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Potential for Use of Seaweed as a Fish Feed Ingredient: A Review

Rachel Mwendwa[1], Michael Wawire[1] & Peter Kahenya[1]

[1] Department of Food Science and Technology, Jomo Kenyatta University of Agriculture and Technology, Nairobi, Kenya

Correspondence: Rachel Mwendwa, Department of Food Science and Technology, Jomo Kenyatta University of Agriculture and Technology, P.O. Box 62000-00200, Nairobi, Kenya. E-mail: ramwa.24@gmail.com

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Abstract

Seaweeds, also known as macroalgae are marine plants used widely as food and applied in other food allied industries, pharmaceuticals, cosmetics and agrochemical industries. Their production has increased over the years with advancement in identification and cultivation of different seaweed species. Over the years seaweeds have been explored as a food due to their nutrition value and bioactive compounds that are beneficial to human nutrition and health. With this principle, seaweeds can also be used as feed ingredient in aqua feeds especially due to the fact that it is a source of omega-3 and hence can be used as an alternative to fish oil whose supply has declined. Studies have shown that polyunsaturated fatty acids which are important in fish nutrition can account for about 50% of total fatty acids in seaweeds. In addition to being a good source of polyunsaturated fatty acids, seaweeds provide protein and minerals, vitamins. They are also characterized with high levels of protein rich in all the amino acids relative to some higher plant-based protein crops like soya bean.

This review, therefore, aims to look at the potential of seaweed as an aqua feed ingredient with the emphasis on the nutritional characteristics.

Keywords: seaweed, nutritional, polyunsaturated fatty acids, polysaccharides, aquaculture, feeds

1. Introduction

Seaweeds (macroalgae), are marine plants that are important for both human and animal nutrition. They are broadly classified as green (Chlorophyta), red (Rhodophyta) and brown (Phaeophyta) based on their surface pigmentation. Globally, the estimated number of species is about 12 000 (M. D. Guiry & G. M. Guiry, 2022). Of these, only 34 species are intensively farmed (FAO, 2013).

The annual global production of seaweeds (wild and cultivated) in 2018 was estimated to be 32.4 million tonnes with 97.1% of the total being from cultivated seaweeds (FAO, 2020). In the same year, Indonesia was the major producer of the farmed seaweed mainly for carrageenan extraction. Production has increased steadily over the past two decades (Figure 1), as more opportunity for use in different industries have opened up.

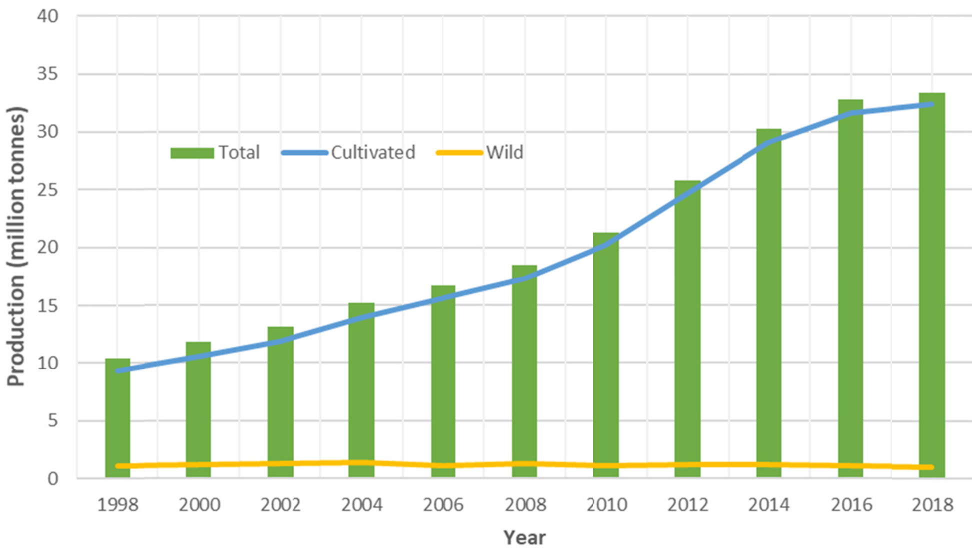

Figure 1. Global production of seaweed 1998-2018 from the wild and cultivated

Source FAOSTAT, 2020.

