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Dietary Effects of Microalgae as a Replacement of Fish Oil in Fish: A Review

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Abstract:- In aquaculture, feed costs contribute for between 50 and 70 percent of overall production costs. Given the world's rapidly expanding aquaculture production, fish oils (FO) obtained from finite wildcatch fisheries will not be able to supply the rising demand for aquafeeds. To decrease reliance on global capture fisheries, it is essential to seek out sustainable alternatives for FO. Microalgal feed stuffs could become one of the aquaculture industry's most promising and sustainable alternatives. Algal meal 8.77% was determined to be the optimum diet for dramatically changing the lipid profile of tilapia fillets at week eight. In one study, the substitution of fish oil with algal flour and vegetable oil resulted in an increase in the weight and nutritional value (n-3 PUFA and LC-PUFA) of shrimp muscle. The combination of algal meal and vegetable oil might replace 75% of the fish oil in shrimp diets. These data indicate that up to 100 percent of FO can be replaced with S.limacinum meals, hence enhancing the growth of T. macdonaldi while maintaining the nutritional value and health advantages of the fillet. This is the first report of increased feed utilization indices, weight gain, and beneficial fatty acid profiles in Nile tilapia when fish oil is completely substituted by 16% of dried whole-cells of a marine microalga species, Schizochytriumsp (Sc). All of these data demonstrate the viability of using microalgae as a fish feed ingredient in place of fish oil to improve the growth and immunity of fish.

Keywords:- *Aquaculture, Microalgae, fish oil, growth performance, immunity*

I. INTRODUCTION

Aquaculture is one of the fastest-growing animal food-producing industries, having grown by an average of 8.8% per year over the past 12 years (Yoshimatsu et al.,2014). In intensive and semi-intensive aquaculture systems, fish feed typically accounts for 60-70 percent of operational costs (Singh et al.,2000). Aquaculture has been expanding globally at an average rate of 8–10% per year over the past few decades (Tacon et al., 2011). Aquaculture's contribution to global fisheries production for human consumption rose from nine to forty-seven percent between 1980 and 2010, and its use of artificial feeds rose from fifty to sixty-six percent of production (FAO, 2012). Analysts anticipate that aquaculture will produce an additional 23 million tonnes of aquatic foods by 2030 in order to maintain the current per capita consumption of aquatic foods for the world's growing population (FAO, 2012). In 2016, global fish production was approximately 171 million tons, with aquaculture accounting for 47% of the total (FAO, 2018). The total first sale value of fisheries and aquaculture production in 2016 was estimated to be USD 362 billion, with USD 232 billion attributable to aquaculture production (FAO, 2018). Bangladesh is an agro-based riverine nation endowed with tremendous fisheries resources and ranks fifth among the world's aquaculture fish-producing nations (DoF, 2019). According to DoF (2018), it contributes 3.61 percent to our national GDP and 25.30 percent to the agricultural GDP. Bangladesh is now one of the world's leading producers of fish, with a total output of 42.77 million metric tons (MT) (DoF, 2018). Government is attempting to maintain this growth rate in order to reach the 45.52 lakh MT production target by 2020-21. Aquaculture is a rapidly expanding industry in our country, with enormous potential to cultivate more fish in the near future. Due to the depletion of marine fish stocks for the production of fish oil (FAO, 2012), alternative lipid sources are required for the production of fish feed in order to meet the growing aquaculture industry's demand (Tacon et al., 2008).It is a highly digestible energy source and a valuable source of essential fatty acids, particularly n-3 highly unsaturated fatty acids (n-3 HUFA), including docosahexaenoic acid (DHA, 22:6n-3) and eicosapentaenoic acid (EPA, 20:5n-3) (Turchini et al., 2009). Lipids are one of the most significant nutrients given

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to fish aquafeeds because they are so important in supplying the essential fatty acids fish need for growth, reproduction, and health as well as satisfying their energy needs (Tocher et al., 2003). These fatty acids are highly valued for their health advantages in cardiovascular and neurological illnesses, neural development, and inflammation prevention in humans (Swanson et al., 2012). The dependence on FO to create aquafeeds is a restrictive factor because of issues with sustainability, the environment, and the economy (Tocher et al., 2019).

