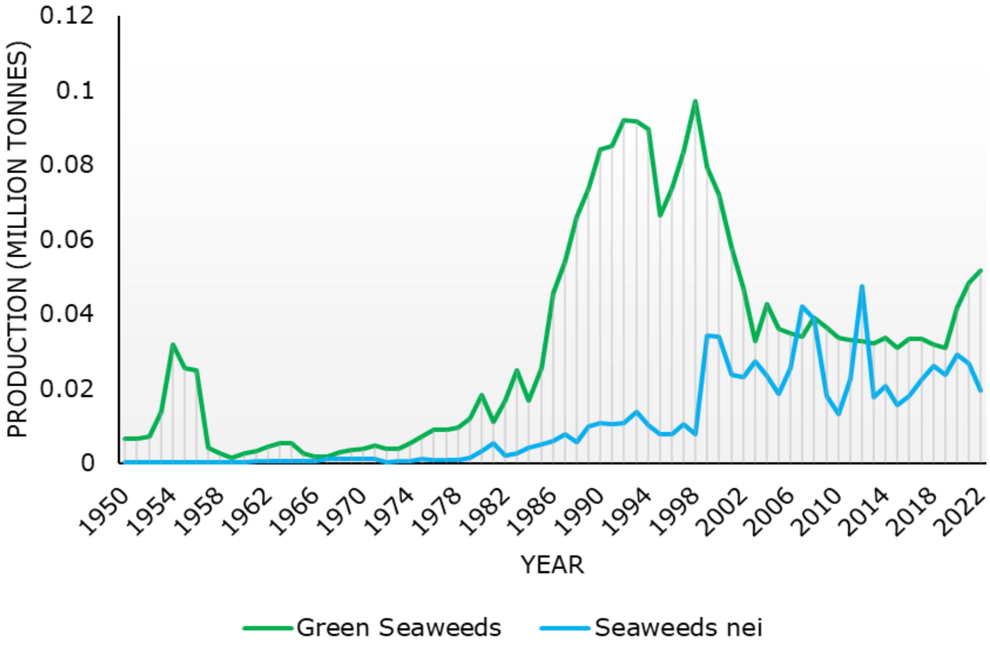


Figure 3. Different types of seaweed (brown and red (a), and green (b)) production (1950-2021) all over the world (FAO 2024). Note: "Seaweed nei" means "seaweed, not elsewhere included" - i.e., unspecified or mixed seaweed species that do not fall under specific listed categories.

***Red seaweeds**.* In general, red algae have higher protein content compared to green and brown algae, with levels reaching up to 47% of dry matter in *Neopyropia tenera* (Cian et al 2015) (Table 1). The proteins from this seaweed group are made up of one or more chains of amino acids, especially glycine, alanine, arginine, proline, glutamic acid, and aspartic acid. In contrast, tyrosine, methionine and cysteine appear in a lower quantity. Glutamic and aspartic acids, which have acidic side chains at neutral pH, account for 14-19% of the amino acids in red seaweeds (Černá 2011). Essential amino acids make up nearly half of the total amino acids, with their protein profile resembling that of egg protein. In general, all algae contain similar levels of nonessential amino acids (Moreda-Piñeiro et al 2012). Red seaweed is particularly rich in polyunsaturated 20-carbon fatty acids, including eicosapentaenoic acid (EPA, ω-3, C20:5) and arachidonic acid (AA, ω-6, C20:4), while palmitic acid (C16:0) is the predominant saturated fatty acid at 26%, and oleic acid is the main monounsaturated fatty acid (Moreda-Piñeiro et al 2012).

***Brown seaweeds**.* Commonly, brown algae (Phaeophyceae) are seaweeds with the lowest protein content compared to red and green algae. The protein content in brown seaweeds occurs within 5 to 15% (Dawczynski et al 2007; Mišurcová 2011). The concentrations of essential amino acids in brown algae differ substantially between species (Table 1). Threonine, valine, isoleucine, leucine, phenylalanine, lysine and methionine concentrations were higher in *Undaria pinnatifida* than in *Laminaria* sp. However, *Laminaria* sp. had higher concentrations of cysteine than *U. pinnatifida*. Aspartic acid and glutamic acid were the most abundant in these algae species tested in the study of Dawczynski et al (2007). Brown algae are balanced sources of ω-3 and ω-6 acids (Hamed et al 2015; Hayes 2015).

Table 1

Nutritional composition of different types of seaweed

Species	*P*	*A*	*DF*	*C*	*L*	*Reference*
Green seaweed						
Caulerpa lentillifera	10-13	24-37	33	38-59	0.86	Morais et al (2020)
Caulerpa racemosa	17.8-18.4	7-19	64.9	33-41	9.8	Morais et al (2020)
Codium fragile	8-11	21-39	5.1	39-67	0.5-1.5	Morais et al (2020)
Enteromorpha sp.	12.34±2.92[a]	25.65±0.98%	-	59.79±1.33	0.02±0.01	Metin & Baygar (2018)
Ulva clathrata	21.9-25.9	44.8-49.6	24.8-26.3	-	2.5-3.5	Peña-Rodríguez et al (2011)
Ulva compressa	21-32	17-19	29-45	48.2	0.3-4.2	Morais et al (2020)
Ulva reticulata	17-20	-	65.7	50-58	1.7-2.3	Morais et al (2020)
Ulva rigida	18-19	28.6	38-41	43-56	0.9-2.0	Morais et al (2020)
Brown seaweed						
Alaria esculenta	9-20	-	42.86	46-51	1-2	Morrissey et al (2001); Abbott (1988)
Ascophyllum nodosum	8.70±0.07	30.89±0.06	-	-	3.62±0.17	Lorenzo et al (2017)
Ecklonia cava	11.30±0.63	15.60±0.57	31.00±0.72	32.47±0.57	1.25±0.19	Choi et al (2017)
Eisenia bicyclis	7.5	9.72	10-75	60.6	0.1	Morais et al (2020)
Fucus spiralis	0.77	-	63.88	-	-	Morais et al (2020)
Fucus vesiculosus	12.99±0.04	20.71±0.04	-	-	3.75±0.20	Lorenzo et al (2017)
Himanthalia elongata	5-15	27-36	33-37	44-61	0.5-1.1	Morais et al (2020)
L. ochroleuca	12.83	18.33	11.65	56.68	0.51	Pacheco et al (2021)
Laminaria digitata	8-15	38	37	48	1.0	Rajauria et al (2015)
Saccharina latissima	6-6.26	34.78	30	52-61	0.5-1.1	Morais et al (2020)
Sargassum fusiforme	11.6	19.77	17-69	30.6	1.4	Morais et al (2020)
Sargassum polycystum	3.65%	24.51%	-	53.66%	0.5% fat	Manteu et al (2018)
Sargassum vulgare	9.19-19.94	13.07-30.35	4.80-10.51	52.62-68.54	0.15-0.79	Marinho-Soriano et al (2006)
Undaria pinnatifida	12-23	26-40	16-51	-	Little amount	Morais et al (2020)
Red seaweed						
Agarophyton chilense	13.7	18.9	-	66.1	1.3	Morais et al (2020)
Chondrus crispus	11-21	21	10-34	55-68	1.0-3.0	Morais et al (2020)
Crassiphycus changii	6.9	22.7	24.7	-	3.3	Morais et al (2020)
Eucheuma denticulatum	4.9	43.6	-	-	2.2	McDermid & Stuercke (2003)
Gelidium pristoides	11.80	14.00	-	43.10	0.90	Foster & Hodgson (1998)

Gracilaria bursa-pastoris	30.2	-	-	-	0.9	Valente et al (2006)
Gracilaria cervicornis	22.96	7.72	5.65	63.12	0.43	Marinho-Soriano et al (2006)
Gracilaria changi	6.90	22.7	24.7	-	3.30	Norziah & Ching (2000)
Gracilaria chilensis	13.7	18.9		66.1	1.3	Ortiz et al (2009)
Gracilaria cornea	11.0	-	-	-	0.7	Valente et al (2006)
Gracilaria gracilis	10.86	6.78	27.48	63.13	0.19	Rasyid et al (2019)
Hypnea charoides	18.40	22.80	50.3	7.02	1.48	Wong & Cheung (2000)
Hypnea japonica	19.00	22.10	53.2	4.28	1.42	Wong & Cheung (2000)
Neopyropia tenera	28-47	8–21	12-35	44.3	0.7-1.3	Morais et al (2020)
Palmaria palmata	8-35	12–37	29-46	46-56	0.7-3	Morais et al (2020)
Porphyra umbilicalis	29-39	12	29-35	43	0.3	Morais et al (2020)
Pterocladia capillacea	20.95± 0.03	15.81 ± 0.29	-	50.96±0.11	2.09± 0.11	Khairy & El-Shafay (2013)
Pyropia tenera	34.20	8.70	4.80	40-70	0.70	Arasaki & Arasaki (1983)

Note: P – protein; A – ash; DF – dietary fiber; C – carbohydrate; L – lipid.

Bioactive compounds in seaweeds and their functional mechanisms

Polysaccharides. Most of these polysaccharides can be broken down by gut microbiota and provide benefits to animal health through a prebiotic effect (O'Sullivan et al 2010). Polysaccharides are considered as prebiotics (compounds that stimulate the growth of beneficial bacteria in the digestive track) and enhance growth status and improve animal health (Vidanarachchi et al 2009). Moreover, seaweed-derived polysaccharides are effective and safe antioxidants (Li & Kim 2011; Souza et al 2012). Mainly, fucoidans are particularly abundant in seaweed as polysaccharides, particularly in *F. vesiculosus*; they may act as antioxidants by scavenging reactive oxygen species directly or by enhancing the activity of cellular endogenous antioxidant defenses, including superoxide dismutase, catalase, glutathione transferase, and glucose-6-phosphate dehydrogenase (Rocha et al 2007). Sulfated polysaccharides prevent activity of many bacterial species as well as viruses (Leonard et al 2010).