The most cultivated species and of economic importance include the brown macroalgae; *Laminaria*, *Undaria*, *Sargassum* and *Fucus* and the red macroalgae *Porphyra*, *Gracilaria*, *Eucheuma* and *Gelidium*. The *Enteromorpha*, *Monostroma*, *Caulerpa* and *Codium* species of the green macroalgae are wide spread globally. Figure 2 shows the percentage production of each group in 2018. Farming of seaweed has substantially increased over the years as a way of diversifying livelihoods, economic empowerment and sustainability of the wild population (Largo et al., 2020).

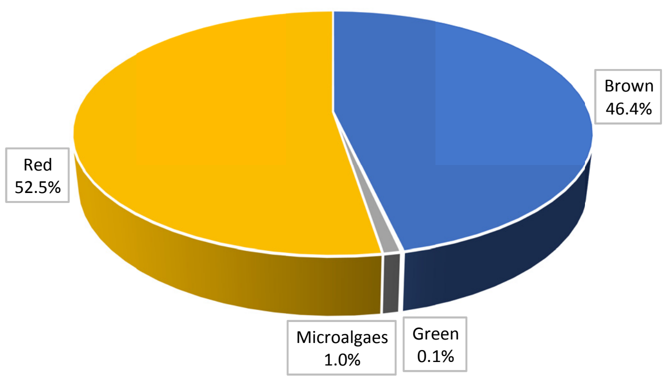

Figure 2. Percentage global production of the different seaweed in 2018

Source FAOSTAT, 2020.

Seaweeds were traditionally consumed directly as salads and in soups in Asian countries like China, Korea and Japan but their use has diversified into European and American countries (North and Southern) (McHugh, 2003; Yuan, 2008). Several epidemiological studies have shown that consumption of seaweed has protective and beneficial effect to human health through their bioactive compounds that have antioxidant capacity, anticoagulant activity, antimicrobial activity, antiproliferation effect, anti-inflammatory and hepatoprotective properties (Athukorala et al., 2007; Dang et al., 2008; Zubia et al., 2009; Costa et al., 2010; Taskin et al., 2010).

Apart from being a direct source of human food, they are widely used in several areas such as the food industry, pharmaceuticals, cosmetics, agrochemicals, water treatment and more recently they are being explored as a biofuel (Faulkner, 2012; Jang et al., 2012; Khan et al., 2009; Chynoweth, 2002). In the food industry their hydrocolloid extracts are used as thickening agents, emulsifiers, stabilizers and gelling agents. The red seaweed has a wide application in different industries especially for its carrageenan and agar extracts while the brown seaweed is mainly exploited for its alginate content.

Over the years, seaweeds have been used as fodder for animals like sheep, cattle and pigs to enhance growth and stimulate uptake of feed (Rajauria, 2015). However, the practical use as feed ingredient in aquafeed has not been widely studied.

Decline in fish meal and oil for aquafeed production has necessitated the need for other alternative feed ingredients to supply the lipids and protein in the feed. Seaweed are great alternative as they are rich in minerals, essential fatty acids, protein and fibre with trace amounts of vitamins (MacArtain et al., 2007; Radulovich et al., 2015). In addition, seaweeds are available throughout the year and are easy to harvest (Rajapakse & Kim, 2011). Furthermore, seaweeds are already in use as a natural food to fish in the wild (Mouritsen, 2013). With these promising characteristics, seaweeds may be harnessed to promote fish growth and sustainability of aquaculture. Therefore, the objective of this review was to assess the potential use of seaweeds as a fish feed ingredient with emphasis on tilapia fish feeds.

The review covers the current studies on the application and benefits of seaweed in aquaculture, nutritional potential, sustainability aspects and future prospects for their use.

2. Nutritional Properties of Seaweeds

2.1 Polysaccharides

Two forms of polysaccharides are found in seaweeds; storage and cell wall polysaccharides. Storage polysaccharide mainly serve as a source of energy to the algae and include laminaran in the brown macroalgae, floridean starch in red macroalgae and starch in green macroalgae (Barry et al., 1949; Usov, 2011; Busi et al., 2014; Barsanti & Gualtieri, 2014).