Fig. 1: Omega-3 enriched fish oil

To achieve a sustainable aquaculture, it is necessary to introduce alternative protein sources, such as cheaper proteins of plant or animal origin, for stable aqua feed production (Higgs et al., 1995). Several algal species have been utilized in aquaculture primarily for nutritional purposes. Algae are a diverse group of aquatic, photosynthetic organisms that are primarily classified as macroalgae (e.g., seaweed) or microalgae (unicellular). In tropical and subtropical regions where algae production is high, algae can be a good alternative protein source for farmed fish (El-Hindawy et al., 2006). Microalgae can grow in a wide variety of habitats, have several times higher biomass production than plants, can divide quickly with simple nutritional requirements, can accumulate useful metabolites, and their availability is not dependent on the capture of wild fish for fishmeal (Hemaiswarya et al., 2011). With encouraging results, the use of microalgae as fish feed ingredients has been investigated. Microalgae are a diverse group of photosynthetic heterotrophic organisms containing essential amino acids, protein, minerals, vitamins, chlorophylls, and various antioxidants and bioactive compounds (Kwak et al., 2012). They are required for the nutrition of larvae during the life cycle of many commercially valuable fish. Size, shape, digestibility, and biochemical compositions determine the nutritional value of microalgae (Brown et al., 1997). On the other hand, they are used not only as basic nutrients and immune stimulants, but also as a source of pigments for coloring the skinA large number of well-designed feeding trials are still necessary to evaluate the potential of microalgae as a replacement for fish oil in order to gain a comprehensive understanding of how microalgae can be used in fish feeds (Shah et al., 2018). Nonetheless, it appears that microalgae will play a significant role in the effort to make aqua-feed formulation more sustainable in the future.

This paper provides a comprehensive review of the potential of microalgal feed as a substitute for fish oil.

Fig. 2: Formulated Micro algal fish feed

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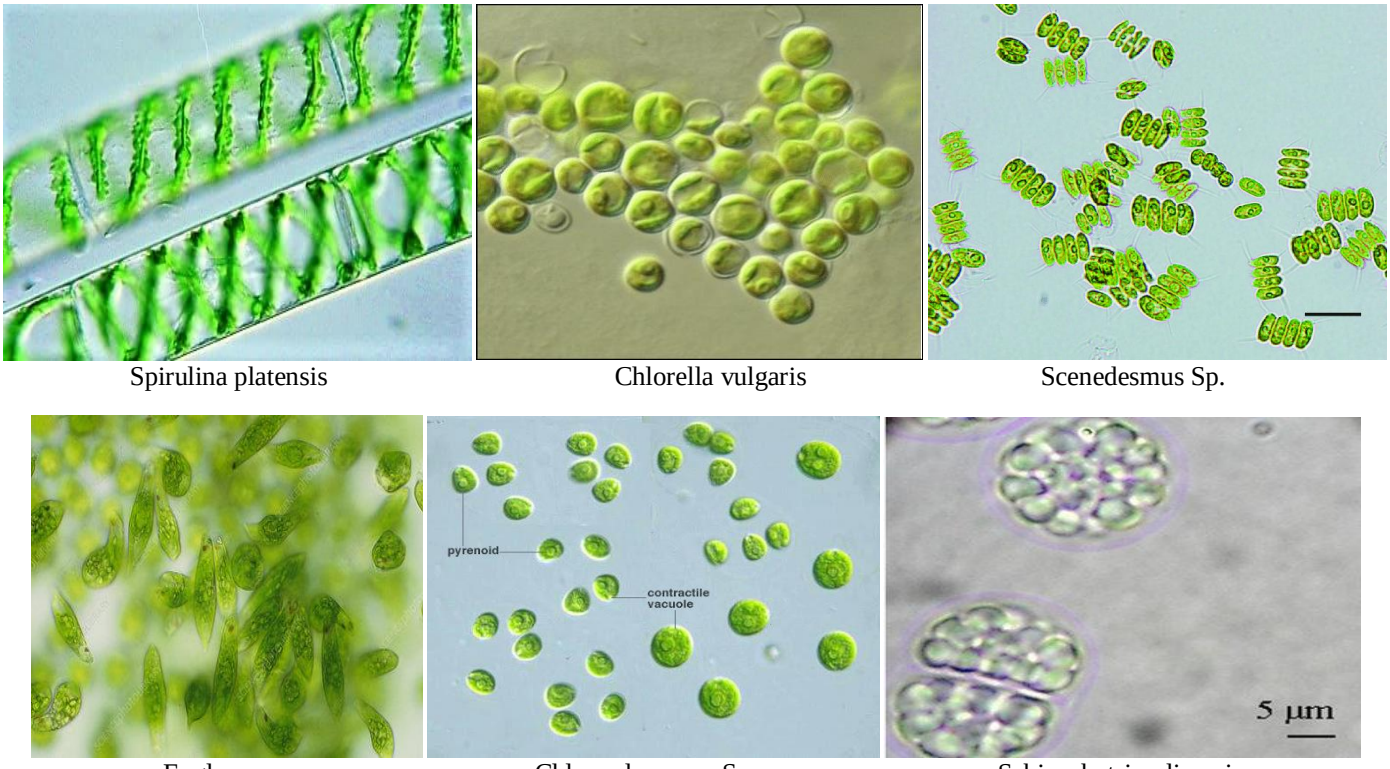
II. MICROALGAE