Polyphenols. Seaweeds are an important source of polyphenolic compounds including, phlorotannins, bromophenols, flavonoids, phenolic terpenoids, and mycosporine (Heo et al 2005; Corona et al 2017; Wells et al 2017; Gómez-Guzmán et al 2018). Also, seaweed extracts contain considerable amounts of polyphenols. Seaweed polyphenols are observed to promote the immune response and improve disease resistance in fish (Gora et al 2018; Safavi et al 2019). Polyphenols are strong antioxidants (Gumul et al 2011). Reactive oxygen species, produced in organisms during metabolism, are highly reactive and can cause cellular dysfunction and cytotoxicity (Alviano & Alviano 2009). Polyphenols can donate hydrogen to free radicals and resulting non-reactive radicals (Gupta & Abu-Ghannam 2011). For their H-atoms transferring ability to free radicals, producing comparatively non-reactive phenoxyl radicals for resonance stabilization, phenolic compounds with more than one hydroxyl group (dOH) are efficient primary antioxidants due to their ability to donate H-atoms to free radicals, creating relatively unreactive phenoxyl radicals due to resonance stabilization (Figure 4).

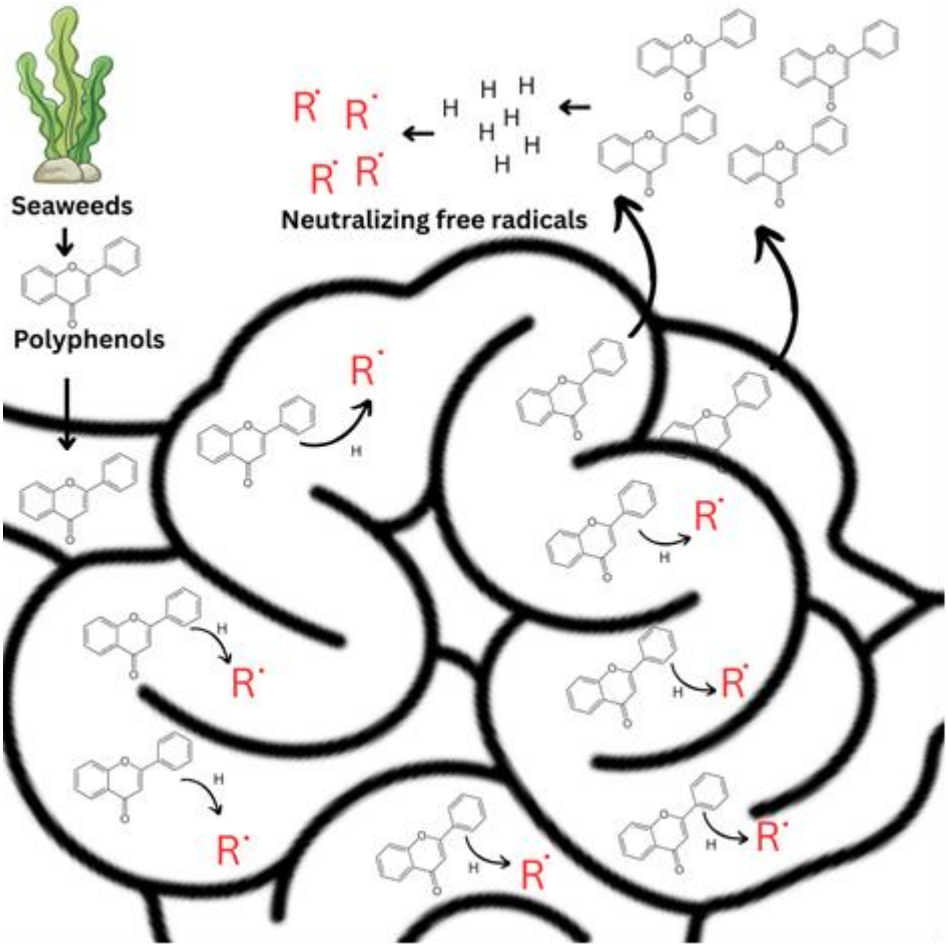


Figure 4. Functional mechanism of seaweed-derived polyphenols in the fish gut.

Proteins. The lowest amounts of proteins were observed in brown seaweeds. A majority of seaweeds contain all of the essential amino acids, which perform various important physiological functions in the fish body (Figure 5). The protein amount of seaweed varies according to species. Generally, the protein content of brown seaweeds is low (15±3% of the dry weight) while the green or red seaweeds is high (47±10% of the dry weight) (Arasaki & Arasaki 1983). Proteins found in seaweed are important for tissue repair, muscle growth, and immune function, while polysaccharides contribute to digestive health and exhibit prebiotic effects (Pereira et al 2012). Alkaloids represent chemical compounds that contain basic nitrogen atoms and are usually derived from amino acids. Alkaloids are colorless and crystalline substances. Several alkaloids and other nitrogenous heterocyclic compounds have been obtained from seaweeds (Ghaliaoui et al 2024).

Polyunsaturated fatty acids (PUFAs). Phospholipids and glycolipids are the major classes of lipids found in seaweeds (Figure 6). Seaweed can accumulate polyunsaturated fatty acids (PUFAs) when temperatures are reduced. And the species that live in cold areas contain more PUFAs than species living in higher temperatures (Holdt & Kraan 2011). Lipids found in seaweeds (0.12-6.73% dry weight, DW) may contain a large proportion of essential fatty acids (Figure 6). The two primary functions of lipids in algae are serving as structural components of cellular membranes (polar lipids) and acting as storage compounds (neutral lipids) (Pérez et al 2016). Omega-3 (n-3) and omega-6 (n-6) PUFAs were in the concentration range of 2-14 mg g^{-1} dry matter (DM), while total lipid content ranged from 7 to 45 mg g^{-1} DM. In the seaweeds analyzed, n-9 fatty acids (FAs) accounted for 3-56% of total FAs, n-6 FAs for 3-32%, and n-3 FAs for 8-63% (Van Ginneken et al 2011).

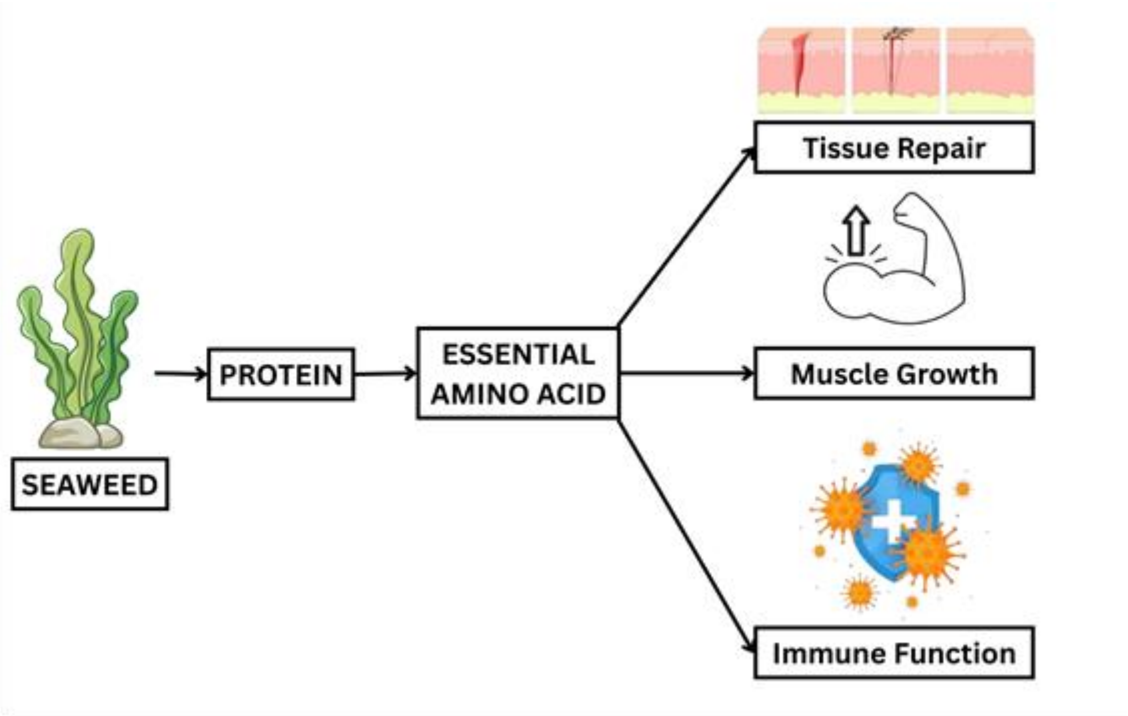


Figure 5. Physiological functions of seaweed-derived proteins in fish.

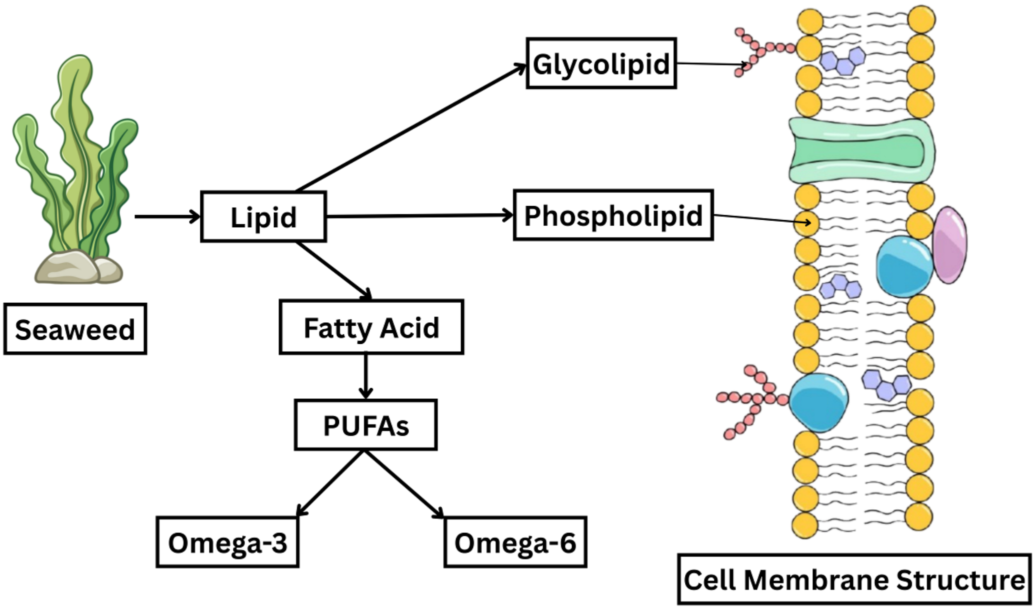


Figure 6. Types of lipids in seaweed and their functional mechanism.

