



Microalgae as an alternative to fish meal: A Review

*Jyothi Kaparapu¹, Hemachandran Jeldi², Krishna Prasad³, Emely Sunethra Gotla⁴

¹Assistant Professor, Gitam deemed to be University, Visakhapatnam, India

²Faculty of Medicine, Dept. of Physiology, Jazan University, Jazan, K.S.A

³Professor, Dept. of Chemical Engineering, GMR Institute of Technology, Rajam, India

⁴Faculty of Science, Jazan University, Jazan, K.S.A

Corresponding author: jkaparap@gitam.edu.in

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Abstract

Aquaculture is the rapidly developing sector of food commerce, admittance to vital feed (fishmeal and fish oil) is becoming progressively inadequate due to the existence of limited resources for uninhabited fish collecting. This causes other bases of feed being examined, specifically plant-derived alternatives for fish feed and fish oil for aquafeed. Similarly, the cumulative manufacture of plant-based food leads to desertification and augmented freshwater usage. Henceforth, substitute and ecologically supportable bases of feedstuff constituents required to be advanced. Microalgae bio-masses signify possible forage basis components as the cell metabolites of these microorganisms comprise a mixture of vital amino acids, and healthy triglycerides as fat, vitamins, and pigments. Moreover, helping the majority constituent in aquafeed, their exceptional collection of bioactive composites can upsurge the survivability of cultivated species, progress pigmentation and superiority of fillet. Microalgae have the maximum spatial biomass production amongst photosynthetic organisms, together with food harvests, and thus has a high marketable probability. Correspondingly, microalgal manufacture has little water and an arable land footprint, causing microalgal-based feedstuff ecologically maintainable. Traditional terrestrial plant harvests have been recommended for some uses as alternatives for a share of the fish feed, nevertheless they might result in variations in the nutritious excellence of the fish formed. Microalgae can be stared as a hopeful substitute that can swap fish feed and fish oil and confirm survivability ethics in aquaculture. This review article will discover the possibility of manufacturing microalgae biomass as a constituent of aquaculture feedstuff.

Keywords: Aquaculture, Aquafeed, fish feed, fishmeal, Fish oil, Microalgae.

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Introduction

Universal microalgae demand is expected to spread US\$4.5 billion by 2021 and is projected to rise by 4.8% over the succeeding ten years (Globenewswire, 2021). Until now, the microalgae trade has focused primarily on food harvests and cosmetic-associated species such as *Spirulina* sp. and *Dunaliella salina*. Moreover, fish hatcheries practice species like *Isochrysis* sp., *Pavlova* sp., and other species as live feed for larvae, nevertheless these manufacturers are naturally diminutive. Yet, in current periods, microalgae are being examined as a probable bulk-food constituent for adult fishes and fingerlings (Hodar et al., 2020). Several

interpretations ensue for the estimation of microalgae as an optimistic alternative fish feedstuff. Microalgae's net biomass productivity is higher than any other global flora or fauna (Rizwan et al., 2018). Unlike terrestrial vegetation, there is no prerequisite for microalgae to cultivate in productive land-dwelling; additionally, microalgae can be cultured using marine water or polluted water (Li et al., 2019). Henceforth, there is no mandate on the prevailing strategies of terrestrial usage on farming and freshwater supply for extensive production of microalgae utilizing non-agricultural areas or polluted water. The feed supplements prerequisite for microalgae is quite modest in contrast to pests and microorganisms.