Microalgae or microphytes are minute algae that live in the water column and sediment and are commonly found in freshwater and marine settings (Thurman et al., 1997). A varied group of unicellular organisms, including eukaryotic protists, prokaryotic cyanobacteria, and blue-green algae, are together referred to as microalgae (Day et al., 1999). Microalgae are a varied category of photosynthetic eukaryotes that come in unicellular and multicellular forms and have a straightforward cellular structure. Light, carbon dioxide, water, and nutrients (with phosphorus and nitrogen as the two most important nutrients) are all necessary for their growth. These needs can be converted by microalgae into energy through photosynthetic means, which they can then employ for cell growth. Lipids, proteins, and different types of carbohydrates are kept in the algal cell and are the main chemical or nutritional components of microalgae. Everywhere that sunlight may penetrate, including soils, ice, lakes, rivers, hot springs, and oceans, the microalgae can be found in large numbers. Microalgae grow 5–10 times as quickly than terrestrial food crops. Microalgae are an undiscovered resource with more than 25,000 species, of which only 15 are used, according to recent claims (Raja et al., 2010). The minor components of microalgae are pigments like phycobiliproteins, chlorophylls, and carotenoids, which can be used in industries like pharmaceuticals, food, and cosmetics. Lipid productivity of microalgae can be 15–300 times higher than in common oil crops, and lipid accumulation of microalgae can be more than 50% under nutrient exhaustion (Choo et al.,2017).



Spirulina platensis | Chlorella vulgaris | Scenedesmus Sp.

Euglena sp. | Chlamydomonas Sp. | Schizochytriumlimacinum

Fig. 3:Microscopic view of some common microalgae.(Source: Wikipedia)

III. MICROALGAE AS A USEFUL NUTRIENT SOURCE

Microalgae are widely utilized to raise aquatic creatures including mollusks, shrimp, and fish at various growth stages and play a significant role in the aquatic food chain (Borowitzka,1998). A number of microalgae with high protein, carbohydrate, and lipid content are regarded as crucial feed ingredients. According to Renaud et al. (1994), diatoms have more protein than other chlorophycean species. Due to their 40–70% protein levels, Spirulina, Scenedesmus, and Chlorella were regarded as sources of single cell protein (Venkataraman et al., 1985). The entire algal biomass's indigestibility is significantly influenced by carbohydrates (Percival and Turvey1974). Algae contain starch, cellulose, sugars, and other polysaccharides among their sources of carbohydrates. Typically, algal lipids are made of glycerol, sugars, or bases that are esterified to form fatty acids with carbon numbers between C12 and C22 that can be saturated or unsaturated. Triglycerides are the most prevalent storage lipids and can make up to 80% of cyanobacteria's total lipid composition (Tornabene et al.1983). In blue green algae, monogalactosyldiglyceride, digalactosyldiglyceride, and sulfoquinovosyldiglyceride are the main cellular lipids (Nichols et al., 1970). Scenedesmus obliquus has a comprehensive lipid profile, according to Choi et al. (1987), with neutral lipid, glycolipid, and phospholipid fractions at levels of 7.24, 2.45, and 1.48% on a dry weight basis, respectively, and a total lipid content of 11.7%.