Pigments. Seaweed pigments can be categorized into three main groups: chlorophylls, carotenoids and phycobiliproteins. Carotenoids are organic pigments present in chloroplasts and chromoplasts (Wijesinghe & Jeon 2012). Different seaweeds possess different kinds of carotenoids, which have strong antioxidant properties and the ability to quench singlet oxygen and scavenge free radicals (Li & Kim 2011). Notably, carotenoids are one of the essential antioxidant compounds in seaweeds (Mikami & Hosokawa 2013).

Vitamins. Seaweeds contain both water- and fat-soluble vitamins. Particularly, seaweed has the presence of vitamin B12, which is rare in vegetables. Different types of vitamin composition are present in seaweed, depending on species, location, season, sea temperature, light, and salinity (Glombitza 1977; Škrovánková 2011). Moreover, seaweed-derived vitamins contain biochemical functions and antioxidant activities for health benefits (Glombitza 1977).

Minerals and trace elements. Seaweeds represents a rich source of minerals (Nwosu et al 2011). Their compounds in the biomass are sometimes as much as 40% (Kumar et al 2011). Seaweeds absorb metal ions from salt water and concentrate those substances as carbonate salts in their fronds (Aslam et al 2010). Researchers have investigated the mineral composition in concentrates from seaweeds and the highest concentrations of potassium (2.71 g L^{-1}), magnesium (0.19 g L^{-1}) and calcium (0.16 g L^{-1}) ions have been identified in an extract from *Sargassum ringgoldianum* subsp. *coreanum*. Also, seaweeds contain sodium ions (1.21 g L^{-1}) (Kuda & Ikemori 2009). Particularly, *Kappaphycus alvarezii* contains significant levels of calcium (460.11 mg L^{-1}) and magnesium (581.20 mg L^{-1}) ions (Rathore et al 2009). Macro-minerals, which include calcium, chlorine, magnesium, phosphorus, potassium, sodium and sulphur, are essential for animals. Trace elements that are required in much smaller amounts than macro-minerals, include iodine, iron, manganese, copper and zinc. Selenium is an impotant trace compound, found in seaweed, for normal body function and considered as a component of glutathione peroxidases and responsible for reducing peroxide free radicals and prostaglandin synthesis to protect the oxidative state of lipid intermediates (Birringer et al 2002).

Potential of seaweed-derived bioactive compounds for aquafeeds

Growth enhancement. Polysaccharides are considered as prebiotics that substances improve the growth of beneficial bacteria in the gastrointestinal tract and boost up growth and enhance health effects (Vidanarachchi et al 2009). Seaweed is also a valuable source of omega-3 fatty acids, especifically eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), in their fatty acid profile (Rocha et al 2021) in contrast to terrestrial plants. These fatty acids are vital for the metabolic function of fish as well as maintaining the structural integrity and the fluidity and permeability of cellular membranes (De Carvalho & Caramujo 2018).

Immunity and disease resistance. Seaweed polyphenols are reported to enhance the immune response and disease resistance in fish (Gora et al 2018; Safavi et al 2019). Polyphenols are strong antioxidants (Gumul et al 2011). Very important bioactive proteins that can be extracted from seaweeds are lectins, which bind with carbohydrates and participate in many biological processes like intercellular communication. Additionally, they have also antibacterial, antiviral or anti-inflammatory activities (Barbalace et al 2019).

Antioxidant property was found also in the protein extract, specifically some phycobiliproteins such as C-phycocyanin and allophycocyanin. It was confirmed that the protection effect against hydroxyurea-teratogenic insult was related to the antioxidant activity of protein extract (Vázquez-Sánchez et al 2009). Phenolic compounds with more than one hydroxyl group (dOH) are efficient primary antioxidants due to their ability to donate H-atoms to free radicals, creating relatively unreactive phenoxyl radicals due to resonance stabilization. Seaweed extracts contain enough amounts of polyphenols, but their content strongly depends on the extraction method (Gupta & Abu-Ghannam 2011).

Gut health and digestibility. Polysaccharides are fermented by gut microbiota, which provide health benefits through prebiotic effect, feed utilization and enhancing digestion (O'Sullivan et al 2010). The probiotic effect of seaweed increased with fiber amount in seaweeds (Hagan & Fungwe 2023). Seaweeds' bioactive substances, specifically polysaccharides and phenols, can be identified as dietary supplements with gastrointestinal health benefits and prebiotics effects (Charoensiddhi et al 2020). Polysaccharides are considered as prebiotics and exert growth-benefits and health-boosting effects (Vidanarachchi et al 2009).

Sustainability and fishmeal replacement. Mainly, aquaculture and fish nutrition depend on the fish meal as a protein source. However, fish meal is a costly and limited substance to be utilized in fish feed formulation. Thus, recently, seaweed is being considered as a substitute protein source for fish nutrition (Patel et al 2018). Seaweed provides a standard feed composition in pellet feeds as it is proven to improve the fish feed with its biochemical compounds (Ismail 2019).

Ulva and *Enteromorpha* seaweeds are demonstrated to provide positive properties on the growth benefits of fish fry and have also decreased the cost of the diet. Moreover, the alternative of pellet feed with seaweeds did not have any adverse effects on the growth benefits of fish fry (Abdel-Aziz & Ragab 2017). Seaweeds efficacy in aquatic nutrition is now promising and provides to cut off the fish meal cost. Fish growth relies on the capability of the organism to digest the feed compounds. Feed ingredient palatability is also a crucial thing for choosing ingredient for fish diet. The current research suggested the digestive stimulating effect of the seaweed along with growth improvement of fish (Chakroborty et al 2025). The replacement of fish feed with the brown seaweed (*Lobophora variegata*) resulted in higher growth benefits and increased feed utilization in seabass (*Lates calcarifer*) fingerlings (Udayasoundari et al 2016).

Seaweed's role in aqua feed

Fin fish feed. Seaweeds are considered as a crucial source of fish feed due to their nutritional perspective (Nur et al 2020). These macroalgae serve as valuable feed supplements or additives due to their rich nutritional profile, which includes indispensable amino acids, essential polysaccharides, diverse fatty acids (including alpha-linolenic acid and EPA), antioxidants, dietary fiber, and essential minerals (Li et al 2009; Guedes et al 2015; Ismail et al 2017). Besides, seaweeds are rich sources of bioactive contents that protect the fish against pathogens (González del Val et al 2001; Liao et al 2003). They can serve as a replacement to fish meals since their proteins do not contain excess P levels and, additionally, they can elevate the immune functions, antiviral and antimicrobial effects, promote digestion and stress resistance (Cyrus et al 2014). Thus, seaweeds extracts are widely considered and used in formulating fish feeds which is best absorbed by herbivorous fish (Horn & Messer 1992).

The seaweed was first used as a fish feed supplement for red seabream (*Pagrus major*) and showed better growth (Nakagawa et al 1997). Later, the research on seaweed gained momentum due to the search for a feedstuff that can promote growth alongside immunity. As a result, all three types of seaweeds were used as fish feed supplements in the case of fish, however, green algae and red algae were dominant. More specifically, *Ulva* (green algae) and *Gracillaria* (red algae) are the most used genera. Seaweed as a fish feed has been experimented on a handful of species so far, of which the most focus was on tilapia (*Oreochromis niloticus*) followed by rainbow trout (*Oncorhynchus mykiss*) and European seabass (*Dicentrarchus labrax*). It is found that in most of the cases, the lower inclusion rate has given the highest result (Table 2).

Shellfish feed

<u>*Shrimp*</u>*.* The declining use of animal protein-based feed in the shrimp industry is highly probable in the coming days due to higher costs, environmental and food safety issues. Generally, fish meal is used in shrimp feed as a protein source which is expensive (Tacon 2002). Additionally, there are several challenges associated with the handling and storage of aquafeeds, such as nutrient degradation, microbial growth, insect and rodent infestations, and rancidity. Commercial feeds have also been linked to disease outbreaks in some shrimp farms. These issues can be mitigated by incorporating higher concentrations of antioxidants, vitamins, and antifungal agents, all of which are present in seaweed. Therefore, the use of seaweed in various forms can help prevent disease outbreaks in shrimp ponds (Kanjana et al 2011; Salehpour et al 2021).

Using seaweed as a shrimp dietary component needs an in-depth analysis of its impact on shrimp health, growth, and the broader sustainability of aquaculture. Table 3 provides a thorough review of specific seaweed species, organized according to their respective algae types - green, red, and brown. It elucidates their respective habitats, thereby contextualizing their availability and potential relevance to shrimp farming practices. Red seaweed (*Gracilaria*) has been extensively used, focusing on its significant findings related to immune response and shelf-life improvement (Sarjito et al 2020). Red seaweed was predominantly used for *Litopenaeus vannamei* and *Penaeus monodon*, while brown seaweed was used only for *P. monodon*, albeit with limited effectiveness. Red seaweed has shown a highly effective response to *Vibrio harveyi* infection on *L. vannamei* shrimp.