Microalgae might also be exploited for fish feedstuff manufacture in the biorefinery approach (Arunetal., 2020; Nagappan and Nakkeeran, 2020). This perception, for instance, might permit valued compounds such as pigments to be formed along with fish feedstuff. The prime purpose meant for the microalgae potential is that it possess an accurate balance of carbohydrates, protein and lipids, suitable to defend the fish vigour. Microalgae, in specific, are a good basis for lipid, protein related to other organisms like bacteria and yeast (Table 1). Microalgae constitute a rich amino acid outline, avoiding the necessity for expensive amino acid complements in the food. For example, the

Table:1. Nutritional content of alternate feedstuff

Feed ingredient	Protein (%)	Lipid (%)	Carbohydrate (%)	References
<i>Chlorella pyrenoidosa</i>	60	4	30	Souza et al.,2020
<i>Chlorella vulgaris</i>	56	20	15	Wan et al.,2019
<i>Dunaliella salina</i>	50–60	7	6–35	Nagappan et al., 2020
<i>Nannochloropsis granulata</i>	35	25	38	Nath et al.,2012
<i>Spirulina platensis</i>	57	15	24	Wan et al.,2019
<i>Scenedesmus obliquus</i>	57-60	14-20	13-55	Dallaire et al., 2007
<i>Haematococcus</i>	33	26	40	Wan et al.,2019
<i>Saccharomyces cerevisiae</i>	51	2	5	Walker and Berlinsky, 2011
Hydrolyzed feather meal	88	12	-	Dragone et al.,2011
Soybean meal	46	25	40	Yao at al.,2012
Wheat meal	13	3	70	Tibaldi et al.,2015
Brown macroalgae	3-17	1-10	40-64	Sharma et al.,2021
Green macroalgae	4–37	0.5–4	20–70	Prabha et al.,2020
Red macroalgae	7-39	0.5-14	40-70	Niccolai et al.,2019

Contrary to plants, the fibre of microalgae is devoid of lignin and comprises little hemicellulose signifying improved digestibleness (Niccolai et al., 2019). Microalgae species

microalgae *Nannochloropsis*, *Chlorella*, *Porphyridium*, *Chlamydomonas*, *Isochrysis*, and are rich in methionine, which is absent in plant-derived elements (Wan et al., 2019). Starch - an easily consumable carbohydrate of microalgae varies from 8% to 50% (Dragone et al., 2011). Species including *Tetraselmis subcordiformis*, *Chlorella vulgaris*, and *Chlamydomonas reinhardtii* fairly have a good amount of starch (29–52%) (Dragone et al., 2011; Yao et al., 2012). Fibre - a composite carbohydrate in microalgae varies from 7% to 20% (Matos et al., 2016).

Nannochloropsis, *Tetraselmis*, *Tisochrysis* and *Phaeodactylum* have higher fiber content, where as *Spirulina* sp. and *Chlorella vulgaris* have a minimum quantity of fibre of 9.0% and 6.0%



correspondingly (Niccolai et al., 2019). Furthermore, the nutrient constraint has been revealed to enhance the starch and fat content in microalgae (Chen et al., 2017; Nagappan et al., 2019a, 2019b). Microalgae are a rich source of pigments with antioxidant features, and few microalgae yield plentiful vitamins and immunostimulants in their cells, which can bestow to the wellbeing of aquatic classes (Prabha et al., 2020; Zhou et al., 2019). Astaxanthin a pigment of microalgae can impart striking colouration to the fish, enhancing their marketableness (Posten and Schaub, 2009). Microalgae are a rich source of organic minerals (Mustafa, 1995). This is attributed to the property of microalgae which permit them to fix metal with greater attraction and also because of their large surface-to-volume proportion (Kaparapu and Krishna, 2018). With minerals-rich microalgal biomass, the drawback of mineral discharge before fish absorption might be evaded. Some microalgae constitute omega-3 fatty acids such as eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), which promote healthiness in fish and also human beings (Ryckebosch et al., 2012). Undoubtedly, high omega-3 fatty acid concentrations of certain marine fishes, are derivative of algal nourishing. In an observation including several substitute feedstuffs, omega-3 fatty acid-rich microalgae were proved to be a suitable substitute for lipids in feed, as well as fish oil (Cottrell et al., 2020)