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Algae	Protein (%)	Lipid (%)	Carbohydrate (%)
Scenedesmus sp.	50-56	10-52	12-14
Chlamydomonas sp.	43–56	2.9-17	14-22
Prymnesium sp.	28–45	25–33	22–38
Spirulina platensis	50–65	8-14	4-9
Chlorella sp.	51-58	12-17	14-22
Euglena sp.	39-61	14-18	14-20
Anabaena sp.	48-50	25-30	4-7
Pavlova sp.	24-29	6-9	9-14
Spirulina maxima	60-71	13-16	6-7
Spirogyra sp.	6-20	33-64	11-21
Porphyridiumcruentum	28-39	9-14	40-57
Dunaliella sp.	49-57	4-32	6-8
Tetraselmis	52	15	16-45

Table 1: Protein, carbohydrate and lipid contents of some major microalgae

(Source: Roy *et al*., 2009)

IV. APPLICATION OF MICROALGAL FEED IN AQUACULTURE

It is commonly recognized that adding microalgae to larval fish culture tanks has many advantages, including preventing bumping into tank walls, increasing zooplankton predation, enhancing zooplankton nutritional value, and promoting digestive and immunological functions in larvae. It has been found that some fish larvae considerably benefit from eating microalgae directly (Reitan et al., 1997). According to one study, feeding microalgae coupled with a specially designed micro particle diet could help Red Drum (Sciaenops ocellatus) larvae consume less live zooplankton (Lazo et al., 2000). The optimum way to employ algae in fish feeds should probably be discovered by focusing on larval meals.

Algae	Fish	Reference
*Nannochloropsisoculata,Tetraselmistetrahele*and *Skeletonemacostatum*	Rotifers and shrimp larvae	Lim *et al*., (1991)
Spirulina, Haematococcus	Shrimp, salmon	Broun et al., (1980)
Tetraselmis, Isocrysis, Chlorella	Rotifers and shrimp larvae	Villegas *et al*., (1990)
Hydrodictyon, Scenedesmus Spirulina, Haematococcus	Tilapia, Red Sea Bream	Appler*et al.*, (1985)

Table 2: List of a few microalgae used in fish aquaculture

V. POTENTIALITY OF MICROALGAE AS A REPLACEMENT OF FISH OIL AND EFFECT ON THEGROWTH PERFORMANCE AND IMMUNITY RESPONSE OF DIFFERENT FISHES

Various studies have been conducted to find out the effect of microalgae as a fish feed ingredient for better growth rate and immunity of fish.

VI. EFFECT OF MICROALGAE AS A REPLACEMENT OF FISH OIL ON GROWTH PERFORMANCES AND SURVIVABILITY

A 84-day feeding experiment with dried whole cells of DHA-enriched microalga Schizochytrium sp. (Sc) to find the optimal level of fish oil substitution (partial or complete) for maximal growth of Nile tilapia. When fish oil was totally replaced by Sc (Sc100 diet), weight growth (g) and protein efficiency ratio (PER) were much higher, but feed conversion ratio (FCR) and feed intake were significantly reduced (improved) (Sc0 diet). At the conclusion of the experiment, the Tilapia appeared healthy and showed no difference in SGR or survival rate across all diets. The range of weight gain was between 23.8 and 27.3 g. Dietary consumption varied between 23.6 and 27.0 g per fish. All dietary regimens had feed conversion ratios (FCR) between 0.9 and 1.1 and protein efficiency ratios (PER) between 2.4 and 3.1.

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	Sc0	**Sc25**	**Sc50**	**Sc75**	**Sc100**
Initial weight(g)	1.4±0.1	1.42±0.1	1.7±0.2	1.5±0.1	1.6±0.1
Final weight(g)	25.3±0.3bc	26.4±0.4bc	27.2±0.7ab	27.4±0.3ab	28.8±0.2a
Weight gain(g)	23.8±0.4bc	24.9±0.3bc	25.5±0.7ab	25.8±0.2ab	27.3±0.2a
FCR	1.1±0.0bc	1.0±0.0bc	1.0±0.1ab	0.9±0.0ab	0.9±0.0a
SGR	3.4±0.1	3.5±0.1	3.3±0.0	3.4±0.1	3.5±0.1
PER	2.4±0.1bc	2.6±0.1bc	2.7±0.2ab	2.8±0.1ab	3.1±0.1a
Feed intake (g/fish)	27.0±0.3a	25.9±0.4ab	25.1±0.6bc	24.9±0.2bc	23.6±0.2c
%Survival rate	92.7±0.37	95.2±1.5	95.8±0.8	92.3±0.2	96.3±2.6