Oyster feed. Seaweed has emerged as a promising alternative feed in oyster aquaculture, offering significant nutritional and economic benefits. Traditionally, live microalgae dominate as feed during key production stages such as broodstock conditioning and larval rearing (Uchida & Murata 2002; Ponis et al 2003; Pronker et al 2008; González-Araya et al 2011, 2012; Ferreira et al 2020), but their high cost - accounting for 30-40% of hatchery expenses - poses economic challenges (Coutteau & Sorgeloos 1992; Boeing 1997; Brown & Robert 2002).

Green seaweed species like *Ulva* sp. are particularly noteworthy due to their high protein content (10-25% of DW) and essential mineral concentrations, such as calcium and magnesium (Noël et al 2012). Incorporating *Ulva* into oyster diets has been known to improve stress response, disease resistance, and overall productivity while enhancing organisms' nutritional profiles and supporting ecological sustainability (Noël et al 2012; Cardoso et al 2015).

Studies on the Pacific oyster (*Crassostrea gigas*) indicate that seaweed-based feeds positively influence growth, wet weight, digestion, and nitrogen turnover rates (Peña-Rodríguez et al 2020; Omont et al 2021) (Table 4). These findings underscore the potential of green seaweed as a sustainable and cost-effective feed source for intensive oyster aquaculture.

Prospects and challenges. Seaweed holds considerable promise as both a feed source and feed additive for sustainable aquaculture despite certain challenges. It has nutritional strengths such as bioactive compounds, vitamins, and minerals, making them suitable for fish growth and enhancing immunity. In addition, seaweed presents a compelling alternative to antibiotics in aquafeed. A major benefit is that seaweed farming is highly sustainable, with multiple harvests possible each year. It also plays a key role in combating climate change by absorbing substantial amounts of CO_2. In aquaculture, the demand for alternative feed ingredients is growing, with the inclusion of seaweed in fish feed formulations emerging as a promising innovation. Additionally, as consumers increasingly seek value-added aquatic products from sustainable practices, this trend further drives the incorporation of seaweed into aquafeed.

Aquaculture of seaweed has been the driving force behind the global seaweed industry, accounting for 94% of the total annual biomass produced since the 1950s. Current cultivation techniques are largely for the production of commoditized species. The stability of seaweed production will depend on developing domesticated seaweed cultivars, the domestication of new species, and the refinement of cultivation methods to enhance quality control and traceability (Hafting et al 2015). Mass cultivation of economically valuable seaweeds is achieved by understanding and altering the parameters regarding water current, temperature, irradiance, dispersion of nutrients, and quality of water. Knowing these factors, along with their physiological response, can further improve the mass production of biomass. There are a lot of challenges in integrating seaweed into aquaculture. To date, only a few species of seaweed have established cultivation methods. Research using seaweed as an aquafeed has only been conducted in a few countries in Asia, Europe and North America (Figure 7). Further research is required to fully understand the impact of seaweed on fish growth and immune response.

Table 2

Key research findings on seaweed in finfish aquaculture

Seaweed species (types)	*Habitat*	*Studied species*	*Study period (days)*	*Administration method; application type*	*Best doses*	*Key findings*	*Reference*
Ascophyllum (B)	Northern Atlantic Ocean	*Pagrus major*	50	Minced; replacement	5%	Growth (+) Protein (+)	Nakagawa et al (1997)
Ecklonia cava (B)		*Paralichthys olivaceus*	42	Powder; supplement	2, 4 & 6%	Immunity (+)	Kim & Lee (2008)
Gracilaria bursa-pastoris (R), *Ulva rigida* (G), *Gracilaria cornea* (R)	Asia, South America, Oceania	*Dicentrarchus labrax*	70	Sun-dried and grounded; replacement	Up to 10% (GP, UR) 5% (GC)	Growth (+) Nutrient utilization (+)	Valente et al (2006)
Gracilaria spp. (R), *Ulva* spp. (G), *Fucus* sp. (B)	Asia, South Asia, Oceania, British Isles	*Dicentrarchus labrax*	84	Powder; supplement	7.5% *Ulva* 2.5%	Growth (0); Improves immune (+); Antioxidant response (+)	Peixoto et al (2016)
Gracilaria vermiculophylla (R)	Asia, South America, Africa and Oceania	*Oncorhynchus mykiss*	91	Powder; supplement	5%	Immunity (+)	Araújo et al (2016)
Hypnea musciformis (R)	Atlantic, Pacific, and Indian Oceans	*Oreochromis niloticus*	60	Replacement	30%	Growth (+) Immunity (+)	Nur et al (2020)
Porphyra dioica (R)	Ireland	*Oncorhynchus mykiss*	87	Powder	10%	Growth (+) Flesh pigmentation (+)	Soler-Vila et al (2009)
Pterocladia capillacea and *Ulva lactuca* (G)	North of Portugal	*Oreochromis niloticus* fingerlings	72	Supplement	5%	Growth (+) Carcass composition (+)	Khalafalla & El-Hais (2015)
Ulva lactuca (G)	Worldwide	*Clarias gariepinus*	70	Powder; replacement	10%	Growth (-) Feed utilization (-)	Abdel-Warith et al (2016)
Ulva reticulata (G)		*Carassius auratus*	40	Powder; supplement		Growth (+), haematological	Rama Nisha et al (2014)

						parameters (+) and Pigment (+)	
Ulva rigida (G)	Eutrophic environments	*Oreochromis niloticus*	112	Powder; supplement	5%	Growth performance (+); Nutrient utilization (+); Body composition (+)	Ergün et al (2009)
Ulva spp. (G)		*Oreochromis niloticus*	63	Powder mixed with pelleted; partial replacement	10%	Growth (+)	Marinho et al (2013)

Note: G - green seaweed; B - brown seaweed; R - red seaweed.

Table 3

Key research findings on seaweed in shrimp aquaculture

Seaweed species (types)	*Habitat*	*Studied species*	*Study period (days)*	*Administration method; application type*	*Best doses*	*Key findings*	*References*
Enteromorpha (G),	Northern Atlantic Ocean	*Macrobrachium rosenbergii*	240	Powder; replacement	30%	Growth (+)	Ghosh & Mitra (2015)
Gracilaria tenuistipitata (R)	Bac Lieu province, Vietnam	*Penaeus monodon*	120	Co culture; supplement	50% and 100%	Cost effective (+) FCR (-)	Anh et al (2022)
Gracilaria verrucosa (R)	Asia, South America, Africa and Oceania	*Litopenaeus vannamei*	14	Extract; additives	16 g/kg	Survival rate (+), Immunity (+)	Sarjito et al (2020)
Gracilaria verrucosa (R)	Asia, South America, Africa and Oceania	*Litopenaeus vannamei*	42	Extract; additives	2 g/kg	Immunity (+)	Jasmanindar et al (2018)
Sargassum polycystum (B) *Gracilaria verrucosa* (R)	Asia, South America, Africa and Oceania	*Penaeus monodon*	30	Co culture; supplement	2 kg/m^3 *G. verrucosa*	Growth (+)	Izzati (2011)
Ulva lactuca (G)	Europe, North, South and Central America, Caribbean Islands, Indian Ocean	*Macrobrachium rosenbergii*	240	Powder; replacement	30%	Growth (+)	Ghosh (2020)

Note: G - green seaweed; B - brown seaweed; R - red seaweed.

Table 4

Key research findings on seaweed in oyster aquaculture

Seaweed species (types)	*Habitat*	*Studied species*	*Study period (days)*	*Administration method; application type*	*Best doses*	*Key findings*	*References*
Ulva lactuca (G)	Mexico	*Crassostrea gigas*	35	Single cell detritus (SCD); replacement	50%	Growth (0) Lipase digestive capacity (+) Nitrogen turnover rates (-)	Omont et al (2021)
Ulva lactuca (G), *Ulva clathrata* (G), *Porphyra* sp.(R)	Mexico	*Crassostrea gigas*	17	Single cell detritus (SCD); replacement	SCD of Ulva is good	Mortality (-)	Peña-Rodríguez et al (2020)

Note: G - green seaweed; B - brown seaweed; R - red seaweed.