Effect of microalgae on fish growth and weight improvement

When aquatic species have nourished a food comprising 3–9% of microalgae, the weight was improved well than that of the controller. In observation, a 35% advanced weight improvement was attained in Atlantic salmon (*Salmo salar* L.) once nourished a food comprising 5% *Schizochytrium* sp. oil than with a food deficiency (Weiet al., 2021). Equally, a 34% advanced weight increase in post-larvae Pacific white shrimp (*Litopenaeus vannamei*) was attained with food comprising 0.8% *Tetraselmis suecica* related to a food missing it (Sharawy et al., 2020a). Related to further fish species, microalgae-founded foods produced more hopeful results for Tilapia. 72%, 60%, and 50% more weight improvements were attained in Nile tilapia (*Oreochromis niloticus*) when it was

nourished a food covering 20% *Chlorella* sp., 15% fat less *Nannochloropsis oculata* and *Schizochytrium* sp., and 12% *N. oculata*, correspondingly related to the controller foods. Similarly, weight expansions for Senegalese sole juveniles were suggestively greater (i.e., 84–97%) with a microalgae-rich food than with the controller food (Vizcaíno et al., 2018).

Though several issues could have bestowed varied changes in the weight improvement standards in diverse species, the optimistic outcome of microalgae's little and modest addition to the food is apparent, as revealed by several observations. The more microalgae quantity in fish feedstuff (mostly higher than 20%) might diminish the rate of development and fish weightiness. Research has exposed that the addition of *Arthospira* biomass in the fish mealtime, more than 35%, diminished the progress of silver seabream (*Rhabdosargus sarba*) (El-Sayed, 1994). Correspondingly, when an assorted culture with green microalgae and cyanobacteria substituted 20–25% of fish mealtime, rain bowtrouts exhibited a reduction in growth (Dallaire et al., 2007). Inflexible cell walls and gastrointestinal enzyme constraints might be the basis of the adverse growing outcome of microalgal food in more quantities. The precise level of microalgae feedstuff replacement fluctuates dependent on microalgal species, aquatic species, and tablet/pellet refining situations. Hence, for each amalgamation of nominated microalgae and fish, distinct observations must be agreed upon, in the meantime, many microalgae are yet to be tried on fishes, and additional revisions need to be directed in the hereafter.

Effect of microalgae on the feed conversion ratio and feed consumptions

The food conversion ratio (FCR) is proposed by the food measure changed into the selected yield. Indeed, fish require energy and nutrient-rich food as related to wildlife (Cottrell et al., 2020). Henceforth, the feed conversion ratio of fish related to animals is little. Nevertheless, the feed conversion ratio varies depending on the constituent of fish feed. The feed conversion ratio in marine species was not affected or even significantly condensed when nourished with a diet comprising a low and modest quantity of microalgae (3–9%). Almost 25% decrease in FCR



was attained with a diet comprising 0.5% *Tetraselmis suecica* related to the reference food in post-larval Pacific white shrimp (*Litopenaeus vannamei*) (Sharawy et al., 2020a). A 32% decrease in FCR was attained with a diet comprising 16% *Chlorella* sp. linked to the reference feed nourishment in Nile tilapia (*Oreochromis niloticus*) (Fadl et al., 2017a). Food consumption was proportionate to the number of microalgae in the food (Abdelghany et al., 2020; Gong et al., 2020; Yuetal.,2020). Usually, diets containing up to 15% microalgae resulted in comparable feed intake to control (Abdelghany et al., 2020; Gong et al., 2020; Walker and Berlinsky, 2011; Yu et al., 2020). These observations showed, that food consumption enhanced as the research advanced. Nevertheless greater algal amount (greater than 30%) recommended undernourishment in species like Atlantic cod, *Gadus morhua* (Walker and Berlinsky, 2011). In conclusion, the variety and quantity of microalgae have to be improved in the fish feedstuff so that designated fish species will have a little food conversion ratio and improved feed consumption.