Table 3: Initial weight, final weight, weight gain, percentage weight gain, feed conversion ratio (FCR), specific growth rate (SGR), protein efficiency ratio (PER), feed intake, and survival rate of tilapia fed experimental diets

Source: Sarker*et al*., (2016)

Weight gain (g) =final wet weight–initial wet weight
FCR, feed conversion ratio = feed intake/ weight gain
Specific growth rate SGR (%/day) = 100 x (ln final wet weight (g)–ln initial wet weight (g)) / Time (days)
PER, protein efficiency ratio = weight gain (g)/protein fed (g)%Survival = (Final number of fish / Initial number of fish) x 100.

Fish fed a FO diet of either northern (NFO) or southern hemisphere (SFO) origin were compared to fish fed a diet of DHA-rich *Schizochytrium* sp. algal meal (AM) at two inclusion levels (11% and 5.5% of diet) in an experiment done by Sprague et al. (2015). Fish fed the 11% AM food grew at a somewhat slower rate than fish fed the 5.5 AM diet and both fish oil treatments. Also, both treatments fed on algae had food conversion ratios (FCR) that were equivalent to SFO but much greater than fish fed on NFO. One cause might have to do with digestion, especially given the larger presence of algal meal. Up to 6% of microalgae inclusion resulted in high 327digestibility, but 12% of microalgae inclusion caused a reduction in digestibility, though appetite remained unaffected.

	NFO	SFO	11% AM	5.5% AM
Initial mass(g)	1544	1527	1543	1522
Final mass(g)	3245	3220	3030	3170
Weight gain(g)	1701	1692	1487	1648
SGR (% bw.day-1)	0.59	0.59	0.53	0.58
Total feed consumption(kg)	251.2	258.7	254.5	248.9
FCR	1.28	1.35	1.42	1.40

Table 4: Growth performance of Atlantic salmon fed experimental diets for 19 weeks. Means (%RSD) bearing identical superscripts are not significantly different 637(P>0.05)

Source: Sprague *et al.,* (2015)

NFO: FO diet of northern, SFO: FO diet of southern, AM: Algal meal DHA- and EPA-rich microalgae Schizochytrium sp. and Nannochloropsis sp. were used in an experiment by Qiao et al. (2014) to replace dietary fish oil in olive flounder (Paralichthysolivaceus). Three experimental diets, each with a lipid supply made up of 50% fish oil (F50S50), 50% (M50 F25 S25), and 100% raw microalgae (M100), were compared with a diet that contained 100% soybean oil (S100) (Table 5). The greatest results were obtained with a fish diet containing a combination of M50 F25 S25 for weight gain (WG), specific growth rate (SGR), feed conversion ratio (FCR), and daily feed intake (DFI).

	Diet			
	S100(control)	F50 S50	M50 F25 S25	M100
Initial mass(g)	15.3	16.5±0.43	17.0±0.9	16.5±1.26
Final mass (g)	35.2	36.0±2.66	40.8±4.37	36.5±3.49
WG (%)	129.1	117.9±17.0	139.8±13.5	121.5±8.4
SGR	1.4	1.3±0.13	1.5±0.09	1.3±0.06
DFI	1.3	1.3±0.02	1.2±0.12	1.4±0.08
FCR	0.9	1.0±0.09	0.9±0.14	1.1±0.08

Table 5.Growth performance of oliveflounder fed experimental diets for 56 days with soybean oil(S100), fish oil(F50S50), 50 (M50F25S25) and 100% microalgae raw material(M100)

Source: Qiaoet al., (2014)

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WG: Weight Gain, SGR: Specific Growth Rate, DFI: Daily Feed Intake, FCR: Feed Conversion Ratio In a 2017 study, Wang et al. investigated the effects of substituting Schizochytrium meal for dietary fish oil on Pacific white shrimp Litopenaeusvannamei) larvae. Schizochytrium meal was used to replace 0 g/kg, 250 g/kg, 500 g/kg, 750 g/kg, 1000 g/kg, or 1500 g/kg of fish oil DHA in six test micro meals (Figure 4). This study shown that Schizochytrium meal may replace fish oil DHA at a rate of 1500 g/Kg in the diet without impairing shrimp growth. The best results were seen for final body weight (FBW) and final body length (FBL) (FBL).