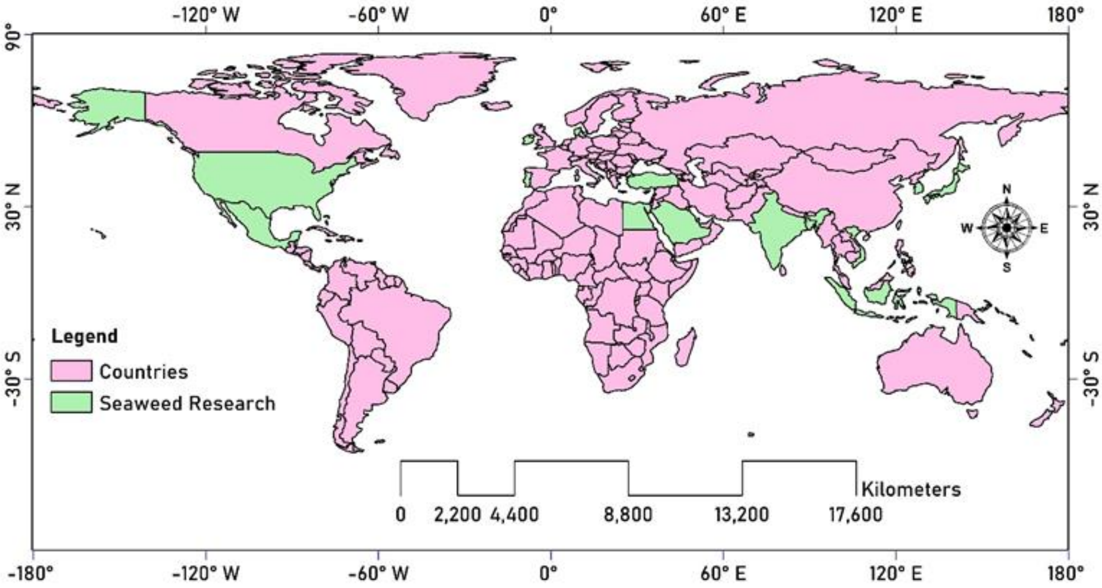
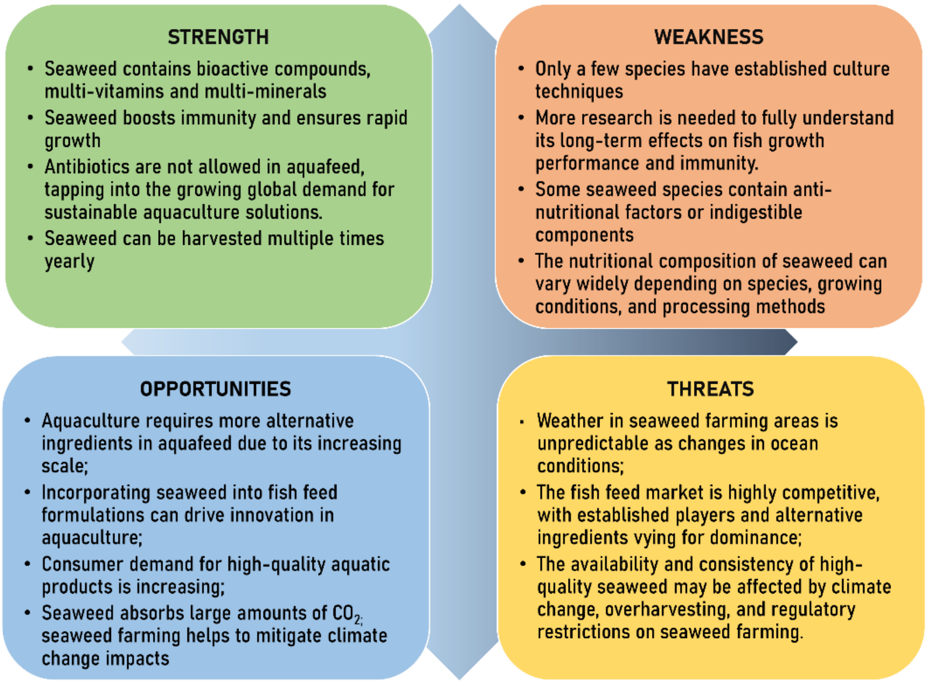


Figure 7. Global distribution of seaweed as an aquafeed ingredient.

Additionally, some seaweed species have anti-nutritional factors or indigestible components that could negatively impact fish health. The nutritional composition of seaweeds varies significantly due to factors including species variety, conditions of cultivation, and processing; all of these may lead to disparities in feed quality. Moreover, the unpredictable climatic trends experienced in areas intended for seaweed culture, the competitive pressures inherent in the fish feed sector, and the consequences of climate change, over-exploitation, and legislative frameworks on seaweed aquaculture constitute significant risk factors to the long-term and sustainable use of seaweed in aquaculture. Collaboration among academia, NGOs, and government agencies is crucial to overcome these obstacles. The focus should be on multi-species cultivation with minimal environmental impact, ensuring the long-term viability of seaweed in aquaculture (Hayashi et al 2020). A SWOT analysis of seaweed as a fish feed ingredient is illustrated in Figure 8.



STRENGTH

- Seaweed contains bioactive compounds, multi-vitamins and multi-minerals
- Seaweed boosts immunity and ensures rapid growth
- Antibiotics are not allowed in aquafeed, tapping into the growing global demand for sustainable aquaculture solutions.
- Seaweed can be harvested multiple times yearly

WEAKNESS

- Only a few species have established culture techniques
- More research is needed to fully understand its long-term effects on fish growth performance and immunity.
- Some seaweed species contain anti-nutritional factors or indigestible components
- The nutritional composition of seaweed can vary widely depending on species, growing conditions, and processing methods

OPPORTUNITIES

- Aquaculture requires more alternative ingredients in aquafeed due to its increasing scale;
- Incorporating seaweed into fish feed formulations can drive innovation in aquaculture;
- Consumer demand for high-quality aquatic products is increasing;
- Seaweed absorbs large amounts of $CO_{2;}$ seaweed farming helps to mitigate climate change impacts

THREATS

- Weather in seaweed farming areas is unpredictable as changes in ocean conditions;
- The fish feed market is highly competitive, with established players and alternative ingredients vying for dominance;
- The availability and consistency of high-quality seaweed may be affected by climate change, overharvesting, and regulatory restrictions on seaweed farming.

Figure 8. SWOT analysis of seaweed as a fish feed ingredient

Conclusions and recommendations. Given the significant growth trend of aquaculture, eco-friendly aquafeeds have become crucial for maintaining a sustainable aquaculture system. Seaweeds have demonstrated significant potential as a sustainable and nutritious component for aquafeed. It contains adequate proteins, essential amino acids, bioactive compounds, minerals, and antioxidants, making it an effective alternative to traditional fishmeal. This helps to promote growth, increase survival rates, boost immunity, and improve fish health. The ability of seaweed to provide pigments and aid in digestibility further underscores its value in aquaculture. These attributes not only support fish production but also contribute to environmental sustainability. Therefore, it is essential to conduct further research on seaweed cultivation processes and analyze their effects on fish growth and immune response. Additionally, determining the optimal inclusion rates of seaweed in aquafeeds for different fish species is crucial for advancing aquaculture applications. Collaboration between academia, the private sector, and government support is vital for strengthening this sector. Through these efforts, seaweed can play a key role in sustainable aquaculture, contributing to ecological balance and enhancing global food security.

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References

Abbott I. A., 1998 Food and food products from seaweeds. In: Algae and human affairs. Lembi C. A., Waaland J. R. (eds), Cambridge University Press, Cambridge, pp. 135-147.

Abdel-Aziz M. F. A., Ragab M. A., 2017 Effect of use fresh macro algae (seaweed) *Ulva fasciata* and *Enteromorpha flaxusa* with or without artificial feed on growth performance and feed utilization of rabbitfish (*Siganus rivulatus*) fry. Journal of Aquaculture Research and Development 8(4):1000482.

Abdel-Warith A. W. A., Younis E. S. M. I., Al-Asgah N. A., 2016 Potential use of green macroalgae *Ulva lactuca* as a feed supplement in diets on growth performance, feed utilization and body composition of the African catfish, *Clarias gariepinus*. Saudi Journal of Biological Sciences 23(3):404-409.

Afewerki S., Asche F., Misund B., Thorvaldsen T., Tveteras R., 2023 Innovation in the Norwegian aquaculture industry. Reviews in Aquaculture 15(2):759-771.

Alviano D. S., Alviano C. S., 2009 Plant extracts: search for new alternatives to treat microbial diseases. Current Pharmaceutical Biotechnology 10(1):106-121.

Anh N. T. N., Vinh N. H., Doan D. T., Lan L. M., Kurihara A., Hai T. N., 2022 Co-culture of red seaweed *Gracilaria tenuistipitata* and black tiger shrimp *Penaeus monodon* in an improved extensive pond at various stocking densities with partially reduced feed rations: a pilot-scale study. Journal of Applied Phycology 34(2):1109-1121.

Arasaki S., Arasaki T., 1983 Vegetables from the sea. Japan Publishing Inc., Tokyo, 196 pp.

Araújo M., Rema P., Sousa-Pinto I., Cunha L. M., Peixoto M. J., Pires M. A., Seixas F., Brotas V., Beltran C., Valente L. M. P., 2016 Dietary inclusion of IMTA-cultivated *Gracilaria vermiculophylla* in rainbow trout (*Oncorhynchus mykiss*) diets: effects on growth, intestinal morphology, tissue pigmentation, and immunological response. Journal of Applied Phycology 28(1):679-689.

Aslam M. N., Kreider J. M., Paruchuri T., Bhagavathula N., DaSilva M., Zernicke R. F., Goldstein S. A., Varani J., 2010 A mineral-rich extract from the red marine algae *Lithothamnion calcareum* preserves bone structure and function in female mice on a Western-style diet. Calcified Tissue International 86(4):313-324.

Austin B., 2023 The impact of disease on the sustainability of aquaculture. Sustainable Aquatic Research 2(1):74-91.

Bandara T., 2018 Alternative feed ingredients in aquaculture: opportunities and challenges. Journal of Entomology and Zoology Studies 6(2):3087-3094.

Barbalace M. C., Malaguti M., Giusti L., Lucacchini A., Hrelia S., Angeloni C., 2019 Anti-inflammatory activities of marine algae in neurodegenerative diseases. International Journal of Molecular Sciences 20(12):3061.

Birringer M., Pilawa S., Flohe L., 2002 Trends in selenium biochemistry. Natural Product Reports 19(6):693-718.

Boeing P., 1997 Use of spray-dried *Schizochytrium* sp. as a partial algal replacement for juvenile bivalves. Journal of Shellfish Research 16:284.

Brown M., Robert R., 2002 Preparation and assessment of microalgal concentrates as feeds for larval and juvenile Pacific oyster (*Crassostrea gigas*). Aquaculture 207(3-4):289-309.

Buschmann A. H., Camus C., Infante J., Neori A., Israel Á., Hernández-González M. C., Pereda S. V., Gomez-Pinchetti J. L., Golberg A., Tadmor-Shalev N., Critchley A. T., 2017 Seaweed production: overview of the global state of exploitation, farming and emerging research activity. European Journal of Phycology 52(4):391-406.

Cardoso C., Afonso C., Lourenço H., Costa S., Nunes M. L., 2015 Bioaccessibility assessment methodologies and their consequences for the risk–benefit evaluation of food. Trends in Food Science and Technology 41(1):5-23.