Effect of microalgae on digestibleness

Measurable digestibleness assessments to find very consumable microalgae might lessen food charges, decrease feedstuff alteration relations, and decline the contrary ecological effects such as eutrophication (Moheimani et al., 2018; Niccolai et al., 2019). Pectin, alginan, cellulose and fibre etc., like non-starch polysaccharides present in microalgae are usually undigestible (Gong et al., 2018). The intractable cell wall of microalgae is an additional main feature that can damage nutritive palatability in monogastric animals such as fish and shrimp (Niccolai et al., 2019). The physiology of microalgal cell walls contrasts from one species to the other. For example, microalgae *Nannochloropsis gaditana* and *Desmodesmus* comprise cell walls more in non-starch polysaccharides alginan and pectin, correspondingly (Becker, 2007; Kaur et al., 2012; Scholz et al., 2014). Nevertheless, the cell wall of *Spirulina* sp. contains mucopeptides, and henceforth it can be effortlessly used up by fish (Becker, 2007; Bleakley and Hayes, 2017). The protein palatability is significant for microalgae-based feedstuff preparation.

The protein digestibleness of abundant cellulosic cell-walled microalgal species together with *Chlorella* sp., *Desmodesmus* sp., *Nannochloropsis* sp., and *Tetraselmis* sp. in aquatic species fluctuated 80–89%, 54–67%, 69–81%, and 70–73%, individually (Gong et al., 2018; Moheimani et al., 2018; Niccolai et al., 2019; Skrede et al., 2011). On the other side, non-cellulosic species like *Isochrysis* sp. and *Spirulina* sp. contain comparable advanced protein digestibleness of 86% (Niccolai et al., 2019; Skrede et al., 2011). The dry matter digestibleness also reproduced the similar tendency of greater standards for non-cellulosic microalgal species compared to thick-walled cellulosic species. Current observations with cultivated marine aquaculture species have revealed that nutritional supplement with numerous microalgae up to 25% is adequate based on abdominal histologic constraints, organ weightiness, sensory assessment, and gastrointestinal enzyme events (Patterson and Gatlin III, 2013; Tibaldi et al., 2015; Vizcaíno et al., 2018).

Cell interruption can intensify the nutrient palatability of microalgae. The level of cell distraction affects nutrient edibleness (Agboola et al., 2019). Implementing a suitable method to disturb the cell wall makes it probable to progress microalgae's nutritious availability and digestibleness by fish (Batista et al., 2020b). In an observation, freeze-drying, pasteurization, cold pasteurization, melting, and bead milling were cast-off to disrupt the cell wall of *Nannochloropsis gaditana* biomass, and then the treated biomass was exploited as a feedstuff component for African catfish and Nile tilapia (Agboola et al., 2019). The fish mass increase and feedstuff alteration relation for cold pasteurization and bead milling nourishments enhanced by 13% and 11%, correspondingly, as related to the control nourishment. Foods comprising enzymatically treated *Nannochloropsis oceanica* and materially treated *Chlorella vulgaris* and *Tetraselmis* sp. had advanced protein and energy digestibleness related to non-treated control (Batista et al., 2020b). Although the enzyme Bromelain enhanced the digestibleness of *Spirulina*-based fish food in Mozambique tilapia fingerlings (*Oreochromis mossambicus*), another two enzymes (i.e., papain and trypsin) were proved to be less effective (Sharma et al., 2021). The



extrusion procedure could interrupt algae cell walls, permitting fishes to digest extra nutrients (Maehre et al., 2016; Venou et al., 2009).

In an investigation concerning the nourishing of *Nannochloropsis* sp. biomass to Atlantic salmon, *S. salar*, extrusion-managed food was revealed to be extra palatable than non-extrusion processed feedstuff in terms of ash and dry matter (Gong et al., 2018). In another observation concerning gibel carp, the extruded feeds exhibited more advanced protein and dry matter digestibleness than the pelleted feeds (Shi et al., 2016). Because of differences in consuming

methods and gastral structures among several fish species, the nutritious profits of a microbial gain in one aimed animal species do not usually assure similar in others. For instance, shrimp do not have an acidic abdomen, and trout have a lengthier gut transit period which may cause meagre digestibleness of composite arrangements of algal nutrients (Tibbetts et al., 2017). As a consequence, a detailed microalgae savoriness investigation is essential. If physical/mechanical and enzymatic cell interruption of microalgae are exploited to enhance microalgal digestibleness, it would likewise be technologically ascendable (Table:2)