The most abundant cell wall or non-starch polysaccharides (NSP) are sulfated galactan (carrageenan and agar) in red seaweeds and sulfated fucans and alginates in brown algae. Others occurring in small quantities include fucoidans (brown seaweeds), xylans (red and green seaweeds) and *Ulva*ns (green seaweeds). In addition, cellulose is found in all the seaweeds in varying levels (Rioux & Turgeon, 2015; Delattre et al., 2011; Craigie, 2010). Most of these polysaccharides found in seaweeds are not digestible in the guts of humans, while in some animals they are digested at a slow rate and is therefore classified as dietary fibre.

Total carbohydrate content in most seaweeds range between 20 to 76% of dry weight (Holdt & Kraan, 2011). Their content is influenced by several factors such as the season of harvest, species, environmental conditions (water salinity, temperature, tides) and the geographical location (Murata & Nakazoe, 2001). NSP also known as dietary fibre are the most abundant of the carbohydrates (Rajapakse & Kim, 2011) accounting for about of 33-62% dry matter. Moreover, these levels are higher than those found in higher plants (Dawczynski et al., 2007).

Apart from being a good source of dietary fibre and a source of energy to fish, polysaccharides also have antioxidant activity that can promote the health and immunity of fish (Jung et al., 2012). Tilapia fish has no specific requirement (in terms of quantity) for carbohydrates (Ng & Romano, 2013). As earlier established, seaweeds are rich in NSP which are relatively indigestible by the fish due to lack of the necessary enzymes (β-glucanases and xylanases) that are required for NSP digestion. This, in turn affects mineral and water absorption in the fish gut resulting in increased digesta viscosity (Leenhouwers et al., 2007) and at high levels of about 9.7% inclusion they reduce protein and lipid digestibility (Hossain et al., 2003). However, studies have shown that pre-treatment (with enzymes, heat, acid) of feed ingredients containing NSP can improve their digestibility and tilapia growth (Li et al., 2009b; Belal, 2008).

2.2 Protein

Protein content in seaweeds varies greatly among the species and is influenced by a number of factors such as the growth environment and season of harvest (Lourenço et al., 2002; McDermid & Stuercke, 2003). Protein can account for 5 to 47% dry weight of seaweed (Černá, 2011). All the ten essential amino acids required for growth in tilapia nutrition are present in seaweeds: threonine, tryptophan, phenylalanine, methionine, histidine, arginine, valine, lysine, isoleucine and leucine (Santiago & Lovell, 1988; Rajapakse & Kim, 2011), with the aspartic and glutamic acid being the most abundant.

In a study carried out by Dawczynski et al. (2007), using 34 varieties of seaweed (17 brown and 17 red), they reported higher levels of crude protein in red seaweeds (30.9-31.4 g/100 g semi-dry weight) as compared to the brown seaweeds (7.5-19.8 g/100 g semi-dry weight). The same range results were reported by Murata and Nakazoe (2001); 30-40%, 15% and 30% of dry matter in the red, brown and green seaweeds respectively. The red seaweeds typically have higher protein content than the brown and green (Kim, 2011) and this is attributed to the occurrence of the functional proteinic pigments phycobiliproteins (phycoerythrin and phycocyanin) in the red seaweeds (Harnedy & FitzGerald, 2011). As regards to seasons, the protein content is highest during the cold seasons and lowest in the summer as result of heat destruction of the phycobiliproteins (Pangestuti & Kim, 2015).

Protein requirement in tilapia is dependent on a number of factors such as protein source, fish body weight, and stage of maturity. Based on the stage of maturity, the recommended protein content in the diet for spawning females and fry is about 30-40% while for the fingerlings and grow- out is 20-30% (Abdel-Tawwab et al., 2010).

Soy bean protein content which is most used plant-based protein source in aqua feeds is comparable to that of seaweed (40-44%). Studies on soy bean meal digestibility in tilapia have reported high digestibility of the meal especially when fermented (Guimarães et al., 2008; Zhou & Yue, 2012).

2.3 Lipids

The main classes of lipid found in seaweeds are glycolipids and phospholipids. The composition of the classes in seaweeds is dependent on species type, season of harvest and environmental factors like water temperature, salinity and light (Marinho-Soriano et al., 2006; Sanchez-Machado et al., 2004).