Černá M., 2011 Seaweed proteins and amino acids as nutraceuticals. Advances in Food and Nutrition Research 64:297-312.

Chakroborty K., Lima R. A., Hossain M. F., Rafiquzzaman S. M., 2025 Biobased functional feed additives in Asian aquaculture: trends, impacts, and future directions. Animal Feed Science and Technology 320:116222.

Charoensiddhi S., Abraham R. E., Su P., Zhang W., 2020 Seaweed and seaweed-derived metabolites as prebiotics. Advances in Food and Nutrition Research 91:97-156.

Choi Y., Hosseindoust A., Goel A., Lee S., Jha P. K., Kwon I. K., Chae B. J., 2017 Effects of *Ecklonia cava* as fucoidan-rich algae on growth performance, nutrient digestibility, intestinal morphology and caecal microflora in weanling pigs. Asian-Australasian Journal of Animal Sciences 30(1):64-70.

Cian R. E., Drago S. R., Sanchez de Medina F., Martínez-Augustin O., 2015 Proteins and carbohydrates from red seaweeds: evidence for beneficial effects on gut function and microbiota. Marine Drugs 13(8):5358-5383.

Corino C., Modina S. C., Di Giancamillo A., Chiapparini S., Rossi R., 2019 Seaweeds in pig nutrition. Animals 9(12):1126.

Corona G., Coman M. M., Guo Y., Hotchkiss S., Gill C., Yaqoob P., Spencer J. P. E., Rowland I., 2017 Effect of simulated gastrointestinal digestion and fermentation on polyphenolic content and bioactivity of brown seaweed phlorotannin-rich extracts. Molecular Nutrition and Food Research 61(11):1700223.

Coutteau P., Sorgeloos P., 1992 The use of algal substitutes and the requirement for live algae in the hatchery and nursery rearing of bivalve molluscs: an international survey. Journal of Shellfish Research 11(2):467-467.

Cyrus M. D., Bolton J. J., Scholtz R., Macey B. M., 2014 The advantages of *Ulva* (Chlorophyta) as an additive in sea urchin formulated feeds: effects on palatability, consumption and digestibility. Aquaculture Nutrition 21(5):578-591.

Dawczynski C., Schubert R., Jahreis G., 2007 Amino acids, fatty acids, and dietary fibre in edible seaweed products. Food Chemistry 103(3):891-899.

De Carvalho C. C. C. R., Caramujo M. J., 2018 The various roles of fatty acids. Molecules 23(10):2583.

Ergün S., Soyutürk M., Güroy B., Güroy D., Merrifield D., 2009 Influence of *Ulva* meal on growth, feed utilization, and body composition of juvenile Nile tilapia (*Oreochromis niloticus*) at two levels of dietary lipid. Aquaculture International 17(4):355-361.

Erlandson J. M., Braje T. J., Gill K. M., Graham M. H., 2015 Ecology of the kelp highway: did marine resources facilitate human dispersal from Northeast Asia to the Americas? Journal of Island and Coastal Archaeology 10(3):392-411.

FAO, 2024 FAO fisheries and aquaculture. FishStatJ - software for fishery and aquaculture statistical time series. Available at: https://www.fao.org/fishery/en/topic/166235/en. Accessed: April, 2024.

Ferreira M., Larsen B. K., Granby K., Cunha S. C., Monteiro C., Fernandes J. O., Nunes M. L., Marques A., Dias J., Cunha I., Castro L. F. C., Valente L. M. P., 2020 Diets supplemented with *Saccharina latissima* influence the expression of genes related to lipid metabolism and oxidative stress modulating rainbow trout (*Oncorhynchus mykiss*) fillet composition. Food and Chemical Toxicology 140:111332.

Foster G. G., Hodgson A. N., 1998 Consumption and apparent dry matter digestibility of six intertidal macroalgae by *Turbo sarmaticus* (Mollusca: Vetigastropoda: Turbinidae). Aquaculture 167(3-4):211-227.

Gaillard C., Bhatti H. S., Novoa-Garrido M., Lind V., Roleda M. Y., Weisbjerg M. R., 2018 Amino acid profiles of nine seaweed species and their in situ degradability in dairy cows. Animal Feed Science and Technology 241:210-222.

Ghaliaoui N., Hazzit M., Mokrane H., 2024 Seaweeds as a potential source of bioactive compounds. Research in Biotechnology and Environmental Science 3(1):1-8.

Ghosh R., 2020 Replacement of fish protein by *Ulva lactuca*: a new dimension in the fresh water prawn (*Macrobrachium rosenbergii*) fishery. In: Animal research today: basic and applied arena. Ghosh G. (ed), Department of Zoology, Midnapore College (Autonomous), Midnapore, West Bengal, India, pp. 49-61.

Ghosh R., Mitra A., 2015 Suitability of green macroalgae *Enteromorpha intestinalis* as a feed form *Macrobrachium rosenbergii*. Journal of Fisheries and Livestock Production 3:138.

Glombitza K. W., 1977 Highly hydroxylated phenols of the Phaeophyceae. In: Marine natural products chemistry. Nato Conference Series, vol 1. Faulkner D. J., Fenical W. H. (eds), Springer, Boston, pp. 191-204.

Gómez-Guzmán M., Rodríguez-Nogales A., Algieri F., Gálvez J., 2018 Potential role of seaweed polyphenols in cardiovascular-associated disorders. Marine Drugs 16(8): 250.

González-Araya R., Quéau I., Quéré C., Moal J., Robert R., 2011 A physiological and biochemical approach to selecting the ideal diet for *Ostrea edulis* (L.) broodstock conditioning (part A). Aquaculture Research 42(5):710-726.

González-Araya R., Lebrun L., Quéré C., Robert R., 2012 The selection of an ideal diet for *Ostrea edulis* (L.) broodstock conditioning (part B). Aquaculture 362-363:55-66.

González del Val A., Platas G., Basilio A., Cabello A., Gorrochategui J., Suay I., Vicente F., Portillo E., Jiménez del Río M., Reina G. G., Peláez F., 2001 Screening of antimicrobial activities in red, green and brown macroalgae from Gran Canaria (Canary Islands, Spain). International Microbiology 4(1):35-40.

Gora A. H., Sahu N. P., Sahoo S., Rehman S., Dar S. A., Ahmad I., Agarwal D., 2018 Effect of dietary *Sargassum wightii* and its fucoidan-rich extract on growth, immunity, disease resistance and antimicrobial peptide gene expression in *Labeo rohita*. International Aquatic Research 10:115-131.

Guedes A. C., Sousa-Pinto I., Malcata F. X., 2015 Application of microalgae protein to aquafeed. In: Handbook of marine microalgae - biotechnology advances. Kim S. K. (ed), Academic Press, pp. 93-125.

Guiry M. D., Guiry G. M., 2022 AlgaeBase. World-wide electronic publication, National University of Ireland, Galway. Available at: https://www.algaebase.org. Accessed: December, 2022.

Gumul D., Ziobro R., Zięba T., Rój E., 2011 The influence of addition of defeated blackcurrant seeds on pro-health constituents and texture of cereal extrudates. Journal of Food Quality 34(6):395-402.

Gupta S., Abu-Ghannam N., 2011 Recent developments in the application of seaweeds or seaweed extracts as a means for enhancing the safety and quality attributes of foods. Innovative Food Science and Emerging Technologies 12(4):600-609.

Güroy D., Güroy B., Merrifield D. L., Ergün S., Tekinay A. A., Yiğit M., 2011 Effect of dietary *Ulva* and *Spirulina* on weight loss and body composition of rainbow trout, *Oncorhynchus mykiss* (Walbaum), during a starvation period. Journal of Animal Physiology and Animal Nutrition 95(3):320-327.

Hafting J. T., Craigie J. S., Stengel D. B., Loureiro R. R., Buschmann A. H., Yarish C., Edwards M. D., Critchley A. T., 2015 Prospects and challenges for industrial production of seaweed bioactives. Journal of Phycology 51(5):821-837.

Hagan M., Fungwe T., 2023 Determining the effect of seaweed intake on the microbiota: a systematic review. Functional Food Science 3(6):79-92.

Hamed I., Özogul F., Özogul Y., Regenstein J. M., 2015 Marine bioactive compounds and their health benefits: a review. Comprehensive Reviews in Food Science and Food Safety 14(4):446-465.

Hayashi L., Cantarino S. D. J., Critchley A. T., 2020 Challenges to the future domestication of seaweeds as cultivated species: understanding their physiological processes for large-scale production. Advances in Botanical Research. Seaweeds around the world: state of the art and perspectives. Volume 95. Bourgougnon N. (ed), Academic Press, pp. 57-83.

Hayes M. 2015 Seaweeds: a nutraceutical and health food. In: Seaweed sustainability. Academic Press, pp 365-387.

Heo S. J., Park E. J., Lee K. W., Jeon Y. J., 2005 Antioxidant activities of enzymatic extracts from brown seaweeds. Bioresource Technology 96(14):1613-1623.

Holdt S. L., Kraan S., 2011 Bioactive compounds in seaweed: functional food applications and legislation. Journal of Applied Phycology 23:543- 597.

Horn M. H., Messer K. S., 1992 Fish guts as chemical reactors: a model of the alimentary canals of marine herbivorous fishes. Marine Biology 113:527-535.

Ismail M. M., 2019 Review on seaweed as supplement fish feed. Oceanography and Fisheries Open Access Journal 11(2):555808

Ismail M. M., El Zokm G. M., El-Sayed A. A. M., 2017 Variation in biochemical constituents and master elements in common seaweeds from Alexandria Coast, Egypt, with special reference to their antioxidant activity and potential food uses: prospective equations. Environmental Monitoring and Assessment 189(12):648.