Table: 2. Applications of microalgae biomass as feed for aquaculture

Microalgae species	Aquaculture species	% replacement of fishmeal/fish oil/dietary inclusion level	Effect of microalgae biomass	References
<i>Arthrospira platensis</i>	Red tilapia (<i>Oreochromis</i> sp.).	30% inclusion in feed as carotenoid supplement	Improved fish colour	Defoirdt et al.,2007
<i>Nannochloropsis gaditana</i> , <i>Tetraselmis chuii</i> , and <i>Phaeodactylum tricornutum</i>	Gilthead seabream (<i>Sparus aurata</i>)	0.5 and 1% inclusion in feed	Enhanced defence activity	Dallaire et al.,2007
<i>Arthrospira</i> sp.	Golden barb (<i>Puntius gelius</i>)	20% replacement of fishmeal in diet	Significantly increased growth rates of fish	Bianchi et al.,2015
<i>Arthrospira maxima</i>	Red tilapia fingerling (<i>Oreochromis</i> sp.).	Up to 30% replacement of fish meal	No negative impact on growth performance	Cao et al.,2018
<i>A. platensis</i>	Ornamental carp (<i>C. carpio</i>)	7.5% inclusion in feed as carotenoid supplement	Improved pigmentation	Cerezuela et al.,2012
<i>Navicula</i> sp. <i>Nannochloropsis salina</i>	Juvenile Red drum (<i>Sciaenops ocellatus</i>)	Replacement of up to 10% of fishmeal	No adverse effect was found on the growth performance.	Fadl et al.,2017
<i>Dunaliella</i> sp.	Shrimp (<i>L. vannamei</i>)	1-2% inclusion of microalgal meal as carotenoid supplement	The survival rate of shrimp increased	Ferreira et al.,2019

<i>Isochrysis sp.</i>	European sea bass (D. labrax L.)	Up to 36% replacement of fish oil	No adverse effect, feed intake or growth performance relative to controls	Dragone et al.,2011
<i>Schizochytrium sp.</i>	Atlantic salmon (S. salar)	Up to 5% replacement of fish oil	No signs of toxicity, stress, inflammation, fillet quality is good.	Cerezuela et al., 2012
<i>Pavlova viridis</i>	European sea bass (D. labrax)	50–100% replacement of fish oil in diets	No negative effects on the growth	Gong et al.,2020
<i>Chlorella vulgaris</i>	Giant freshwater prawn (<i>Macrobrachium rosenbergii</i>)	6–8% replacement of fish meal	Increased specific growth rate, enhanced immune response (total haemocyte count and prophenol oxidase activity) in fish	Hodar et al.,2020

Microalgae-based diet and fish vigor

Outcome of microalgae-based food on the practicality

Numerous investigations have revealed that the sustainability of fish might be upgraded by nourishing microalgae-comprising food. The addition of microalgae, together with *Pavlova sp.*, *Chaetoceros sp.*, *Nannochloropsis oculata*, and *Isochrysis sp.*, in feedstuff, the seahorses (*Hippocampus reidi*) and oysters (*Pinctada margaritifera*), improved their sustainability (Martínez-Fernández and Southgate, 2007; Melo et al., 2016). The persistence degree of *L. vannamei* shrimp amplified when 1–2% of its food was enriched with *Dunaliella salina* (Medina-Félix et al., 2014). The improvement of fish sustainability by microalgae-based foods might similarly be connected with their useful features, as well as the properties of probiotics, prebiotics, immunostimulants, antiviral, antibacterial, etc.