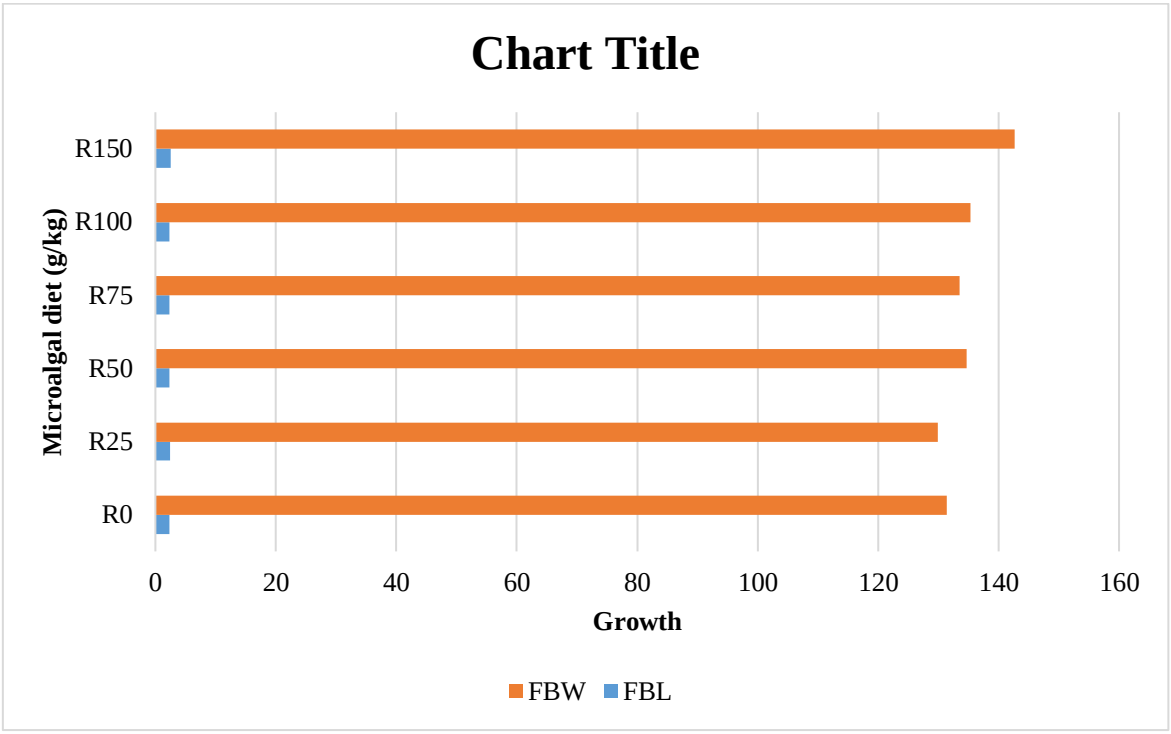

Fig. 4: Observed Final Body Weight(FBW) and Final Body Length(FBL) of shrimp (*Litopenaeusvannamei*) with the replacement of Microalgal diet. (Source: Wang*et al*., (2017)

According to Eryalçınet al., (2015) four experimental micro diets with different sources of EPA and DHA were prepared a control diet (Control) based on fish oil, a diet containing11% *Nannochloropsisgaditana* (diet N), a diet containing 8% *Crypthecodiniumcohnii*(diet C), a diet containing equal amounts of 5.5 % *Nannochloropsisgaditana* and *Crypthecodiniumcohnii* (diet N+C). 8%*Crypthecodiniumcohnii* (diet C) showed Significant survival rate showed by diet C than the others diet.