Izzati M., 2011 The role of seaweeds *Sargassum polycistum* and *Gracilaria verrucosa* on growth performance and biomass production of tiger shrimp (*Penaeous monodon* Fabr). Journal of Coastal Development 14(3):235-241.

Jamal P., Olorunnisola K. S., Jaswir I., Tijani I. D. R., Ansari A. H., 2017 Bioprocessing of seaweed into protein enriched feedstock: process optimization and validation in reactor. International Food Research Journal 24:382-386.

Jasmanindar Y., Sukenda S., Zairin Jr. M., Alimuddin A., Utomo N. P. B., 2018 Dietary administration of *Gracilaria verrucosa* extract on *Litopenaeus vannamei* immune response, growth, and resistance to *Vibrio harveyi*. AACL Bioflux 11(4):1069-1080.

Kanjana K., Radtanatip T., Asuvapongpatana S., Withyachumnarnkul B., Wongprasert K., 2011 Solvent extracts of the red seaweed *Gracilaria* fisheri prevent *Vibrio harveyi* infections in the black tiger shrimp *Penaeus monodon*. Fish and Shellfish Immunology 30(1):389-396.

Khairy H. M., El-Shafay S. M., 2013 Seasonal variations in the biochemical composition of some common seaweed species from the coast of Abu Qir bay, Alexandria, Egypt. Oceanologia 55(2):435-452.

Khalafalla M. M. El-Hais A. M. A., 2015 Evaluation of seaweeds *Ulva rigida* and *Pterocladia capillaceaas* dietary supplements in Nile tilapia fingerlings. Journal of Aquaculture Research and Development 6(3):1000312.

Kim S. S., Lee K. J., 2008 Effects of dietary kelp (*Ecklonia cava*) on growth and innate immunity in juvenile olive flounder *Paralichthys olivaceus* (Temminck et Schlegel). Aquaculture Research 39(15):1687-1690.

Kuda T., Ikemori T., 2009 Minerals, polysaccharides and antioxidant properties of aqueous solutions obtained from macroalgal beach-casts in the Noto Peninsula, Ishikawa, Japan. Food Chemistry 112(3):575-581.

Kumar M., Kumari P., Trivedi N., Shukla M. K., Gupta V., Reddy C. R. K., Jha B., 2011 Minerals, PUFAs and antioxidant properties of some tropical seaweeds from Saurashtra coast of India. Journal of Applied Phycology 23(5):797-810.

Leonard S. G., Sweeney T., Pierce K. M., Bahar B., Lynch B. P., O'Doherty J. V., 2010 The effects of supplementing the diet of the sow with seaweed extracts and fish oil on aspects of gastrointestinal health and performance of the weaned piglet. Livestock Science 134(1-3):135-138.

Li M. H., Robinson E. H., Tucker C. S., Manning B. B., Khoo L., 2009 Effects of dried algae *Schizochytrium* sp., a rich source of docosahexaenoic acid, on growth, fatty acid composition, and sensory quality of channel catfish *Ictalurus punctatus*. Aquaculture 292(3-4):232-236.

Li Y. X., Kim S. K., 2011 Utilization of seaweed derived ingredients as potential antioxidants and functional ingredients in the food industry: an overview. Food Science and Biotechnology 20:1461-1466.

Liao W. R., Lin J. Y., Shieh W. Y., Jeng W. L., Huang R., 2003 Antibiotic activity of lectins from marine algae against marine vibrios. Journal of Industrial Microbiology and Biotechnology 30(7):433-439.

Lorenzo J. M., Agregán R., Munekata P. E. S., Franco D., Carballo J., Şahin S., Lacomba R., Barba F. J., 2017 Proximate composition and nutritional value of three macroalgae: *Ascophyllum nodosum*, *Fucus vesiculosus* and *Bifurcaria bifurcata*. Marine Drugs 15(11):360.

MacArtain P., Gill C. I. R., Brooks M., Campbell R., Rowland I. R., 2007 Nutritional value of edible seaweeds. Nutrition Reviews 65(12):535-543.

Manteu S. H., Nurjanah, Nurhayati T., 2018 [Characteristics of brown seaweeds *Sargassum policystum* and *Padina minor* from Pohuwato water, Gorontalo]. Jurnal Pengolahan Hasil Perikanan Indonesia 21(3):396-405. [in Indonesian]

Marinho G., Nunes C., Sousa-Pinto I., Pereira R., Rema P., Valente L. M., 2013 The IMTA-cultivated Chlorophyta *Ulva* spp. as a sustainable ingredient in Nile tilapia (*Oreochromis niloticus*) diets. Journal of Applied Phycology 25(5):1359-1367.

Marinho-Soriano E., Fonseca P. C., Carneiro M. A. A., Moreira W. S. C., 2006 Seasonal variation in the chemical composition of two tropical seaweeds. Bioresource Technology 97(18):2402-2406.

McDermid K. J., Stuercke B., 2003 Nutritional composition of edible Hawaiian seaweeds. Journal of Applied Phycology 15(6):513-524.

Metin C., Baygar T., 2018 Determination of nutritional composition of *Enteromorpha intestinalis* and investigation of its usage as food. Ege Journal of Fisheries and Aquatic Sciences 35(1):7-14.

Mikami K., Hosokawa M., 2013 Biosynthetic pathway and health benefits of fucoxanthin, an algae-specific xanthophyll in brown seaweeds. International Journal of Molecular Sciences 14(7):13763-13781.

Mišurcová L., 2011 Chemical composition of seaweeds. In: Handbook of marine macroalgae: biotechnology and applied phycology. Kim S. K. (ed), John Wiley & Sons, Ltd., pp. 171-192.

Morais T., Inácio A., Coutinho T., Ministro M., Cotas J., Pereira L., Bahcevandziev K., 2020 Seaweed potential in the animal feed: a review. Journal of Marine Science and Engineering 8(8):559.

Moreda-Piñeiro J., Moreda-Piñeiro A., Romarís-Hortas V., Domínguez-González R., Alonso-Rodríguez E., López-Mahía P., Muniategui-Lorenzo S., Prada-Rodríguez D., Bermejo-Barrera P., 2012 Trace metals in marine foodstuff: bioavailability estimation and effect of major food constituents. Food Chemistry 134(1):339-345.

Morrissey J., Kraan S., Guiry M. D., 2001 A guide to commercially important seaweeds on the Irish coast. Bord Iascaigh Mhara/Irish Sea Fisheries Board, Dublin, 67 pp.

Mouritsen O. G., 2013 Seaweeds: edible, available, and sustainable. University of Chicago Press, 304 pp.

Nakagawa H., Umino T., Tasaka Y., 1997 Usefulness of *Ascophyllum* meal as a feed additive for red sea bream, *Pagrus major*. Aquaculture 151(1-4):275-281.

Natify W., Droussi M., Berday N., Araba A., Benabid M., 2015 Effect of the seaweed *Ulva lactuca* as a feed additive on growth performance, feed utilization and body composition of Nile tilapia (*Oreochromis niloticus* L.). International Journal of Agronomy and Agricultural Research 7(3):85-92.

Pronker A. E., Nevejan N. M., Peene F., Geijsen P., Sorgeloos P., 2008 Hatchery broodstock conditioning of the blue mussel *Mytilus edulis* (Linnaeus 1758). Part I. Impact of different micro-algae mixtures on broodstock performance. Aquaculture International 16(4):297-307.

Noël L., Chekri R., Millour S., Vastel C., Kadar A., Sirot V., Leblanc J. C., Guérin T., 2012 Li, Cr, Mn, Co, Ni, Cu, Zn, Se and Mo levels in foodstuffs from the Second French TDS. Food Chemistry 132(3):1502-1513.

Norziah M. H., Ching C. Y., 2000 Nutritional composition of edible seaweed *Gracilaria changgi*. Food Chemistry 68(1):69-76.

Nur A., Hossain M. F., Hasan M. N., Zannat S., Chakroborty K., Rafiquzzaman S. M., 2020 Effect of selected seaweed powder as a fish feed on growth and immune system of tilapia (*Oreochromis niloticus*). International Journal of Fish Aquaculture Studies 8(4):24-30.

Nwosu F., Morris J., Lund V. A., Stewart D., Ross H. A., McDougall G. J., 2011 Anti-proliferative and potential anti-diabetic effects of phenolic-rich extracts from edible marine alga. Food Chemistry 126(3):1006-1012.

O'Sullivan L., Murphy B., McLoughlin P., Duggan P., Lawlor P. G., Hughes H., Gardiner G. E., 2010 Prebiotics from marine macroalgae for human and animal health applications. Marine Drugs 8(7):2038-2064.

Omont A., Py C., Gamboa-Delgado J., Nolasco-Soria H., Spanopoulos-Zarco M., Peña-Rodríguez A., 2021 Nutritional contribution of seaweed *Ulva lactuca* single-cell detritus and microalgae *Chaetoceros calcitrans* to the growth of the Pacific oyster *Crassostrea gigas*. Aquaculture 541:736835.

Ortiz J., Uquiche E., Robert P., Romero N., Quitral V., Llantén C., 2009 Functional and nutritional value of the Chilean seaweeds *Codium fragile*, *Gracilaria chilensis* and *Macrocystis pyrifera*. European Journal of Lipid Science and Technology 111(4):320-327.

Pacheco D., Miranda G., Pato R. L., Cotas J., Santos S. M. D., Pereira L., Bahcevandziev K., 2021 Nutritional evaluation of *Laminaria ochroleuca* harvested in the North of Portugal. 3rd Seaweed 4 Health Virtual Conference, 18020 May 2021, online.

Patel P. V., Vyas A. A., Chaudhari S. H., 2018 Effect of seaweed (*Ulva* sp.) as a feed additive in the dieton growth and survival of *Labeo rohita* fry. Scire Science Multidisciplinary Journal 2(3):97-113.