Microalgae as probiotic

Probiotics are any micro-organisms or composites of micro-organisms that benefit expand colonic healthiness after ingestion. Microalgae are acknowledged to have probiotic properties in fish. When a fish eats algal cells, the micro-environment of the intestine assimilates the algal cell, liberating probiotic constituents that hinder pathogens (Austin, 2006; Ghanbari et al., 2015; Nayak, 2010). In observation, the *Tetraselmis suecica* live cells were nourished by white shrimp (*Litopenaeus indicus*), and the

number of pathogenic bacteria in its intestine was condensed when related to control (Regunathan and Wesley, 2004). The addition of a 1.3% *Schizochytrium sp.* feed to the nourishment predisposed the intestinal microbiota, ensuing in enhanced Nile tilapia healthiness (Souza et al., 2020). The addition of freeze-dried microencapsulated *Chaetoceros sp.* in the water maintained the development of valuable bacteria in the intestinal tract of Pacific white shrimp (*Litopenaeus vannamei*) (Nimrat et al., 2011)

Microalgae as prebiotic

Prebiotics, similar to probiotics is valuable to fish well-being as these also progress intestinal vigour. Contrary to probiotics, prebiotics mostly denotes to the impenetrable cell wall polysaccharides/fibres that can aggravate the development of useful bacteria such as Bifidobacteria, Lactobacilli, etc. of the intestine (Dawood et al., 2018; Wangetal., 2017a). However, the oligosaccharide, fibre, and polysaccharide, from microalgae, such as beta-glucan from *C. vulgaris* and homogalactan from *Gyrodinium sp.*, are regularly conveyed, and their prebiotic outcome in fishes are yet to be examined systematically (Hemaiswaryaetal.,2011). Dineshbabu et al., 2019 and Hemaiswarya et al., 2011 studied that, the entire biomass of *Spirulina platensis* and *Isochrysis galbana* were revealed to encourage the development of useful bacteria in vitro and in vivo studies. At present, algae-based



corporations like Algotech are commercially marketing beta-glucan – a prebiotic composite from microalgae, *Euglena* sp., Prebiotics and probiotics, have perceived sturdy progress in the marketplace after the prohibition of antibiotics in animal fodder in numerous countries (Defoirdt et al., 2007). In this context, the probiotic properties can be supplemented as a marketing theme for microalgae-based fish feedstuff.

Immunostimulants

Nourishing of cell wall components like lipo- polysaccharides, glucans, chitin, peptidoglycans, fucoidan, and whole algae can improve the natural defences in aquatic species (Dawood et al., 2018). The cell-wall polysaccharides have been revealed to surge immune status by growing cytokine, phagocytosis, and propagation of immune cells, together with neutrophils and monocyte-macrophages in aquatic species (Dawood et al., 2018). Paramylon, a β -1,3 polymer of glucose (beta-glucan) present in the cell wall of *Euglena* sp., has been proven to perform as an immunestimulant in species such as Atlantic salmon, red drum, and matrinxa (Bianchi et al., 2015; Kiron et al., 2016; Montoya et al., 2017; Yamamoto et al., 2018). Post-larvae of *Macrobrachium rosenbergii* exhibited enhanced immune status (total haemocyte count and prophenol oxidase activity), and sustainability against *Aeromonas hydrophila* infection, when 5–7% of fish feed was swapped with *Chlorella vulgaris* (Maliwat et al., 2017). Gilthead seabream (*S. aurata*) showed an enhanced immune mechanism when orally fed with *Tetraselmis chuii*, *Nanno- chloropsis gaditana*, and *P. tricornutum* (Cerezuela et al., 2012).

When Rohu fish (*Labeorohita*) was fed with *Euglena viridis* biomass, it exhibited immunostimulatory properties, for example, pathogen lysozyme, amplified serum bactericidal properties, and superoxide anion release in counter to *A. Hydrophila* (Das et al., 2009). *Dunaliella salina* augmented the existence rate of *P. monodon* infested by white spot syndrome by enhancing the antioxidant factors like catalase and superoxide dismutase in shrimp (Madhumathi and Rengasamy, 2011). A nourishment comprising a combination of *Lactobacillus sakei* and *Navicula* sp. amended the humoral immune response of the pacific red snapper (*Lutjanus peru*) (Reyes-Becerril et al.,

2013). Food comprising microalgae *P. incisa* enlarged the existence capacity by growing lysozyme levels in Guppy fish (*Poecilia reticulata*) (Nathet al., 2012). Spirulina has been shown to raise non-specific immune reactions against infectious agents in numerous species (Cao et al., 2018; Sheikh-zadeh et al., 2019). The total protein count, white blood cell count, red blood cell count, albumin levels, haemo- globin improved when a 10% *A. Platensis* was nourished by rainbow trout (*O. mykiss*) (Yeganeh et al., 2015). Pathogens that affect fish persistence and progress could be repressed by microalgal immunostimulant properties, making algae-based feed added worth.