Total lipid content of seaweeds is low, ranging from about 1-5 g/100 g dry weight (Terasaki et al., 2009; Li et al., 2002; Vaskovsky et al., 1996). However, some studies have shown that the total lipid content in brown seaweeds of the sargassum can rise to 15% dry weight with 40% of the total fatty acids being the omega 3 polyunsaturated fatty acids (PUFA) (Nomura et al., 2013). This difference in the contents of lipid could be due to species and seasonal variations; production of lipids increases in the hot seasons and the poly unsaturated fatty acids in cold seasons (Narayan et al., 2005).

Seaweeds lipids comprise both the saturated and unsaturated fatty acids. The saturated fatty acids include the lauric acid (C12:0), myristic (C14:0), pentadecylic (C15:0), palmitic (C16:0), margaric (C17:0), stearic (C18:0) and arachidic (C20:0) acids while the unsaturated fatty acid include the monounsaturated (C12:1-C18:1) and polyunsaturated long chain (omega-3 and omega-6) fatty acids (Hamid et al., 2015; Ragonese et al., 2014; Sánchez-Machado et al., 2004). Moreover, seaweeds contain significantly higher levels of polyunsaturated fatty acids compared to terrestrial vegetables (Mendis & Kim, 2011). Omega 3 PUFAs in seaweeds include the α-linolenic acid, ALA (C18:3n-3), stearidonic acid, SDA (C18:4n-3) and eicosapentaenoic acid, EPA (C20:5n-3) while the omega 6 PUFA is the arachidonic acid (C20:4n-6) (Miyashita et al., 2013; Terasaki et al., 2009). In most seaweeds the EPA accounts for almost half of the total fatty acids (Dawczynski et al., 2007).

Lipids in fish feeds are important source of concentrated energy for growth and survival. Tilapia fish need 5-12% lipid inclusion in their diet for optimum growth (Chou & Shiau, 1996). Seaweeds can meet the lipid requirement for tilapia although it would require the supplementation with linolenic acid, LA (C18:2n-6) which is an essential fatty acid for tilapia diet.

2.4 Vitamins and Minerals

Seaweeds contain a wide array of minerals both macro-elements and trace-elements like Iodine, calcium, sodium, selenium, iron, zinc, potassium and phosphorus (Holdt & Kraan, 2011) that they draw mostly from the marine waters. They have high sorbent capacity for minerals than terrestrial plants and can account for about 36% of dry matter (Rajapakse & Kim, 2011). Higher mineral contents are recorded in brown seaweeds (30.1-39.3%) than in the red seaweeds (20.6-21.1%) (Rupérez, 2002).

Seaweeds contain both the hydro-soluble vitamins, C and B group as well as the fat-soluble A and E (MacArtain et al., 2007). The vitamin concentrations and profile are affected by a number of factors; species, stage of maturity, season, geographical location, temperature and salinity (Škrovánková, 2011). Vitamin B12 which is generally present in animal products is also found in seaweeds and can reach to highs of 134 μg/100 g dry weight in the red seaweed *Porphyra* sp. (Miyamoto et al., 2009). This could be attributed to the microorganisms especially the bacteria living on the surface of waters, that serve as a source of the vitamin (Baweja et al., 2016).

Most aqua feeds are supplemented with mineral and vitamin premixes to meet the needs of tilapia. Fish can accumulate some minerals from their culture environment and diet. Seaweeds in a tilapia diet can provide most of the required minerals at varying percentages (Ca, Na, K, P, Zn & Fe). However, the interaction of the dietary mineral with carbohydrates and proteins in the diet may affect its bioavailability and therefore the need for supplementation (Ng & Romano, 2013). Bioavailability of the minerals in seaweeds has to be considered since some of the minerals are linked to polysaccharides that are not easily digested (Gómez-Ordóñez et al., 2010). For instance, calcium is linked to alginates in brown macroalgae and this limits its bioavailability.

Table 1. Nutritional composition of some commercially important seaweeds (% dry weight)