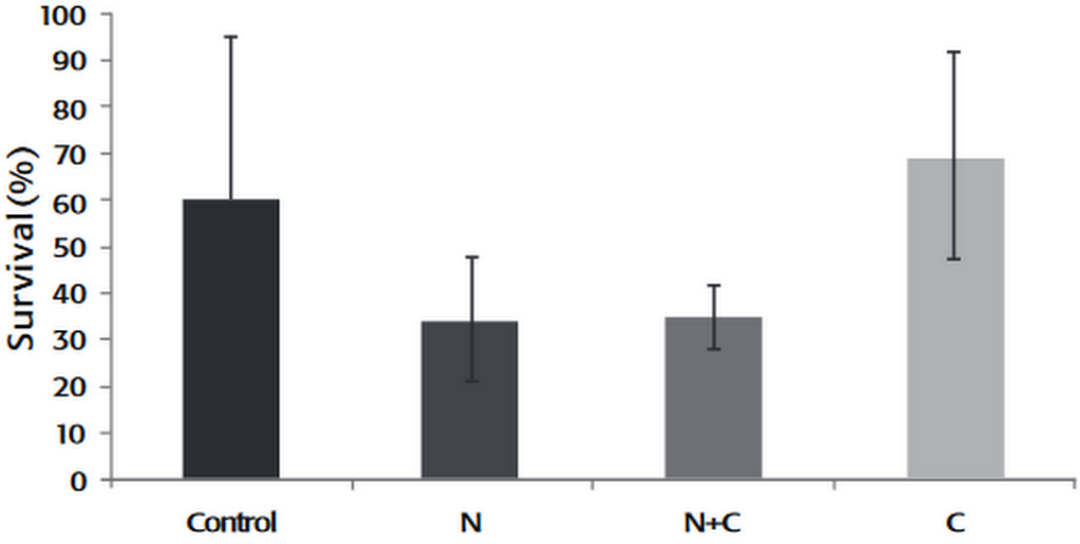

Fig. 5: Survival of gilthead sea bream larvae fed with different experimental diets after 17 days.

(Source: Eryalçın*et al.*, 2015)

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VII. EFFECT OF MICROALGAE AS A REPLACEMENT OF FISH OIL ON FATTY ACIDS COMPOSITION AND BLOOD CHEMISTRY

The composition of dietary fatty acids (FA) has a pronounced influence on the FA profile of fish tissues (Tanet et al., 2009). (Table 6). In a second study, decreasing quantities of C18:1n-9, C18:2n-6, and C18:3n-3 were found in the muscle and liver of fish as the fish oil and soybean oil content of their diets decreased. In addition, replacing fish oil with Microalgae Raw Material (MRM) increased C22:5n-6 content and the n-3/n-6 ratio, although DHA, EPA, and n-3 PUFA were not significantly reduced. When M100 was swapped for DHA, the DHA level in the liver significantly increased. Our research revealed that the n-3 PUFA in MRM were digested and absorbed. Full replacement of fish oil with MRM can not only preserve the EPA and DHA content of fish muscle, but also increase the n-3/n-6 ratio, both of which are beneficial to human health. This study reveals that MRM can be substituted for fish oil in the meals of olive flounder for 56 days without impairing the performance or lipid metabolism of the fish.

	S100	F50 S50	M50 F25 S25	M100
C14:0	5.4	4.7±0.04	8.9±0.92	8.1±0.42
C16:0	47.4	38.0±1.40	49.3±3.87	45.7±3.30
C18:0	11.3	8.5±0.35	12.3±2.41	11.6±1.36
C22:1n-11	0.5	0.8±0.04	0.9±0.06	0.9±0.07
C22:5n-6	0.8	4.2±0.84	16.3±0.79	17.8±1.86
C22:5n-3	3.1	12.8±1.25	13.1±0.79	13.4±1.10
EPA	3.8	13.2±1.76	12.3±1.43	13.9±1.14
DHA	6.4	45.7±4.17	54.9±2.82	59.2±4.89
PUFA	35.2	92.8±8.65	97.4±6.42	102.3±8.48
n-3/n-6	0.3	1.1±0.03	2.2±0.09	2.3±0.11
DHA/EPA	1.7	3.3±0.13	4.5±0.35	4.6±0.31

Table 6: Fatty acid composition (g/kg dry weight) of liver ofjuvenile*Paralichthysolivaceus*at the end of the experimental period

Source: Qiao*et al.*, (2014)

Qiao et al. (2014) investigated the impact of microalgal diets on the blood chemistry of olive flounder (Paralichthysolivaceus) fish (Figure 5). It was demonstrated that n-3 PUFA inhibited TG accumulation (Kimet et al., 2006), specifically limited fat depot hypertrophy (Belzunget et al., 1993), and therefore downregulated adipocyte differentiation and decreased fat production (Kimet et al., 2006; Belzunget et al., 1993). (Kimet et al., 2006; Belzunget et al., 1993). (Okunoet et al.1997). The triglyceride (TG), cholesterol (CHO), and high-density lipoprotein cholesterol (HDL-CHO) concentrations of S100 fish were considerably higher or lower than those of fish fed other diets. S100 fish exhibited the highest TG concentration among those fed the four diets, yet the lowest CHO and HDL-CHO values. In addition, a low concentration of HDL-CHO was observed in the plasma of S100 fish, indicating that replacing fish oil with soy oil has an effect on lipid deposition and metabolism. The graph demonstrates that replacing a fish's meal with microalgae reduces plasma levels of cholesterol and triglycerides and, sssubsequently, fat formation.