Effect of microalgae on the worth of fish

Firmness and palatability

Fillet firmness is an important characteristic for consumer reception of farmed fish, and soft fillets are undervalued by the food trade. Gaping arises as connective tissue flanked by muscle layers tears, ensuing in slits gaps in the fillet and loss of inflexibility. Microalgae have been revealed to lessen such gaping in the fillet. A 5% *Schizochytrium* sp. diet enhanced fillet quality in Atlantic salmon by dropping gaping when related to control nourishment (Kousoulaki et al., 2016). The fish feedstuff comprising 5% Spirulina enhanced the consistency and taste of Striped jack (*Pseudocaranx dentex*) in another observation (Watanabe, 1990). Fish feedstuff comprising 3% Spirulina, augmented the firmness, fibrousness and of Nile Tilapia (*Oreochromis niloticus*) (Mustafa, 1995). Salmon filets formed from *Schizochytrium limacinum* were noticed to have a similar palate and odour as filets formed from conservative fish oil (Katerinaetal., 2020). PUFA levels along with organic minerals such as selenium, glutamate and vitamin E have been revealed to significantly diminish gaping (Tavakoli et al., 2021). Microalgae can gather high levels of vitamins, including Vit E (Madeira et al., 2017). Micro- algae have a mineral alignment fluctuating from 2.2% to 4.8% of total dry weight (Guedes et al., 2015). Iron, copper, calcium, potassium, sodium, sulfur, phosphorous, magnesium and zinc are all rich in microalgae (Dineshbabu et al., 2019). Guedes et al., 2015, observed the addition of mineral-rich microalgae to salmon nourishments surges the fish's quality and taste.

Healthy fat

Microalgae hold relatively high lipid content than other species (20–60%) (Ferreira et al., 2019; Madeira et al., 2017; Nagappan et al., 2020). Polyunsaturated fatty acids (PUFAs) are one of the lipid classes of microalgae with a high nutritional value. The optimistic assets of PUFAs on human well-being are familiar (Katiyar and Arora, 2020). Microalgae possess high contents of eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) which are nutritionally significant PUFAs. The fish AND oils microalgae that comprise these lipids are extremely marketed since long-chain PUFAs are hard to be manufactured theatrically. In general, vegetable oils from canola, palm, and soybean seeds may contain these oils in little amounts (Hashempour-Baltork et al., 2016). Microalgae rich in PUFA include Schizochytrium and Cryptocodinium, (which contain DHA), Isochrysis, Phaeodactylum, Nannochloropsis, Diacronema and Nitzschia, (which produce EPA), Porphyridium, (which produce arachidonic acid) and Desmodesmus sp. (which produce alpha-linolenic acid) (Lu et al., 2021; Nagappan and Verma, 2018). Correspondingly, species like Aurantiochytrium sp., Thalassiosira sp., Monodus sp., Thraustochytrium sp., Isochrysis sp., Pavlova sp. and Phaeodactylum sp. comprise a weighty quantity of PUFA ranges from as low as 2.2% to high as 37% (Lu et al., 2021; Ferreira et al., 2019). Commercially salmon is fed with thraustochytrid Schizochytrium sp. one of the rich sources of PUFAs, especially omega-3 fatty acids, are solely for PUFA (Leyland et al., 2017; Ren et al., 2010). Thraustochytrids were also cast off to improve zooplankton and nourished finfish larvae (Barclay and Zeller, 1996).