Species	Carbohydrates	Protein	Lipid	Ash	Fibre	References
Rhodophyta						
Porphyra umbilicalis	43.0	29-39	0.3	12	29-35	Holdt & Kraan, 2011, Morais et al., 2020
Gracilaria cerviconis	57.71-68.29	14.29-22.70	0.33-0.51	8.07-13.11	4.87-7.67	Marinho-Soriano et al., 2006
Eucheuma denticulatum	-	4.9	2.2	43.6	-	McDermid & Stuercke, 2003
Phaeophyta						
Laminaria digitata	48	8-15	1.0	38	37	Rajauria et al., 2015
Sargassum vulgare	52.62-68.54	9.19-19.94	0.15-0.79	13.07-30.35	4.80-10.51	Marinho-Soriano et al., 2006
Undaria pinnatifida	-	19.8	4.5	-	45.9	Dawczynski et al., 2007
Chlorophyta						
Ulva clathrata	-	21.9-25.9	2.5-3.5	44.8-49.6	24.8-26.3	Peña-Rodríguez et al., 2011
Codium fragile	39-67	8-11	0.5-1.5	21-39	5.1	Holdt & Kraan, 2011; Morais et al., 2020
Caulerpa lentilifera	-	9.7	7.2	46.4	-	McDermid & Stuercke, 2003

3. Other Components of Interest

3.1 Pigments

Fucoxanthin is the major carotenoid found in brown seaweeds and contributes to more than 10% of carotenoid produced in nature (Rodríguez-Bernaldo et al., 2010). The characteristic green color in green seaweeds is due to the presence of chlorophyll a and b, β-carotene and xanthophylls (yellowish) while the proteinic pigments, phycoerythrin and phycocyanin in the red seaweeds is responsible for their red color (O'Sullivan et al., 2010; Hamid et al., 2015).

Pigments play an important role in fish nutrition and in the overall health (Rodriguez-Amaya, 2016). They contribute and enhance to the skin and flesh color of some fish like salmon, tilapia and seabream (Gomes et al., 2002; Araújo et al., 2016). Color of fish skin and flesh influences consumer choice. In promoting organic aquaculture, use of seaweeds in aquafeeds is great natural alternative to artificial colorants in feeds.

3.2 Toxins

With use of macroalgae as fish feed there is need to assess the presence of toxins such as heavy metal and pesticide residues that may accumulate over time due to pollution from anthropogenic sources such as industries, agricultural water runoff, oil spillage and mining activities in the sea (Sudharsan et al., 2012). Furthermore, fish and other sea foods are known to build up these toxins in the fat tissues, thus accumulating them in the food chain as the fish feed on each other. Due to this ability, they have been used worldwide as biomonitors for metal pollution in coastal waters (Melville & Pulkownik, 2006). The level of contamination with pollutants in seaweeds is not only affected by the bioavailability of the pollutant but also by the environmental conditions such as temperature, light, oxygen and salinity and the seaweed uptake ability (Żbikowski et al., 2006; Sánchez-Rodrıguez et al., 2001).

Heavy metals such as mercury, cadmium, arsenic, lead and tin have been found in seaweeds and pose a threat to both human and animal health. Arsenic is a major pollutant in seaweed and contributes to about 50% of dietary source of the pollutant (Scoop, 2004). A study by Van Netten et al., (2000) showed that commercial seaweeds can have arsenics to levels between 17 to 88 mg/kg (dwb) with the brown species having higher concentrations than the other species. Brown macroalgae have a higher metal binding capacity than the green and red species.

The EU regulation for the minimum levels permitted in food for lead and cadmium is less than 3 ppm per dry weight and less than 0.1 ppm dry weight for mercury (EU, 2008). These standards could also apply for fish feeds since the fish is finally consumed as food. In addition, seaweeds need to be tested for heavy metal (organic & inorganic) contamination before any feed formulation to avoid transfer up in the food chain.

4. Use in Aquaculture

Macroalgae have been used in the past years as livestock feeds for chicken, pig, sheep, cattle and studies have shown that they improve growth, reduce stress and enhance gastrointestinal health, increase egg, meat and milk quality when included in feed (Archer, 2005; Leonard et al., 2011; Rajauria, 2015). The most common seaweeds used in livestock feed include the *Laminaria* sp., *Ulva* sp., *Enteromorpha* sp., *Sargassum* sp. and *Gracilaria* sp. (Rajauria et al., 2015).

Application of macroalgae as feed ingredient in aqua feeds is an option of ensuring sustainability of fish meal and oil whose production is on the decline. It is a novel aquaculture feedstuff that can supply protein, lipids and minerals to farmed fish (FAO, 2018). The practical use of seaweeds as feed in cultured tilapia is relatively low (Fiogbé et al., 2004). This is because seaweed has high moisture content (64.9%-94.0%) and therefore larger quantities of fresh seaweed biomass would be needed to produce the same amount of dry matter compared to terrestrial flora (Wan et al., 2019). However, scientific studies have been done to evaluate the effects of seaweed supplementation and inclusion at different doses in experimental diets for fish and beneficial effect have been identified. Most of the feeding experiment focus on assessing the quality of the seaweed based on palatability, digestibility, utilization, immunological effect, functionality and the effects on growth of the fish (Glencross, 2020). Typically, more than one of these aspects is assessed in studies to get an understanding of the ingredient quality as summarized in Table 2.