Peixoto M. J., Salas-Leitón E., Pereira L. F., Queiroz A., Magalhães F., Pereira R., Abreu A., Reis P. A., Gonçalves J. F. M., de Almeida Ozório R. O., 2016 Role of dietary seaweed supplementation on growth performance, digestive capacity and immune and stress responsiveness in European seabass (*Dicentrarchus labrax*). Aquaculture Reports 3:189-197.

Peña-Rodríguez A., Mawhinney T. P., Ricque-Marie D., Cruz-Suárez L. E., 2011 Chemical composition of cultivated seaweed *Ulva clathrata* (Roth) C. Agardh. Food Chemistry 129(2):491-498.

Peña-Rodríguez A., Morales-Alvarado G., Elizondo-González R., Mendoza-Carrión G., Tovar-Ramírez D., Escobedo-Fregoso C., 2020 Seaweed single cell detritus effects on the digestive enzymes activity and microbiota of the oyster *Crassostrea gigas*. Journal of Applied Phycology 32(5):3481-3493.

Pereira R., Valente L. M. P., Sousa-Pinto I., Rema P., 2012 Apparent nutrient digestibility of seaweeds by rainbow trout (*Oncorhynchus mykiss*) and Nile tilapia (*Oreochromis niloticus*). Algal Research 1(1):77-82.

Pérez M. J., Falqué E., Domínguez H., 2016 Antimicrobial action of compounds from marine seaweed. Marine Drugs 14(3):52.

Ponis E., Robert R., Parisi G., 2003 Nutritional value of fresh and concentrated algal diets for larval and juvenile Pacific oysters (*Crassostrea gigas*). Aquaculture 221(1-4):491-505.

Radulovich R., Umanzor S., Cabrera R., Mata R., 2015 Tropical seaweeds for human food, their cultivation and its effect on biodiversity enrichment. Aquaculture 436:40-46.

Rajauria G., Cornish L., Ometto F., Msuya F. E., Villa R., 2015 Identification and selection of algae for food, feed, and fuel applications. In: Seaweed sustainability: food and non-food applications. Tiwari B. K., Troy D. J. (eds), Academic Press, pp. 315-345.

Rama Nisha P., Elezabeth Mary A., Uthayasiva M., Arularasan S., 2014 Seaweed *Ulva reticulata* a potential feed supplement for growth, colouration and disease resistance in fresh water ornamental gold fish, *Carassius auratus*. Journal of Aquaculture Research and Development 5:254.

Rasyid A., Ardiansyah A., Pangestuti R., 2019 Nutrient composition of dried seaweed *Gracilaria gracilis*. Ilmu Kelautan: Indonesian Journal of Marine Sciences 24(1):1-6.

Rathore S. S., Chaudhary D. R., Boricha G. N., Ghosh A., Bhatt B. P., Zodape . T., Patolia J. S., 2009 Effect of seaweed extract on the growth, yield and nutrient uptake of soybean (*Glycine max*) under rainfed conditions. South African Journal of Botany 75(2):351-355.

Rocha C. P., Pacheco D., Cotas J., Marques J. C., Pereira L., Gonçalves A. M. M., 2021 Seaweeds as valuable sources of essential fatty acids for human nutrition. International Journal of Environmental Research and Public Health 18(9):4968.

Rocha de Souza M. C., Marques C. T., Guerra Dore C. M., Ferreira da Silva F. R., Oliveira Rocha H. A., Leite E. L., 2007 Antioxidant activities of sulfated polysaccharides from brown and red seaweeds. Journal of Applied Phycology 19(2):153-160.

Rodríguez-Bernaldo de Quirós A., Frecha-Ferreiro S., Vidal-Pérez A. M., López-Hernández J., 2010 Antioxidant compounds in edible brown seaweeds. European Food Research and Technology 231(3):495-498.

Safavi S. V., Kenari A. A., Tabarsa M., Esmaeili M., 2019 Effect of sulfated polysaccharides extracted from marine macroalgae (*Ulva intestinalis* and *Gracilariopsis persica*) on growth performance, fatty acid profile, and immune response of rainbow trout (*Oncorhynchus mykiss*). Journal of Applied Phycology 31: 4021-4035.

Salehpour R., Biuki N. A., Mohammadi M., Dashtiannasab A., Ebrahimnejad P., 2021 The dietary effect of fucoidan extracted from brown seaweed, *Cystoseira trinodis* (C. Agardh) on growth and disease resistance to WSSV in shrimp *Litopenaeus vannamei*. Fish and Shellfish Immunology 119:84-95.

Sarjito S., Haditomo A. H. C., Erlinda K., Desrina, Prayitno S. B., 2020 Role of *Gracilaria verrucosa* extract in the feed as immunostimulant of white shrimp (*Litopenaeus vannamei*) infected *Vibrio harveyi*. Advances in Animal and Veterinary Sciences 8(12):1427-1434.

Siddik M. A. B., Francis P., Rohani M. F., Azam M. S., Mock T. S., Francis D. S., 2023 Seaweed and seaweed-based functional metabolites as potential modulators of growth, immune and antioxidant responses, and gut microbiota in fish. Antioxidants 12(12):2066.

Škrovánková S., 2011 Seaweed vitamins as nutraceuticals. Advances in Food and Nutrition Research 64:357-369.

Soler-Vila A., Coughlan S., Guiry M. D., Kraan S., 2009 The red alga *Porphyra dioica* as a fish-feed ingredient for rainbow trout (*Oncorhynchus mykiss*): effects on growth, feed efficiency, and carcass composition. Journal of Applied Phycology 21(5):617-624.

Souza B. W. S., Cerqueira M. A., Bourbon A. I., Pinheiro A. C., Martins J. T., Teixeira J. A., Coimbra M. A., Vicente A. A., 2012 Chemical characterization and antioxidant activity of sulfated polysaccharide from the red seaweed *Gracilaria birdiae*. Food Hydrocolloids 27:287-292.

Tacon A. G., 2002 Thematic review of feeds and feed management practices in shrimp aquaculture. Report prepared under the World Bank, NACA, WWF and FAO consortium program on shrimp farming and the environment. Published by the Consortium, 69 pp.

Uchida M., Murata M., 2002 Fermentative preparation of single cell detritus from seaweed, *Undaria pinnatifida*, suitable as a replacement hatchery diet for unicellular algae. Aquaculture 207(3-4):345-357.

Udayasoundari D., Jeyanthi S., Santhanam P., Devi A. S., Shyamala V., Thangaraju N., 2016 Effects of partial replacement of fishmeal with seaweed (*Lobophora variegata*) meal on the growth and biochemical composition of commercial important fish Asian seabass *Lates calcarifer* (Bloch,1790) fingerlings. Internation Journal of Marine Science 6(25):1-8.

Valente L. M. P., Gouveia A., Rema P., Matos J., Gomes E. F., Pinto I. S., 2006 Evaluation of three seaweeds *Gracilaria bursa-pastoris*, *Ulva rigida* and *Gracilaria cornea* as dietary ingredients in European sea bass (*Dicentrarchus labrax*) juveniles. Aquaculture 252(1):85-91.

Van Doan H., Doolgindachbaporn S., Suksri A., 2014 Effects of low molecular weight agar and *Lactobacillus plantarum* on growth performance, immunity, and disease resistance of basa fish (*Pangasius bocourti*, Sauvage 1880). Fish and Shellfish Immunology 41(2):340-345.

Van Ginneken V. J. T., Helsper J. P. F. G., De Visser W., Van Keulen H., Brandenburg W. A., 2011 Polyunsaturated fatty acids in various macroalgal species from north Atlantic and tropical seas. Lipids in Health and Disease 10:104.

Vázquez-Sánchez J., Ramón-Gallegos E., Mojica-Villegas A., Madrigal-Bujaidar E., Pérez-Pastén-Borja R., Chamorro-Cevallos G., 2009 *Spirulina maxima* and its protein extract protect against hydroxyurea-teratogenic insult in mice. Food and Chemical Toxicology 47(11):2785-2789.

Vidanarachchi J. K., Iji P. A., Mikkelsen L. L., Sims I., Choct M., 2009 Isolation and characterization of water-soluble prebiotic compounds from Australian and New Zealand plants. Carbohydrate Polymers 77(3):670-676.

Wan A. H. L., Davies S. J., Soler-Vila A., Fitzgerald R., Johnson M. P., 2019 Macroalgae as a sustainable aquafeed ingredient. Reviews in Aquaculture 11(3):458-492.

Wassef E. A., El-Sayed A. F. M., Sakr E. M., 2013 *Pterocladia* (Rhodophyta) and *Ulva* (Chlorophyta) as feed supplements for European seabass, *Dicentrarchus labrax* L., fry. Journal of Applied Phycology 25:1369-1376.

Wells M. L., Potin P., Craigie J. S., Raven J. A., Merchant S. S., Helliwell K. E., Smith A. G., Camire M. E., Brawley S. H., 2017 Algae as nutritional and functional food sources: revisiting our understanding. Journal of Applied Phycology 29(2):949-982.

Wijesinghe W. A. J. P., Jeon Y. J., 2012 Enzyme-assistant extraction (EAE) of bioactive components: a useful approach for recovery of industrially important metabolites from seaweeds: a review. Fi-toterapia 83(1):6-12.

Wong K. H., Cheung P. C. K., 2000 Nutritional evaluation of some subtropical red and green seaweeds. Part I: proximate composition, amino acid profiles and some physico-chemical properties. Food Chemistry 71(4):475-482.

Yang L. E., Lu Q. Q., Brodie J., 2017 A review of the bladed Bangiales (Rhodophyta) in China: history, culture and taxonomy. European Journal of Phycology 52(3):251-263.

Zhang L., Liao W., Huang Y., Wen Y., Chu Y., Zhao C., 2022 Global seaweed farming and processing in the past 20 years. Food Production, Processing and Nutrition 4(1):23.

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