Microalgae as a colouring agent

Clienteles practice colour as one of their priorities when selecting seafood. Fish colouration is known to be enhanced by microalgal biomasses. The current microalgae used precisely for fish pigmentation is *Haematococcus pluvialis* which is abundant in astaxanthin. Whole-cell *H. pluvialis* and isolated astaxanthin are employed as feed essences (1.5% in range) in the aquaculture trade (Chen et al., 2017). Similarly, lutein pigment from *Chlorella* and *Scenedesmus* species is employed as a feed additive mostly for red/yellow colour (Dawood et al., 2018). The colouration of many species for

instance striped jack, Koi, Black tiger prawn, Red tilapia and yellow catfish was upgraded by *Spirulina* sp. (Ansarifard et al., 2018; Dineshbabu et al., 2019; Liu et al., 2021; Nur-E-Borhan, 1993). When the Yellow catfish (*Pelteobagrus fulvidraco*) fed with 0.5% *Spirulina*-lipid-ex-tract and 5% defatted-*Spirulina*, showed suggestively improved skin colour than those fed with a control diet (Liu et al., 2021). Sun et al., 2012 studied, the pigmentation of Showa koi was observed to be revised by adding the diet with 7.5% *Spirulina platensis*. When gilthead seabream was fed with a diet containing 2.5% *Phaeodactylum tricornutum*, a diatom having high fucoxanthin content, it was exposed to give a bright yellow colouration (Ribeiro et al., 2017). Customer preference for natural products can permit algal pigments to enter the market.

Challenges and future of algae in aquafeed:

For microalgae to turn out to be a fruitful substitute for fish mealtime, it has to overawed a sum of complications.

Analogous to various substitute feedstuffs, the microalgae based fish feedstuff has a little tastiness, then this can be enhanced by shifting the surface of the feedstuff and the addition of attractants and stimulants that fish's chemosensory structures admit. Microalgae *Chlorella* sp., *Nannochloropsis* sp., etc., have little digestibleness because of the existence of non-carbohydrate materials and firm cell walls. In the instance of firm cell walls, automatic approaches can be used to disrupt them, enhancing savoriness and revealing nutrients to the fish. Nevertheless, any pre-treatment practices for the cell disruption would sustain extra charges for the fish feedstuff manufacture. Cautious species collection and assessment of growth in several situations is essential to decrease the manufacture cost. An in-house examination of collected biomass for lethal complexes and toxic microalgae can overcome the problem of toxic microalgae. The addition of suitable additives throughout biomass dispensation, the use of proper drying methods and the use of cold pelletization can avoid the deprivation of algal pigments and other nutrients. Biorefinery techniques, the use of waste flue gas from industries, and heterotrophic growing systems based chiefly on biological carbon bases are some of the methods to dropping manufacturing expenses, and active study is mandatory to

address the issues of solving high-cost microalgal cultivation techniques. More investigation is required to demonstrate that microalgae can have probiotic, prebiotic, and upsurge fish survivability by diminishing infective bacteria weight.

Conclusion Aquaculture harvests and aquafeed are in advanced demand round the globe. Conventional fish feedstuff containing fish meal and soybean meal as wholesale constituent, still, does not encounter demand and unsustainability. Fish feed made from microalgae has a lot of potential to swap fish meal and soybean meal. It has features such as a quicker growth rate and the capability to raise and yield high-valued foodstuffs without the usage of agricultural land and domestic water. Besides helping as a source of carbohydrates, protein, and lipids, microalgae comprise an amount of useful complexes. This contains events such as prebiotics, probiotics, and immune confrontation. Microalgae can be cast-off in aquaculture in numerous customs, together with algal paste, extruded pellets, and poly aquaculture. The high cost of manufacture is one of the most important difficulties with microalgae. The choice of microalgal strains with chosen cellular alignment and lesser manufacture cost as feedstuff might encounter a substantial demand for fish feedstuff in the forthcoming.

Production systems, harvesting, and processing technologies are yet to be optimized at large scales. In the future, innovative manufacturing in feed combined with novel upstream and downstream processing technologies for microalgae biomass production can effectively replace fish meals and provide a sustainable solution.

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