Table 2. Effects on characteristics of various cultured aquatic animals fed on seaweed enhanced diet

Seaweeds studied	Studied species	Doses of inclusion	Study period	Findings	References
Gracilaria spp. *Ulva* spp. *Fucus* spp.	European seabass (*Dicentrarchus labrax*)	2.5% & 7.5%, Mixed (2.5% each)	84 days	Growth performance-(0); Digestive capacity- (+); Antioxidant response (+)	Peixoto et al., 2016
Ulva spp.	Nile tilapia (*Oreochromis niloticus*)	10, 15 & 20%	63 days	Growth performance was higher in 10% than in 15 & 20%; Highest Lipid content at 20%	Marinho et al., 2013
Gracilaria bursa-pastoris, GP *Ulva rigida*, UR *Gracilaria cornea*, GC	European seabass (*Dicentrarchus labrax*)	5 & 10%	10 weeks	Growth performance (+) in all diets except in GC-10% (-); Nutrient utilization (+) in all diets except in GC-10% (-); Muscle composition (0)	Valente et al., 2006
Gracilaria spp. *Porphyra* spp. *Ulva* spp.	Nile tilapia (*Oreochromis niloticus*)	10%	84 days	Growth performance and feed intake in *Gracilaria* spp. is (-), while in the other seaweeds (+); Body composition (0)	Silva et al., 2015
Ulva rigida *Ulva lactuca*	Nile tilapia (*Oreochromis niloticus*)	5 & 10%	68 days	Sensory attributes (0); Carotenoid deposition on skin (+); Lysosome and peroxidase activity (0); Alternative complement activity (ACH50) (+)	Valente et al., 2016
Ulva rigida	Nile tilapia (*Oreochromis niloticus*)	5%	16 weeks	Growth performance (+); Nutrient utilization (+); Muscle composition (+)	Ergün et al., 2009
Gracilaria vermiculophylla	Rainbow trout (*Oncorhynchus mykiss*)	5 & 10%	91 days	Carotenoid deposition on skin (+); Innate Immunity response (+)	Araújo et al., 2016
Ulva sp.	Red tilapia (*Oreochromis* sp.)	5, 10, 15, 20 & 25%	9 weeks	Growth performance (+) up to 15%. No additional effect from 15% to 25%; Muscle lipid content (+) up to 10%. No additional effect from 10%; Muscle protein content (+)	El-Tawil, 2010
Ecklonia cava	Olive flounder (*Paralichthys olivaceus*)	2, 4 & 6%	6 weeks	Non-specific immunity (+)	Kim & Lee, 2008
Schizochytrium sp.	channel catfish (*Ictalurus punctatus*)	0.5, 1.0, 1.5 & 2.0%	9 weeks	Growth performance (+) from 1% inclusion to 2%; Filet protein, moisture & fat concentration (no effect); Long chain polyunsaturated fatty acid composition (+)	Li et al., 2009a
Porphyra dioica	Rainbow trout (*Oncorhynchus mykiss*)	5, 10 & 15%	12.5 weeks	Growth performance (0); Protein content (+); Flesh pigmentation (+)	Soler-Vila et al., 2009
Ulva lactuca	African catfish (*Clarias gariepinus*)	10, 20, & 30%	10 weeks	Growth performance (-) at 20 & 30% inclusion while (+) at 10%; Feed utilization (-) at 20 & 30% inclusion	Abdel-Warith et al., 2016

Note. (+): indicates increase or improvement; (-): indicates decrease or detrimental effect; (0): indicates no effect.

As shown in Table 2, the inclusion of seaweeds in the diets of fish has diverse effects on its overall performance and quality varying among the species (both of fish and seaweed). Incorporating seaweeds in feeds at low levels (< 15%) enhances growth performance (weight gain, feed conversion ratio, survival) while an increment in inclusion above this level results in detrimental effects (Marinho et al., 2013; El-Tawil, 2010; Valente et al., 2006). This suggests that small quantities of seaweeds in fish diet are adequate to promote their growth.

Kamunde et al., (2019), evaluated the effect of supplementing the diet of Atlantic salmon with a brown seaweed meal (Laminaria sp.) on growth, antioxidant activity and resistance to temperature stress. The study showed enhanced growth and antioxidant activity while reducing the stress effect of acute temperature rise on mitochondrial respiration when the meal was included in the diet at 3% and 10%.

5. Feasibility and Sustainability of Using Seaweeds as Feed Ingredients

The highest volume of seaweeds produced globally is cultivated, contributing to about 97% of the global production, of which more than 90% is used in the hydrocolloid industries (FAO, 2020). A relatively small group of seaweed species are cultivated due to their commercial importance. Despite this loss of diversity in cultivation of seaweeds, the focus on aquaculture as the major source of seaweed creates the space to conserve the species in the wild (open waters) especially from dredgers that destroy the natural habitat of aquatic animals and plants (Buschmann et al., 2017). A promising strategy in sustainability of using seaweed as a feed ingredient is using the biorefinery approach, where waste from the hydrocolloid extraction can be redirected into production of feed additives (Wan et al., 2019). Multiple products such as functional additives, meal can be generated from the waste after hydrocolloid extraction. This could reduce the need to expand the cultivation of seaweeds as well as the cost of feed additives.

Another sustainable approach to meeting the demand for seaweed as a feed ingredient is the use of Integrated multi-Trophic Aquaculture concept (IMTA). IMTA systems are practiced in controlled environment where seaweeds are cultivated together or in proximity to aquatic animals such as fish at different trophic levels (Troell et al., 2009). This system allows for waste from aquaculture to be reduced while at the same time providing feed for the fish. In addition, the cultivation of seaweeds can be augmented (to meet the demand for feeds) without competing with food crops for land since most of the farming is carried out offshore using nets, floating lines or rafts (Radulovich et al., 2015).

Sustainable production of seaweeds has diversified the livelihoods of rural, poor, coastal communities (Largo et al., 2020). A study by Mirera et al. (2020) in the south coast of Kenya showed that seaweed farming has a high return in investment while contributing to development infrastructure and production of value-added products such as fish feed. The study also indicted that women participation as seaweed farmer was highest (75.2%) compared to men. This translated to empowering them in decision making in the family and community. Similar studies in Asia demonstrated that seaweed cultivation benefitted the local communities by improving the infrastructure (Beveridge et al., 2010). With proper management of seaweed farms, negative effects such as introduction of pathogens, invasive species in IMTA can be mitigated to cushion the environment and society (Skjermo et al., 2014).

6. Future Prospects and Conclusions

Seaweeds are an important marine resource gaining diverse use. The increase in global production over the decades is an indication that they have great potential for uses in diverse areas, undoubtedly aquaculture being among the core areas.

Seaweeds have a great potential for exploitation in aquaculture as a feed ingredient due to its unique nutritional profile. It is rich in protein, minerals and PUFA, in addition to other functional compounds like pigments and polysaccharides that are important for fish nutrition.

Use of seaweeds in aquaculture is an interesting prospect because, besides having nutritional benefits, it also helps improve growth performance in fish and boosted their immunity. When grown in an integrated multi-trophic aquaculture system, they can serve as both feed to the fish and help in cleaning the water by removing nutrients from the water.

With careful selection of seaweeds based on the target nutrient in the feed and understanding optimum conditions for production of the specific nutrients will help in achieving the desired results in the fish. Therefore, more research focused on strains and species of seaweed tailored for feeds as has been the case in hydrocolloid industry.

The high mineral content in seaweeds make them an excellent resource for the manufacture of natural mineral supplements for use in feeds. In addition, its natural pigments are a great alternative to artificial colorants in feeds.

Use of sea weed as source of feed in aquaculture is important in developing countries like Kenya, as it will free up important fish feed like soya, to be used for human food. Currently the feed industry takes up 80% of food crops in aquafeeds, therefore seaweeds can be a great replacer and reduce the competition.

In conclusion, with the growth in global seaweed production expected to continue to be on the rise, the uses and demand will also increase and aspects of sustainable production and use should be addressed. New production systems like the integrated multi-trophic aquaculture systems should be adapted.

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