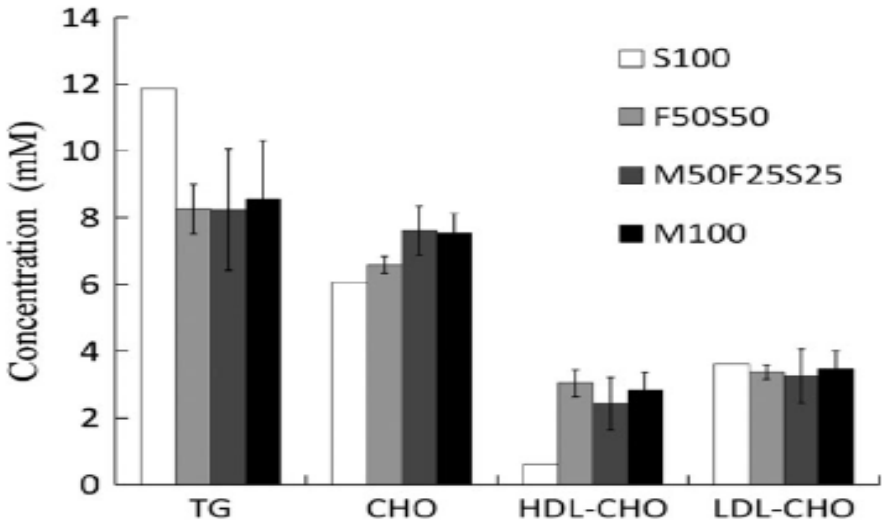

Fig. 6: The concentrations of some plasma constituents of juvenile olive flounder fed the different experimental diets for 8 weeks. (TG, triglyceride; CHO, cholesterol; HDL-CHO, high-density lipoprotein cholesterol; LDL-CHO, low-density lipoprotein cholesterol).Source: Qiao*et al.*, (2014)

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Kumar et al. (2018) conducted a 12-week experiment to investigate the replacement of fish oil (FO) and vegetable oils in the diets of Pacific white shrimp (Litopenaeusvannamei) (VO: linseed oil [L] and soybean oil [S]). Five experimental diets such as control (50g/kg FO), FO-AM0 (80g/kg FO), FVO-AM1 (40 g/kg FO+20 g/kg VO + 28.8 g/kg AM), FVO-AM2 (20 g/kg FO +20 g/kg VO + 58.7 g/kg AM) and VO-AM3 (0FO + 20 g/kg VO + 88.5 g/kg AM). In the case of the FVO-AMO 1 diet, significant levels of albumin, globulin, total protein, and glucose were observed.

	Control	FO-AM0	FVO-AM 1	FVO-AM 2	VO-AM 3
Albumin	11.0 ± 0.0	12.7 ± 2.5	13.3 ± 2.5	9.7 ± 2.1	10.7 ± 4.6
Globulin	79.3 ± 11.7	97.0 ± 22.2	88.3 ± 19.9	77.3 ± 31.5	77.7 ± 22.9
Total protein	90.0 ± 11.1	73.5 ± 24.6	101.7 ± 22.2	87.0 ± 33.5	88.3 ± 27.5
Glucose	543.3 ± 77.7	730.0 ± 235.0	773.3 ± 299.4	560.0 ± 262.1	583.3 ± 193.0

Table 7: Haemolymph biochemical parameters (mg/L) of Pacific white shrimp (*Litopenaeusvannamei)* fed the experimental diets for 12 weeks.

Source: Kumar *et al.*, (2018)

Stoneham et al. (2018) observed a study in which tilapia was cultivated on experimental meals containing varying concentrations of n-3 fatty acids. The experimental diets consisted of a control (cornoil, 6.3%), FO1%, FO3%, FO5%, AM1.75%, AM5.26%, and AM8.73%. In this study, the optimal diet for enhancing the fatty acid profile was AM8.77%, which led to more DHA and Omega-3 accumulation in fish fillet.

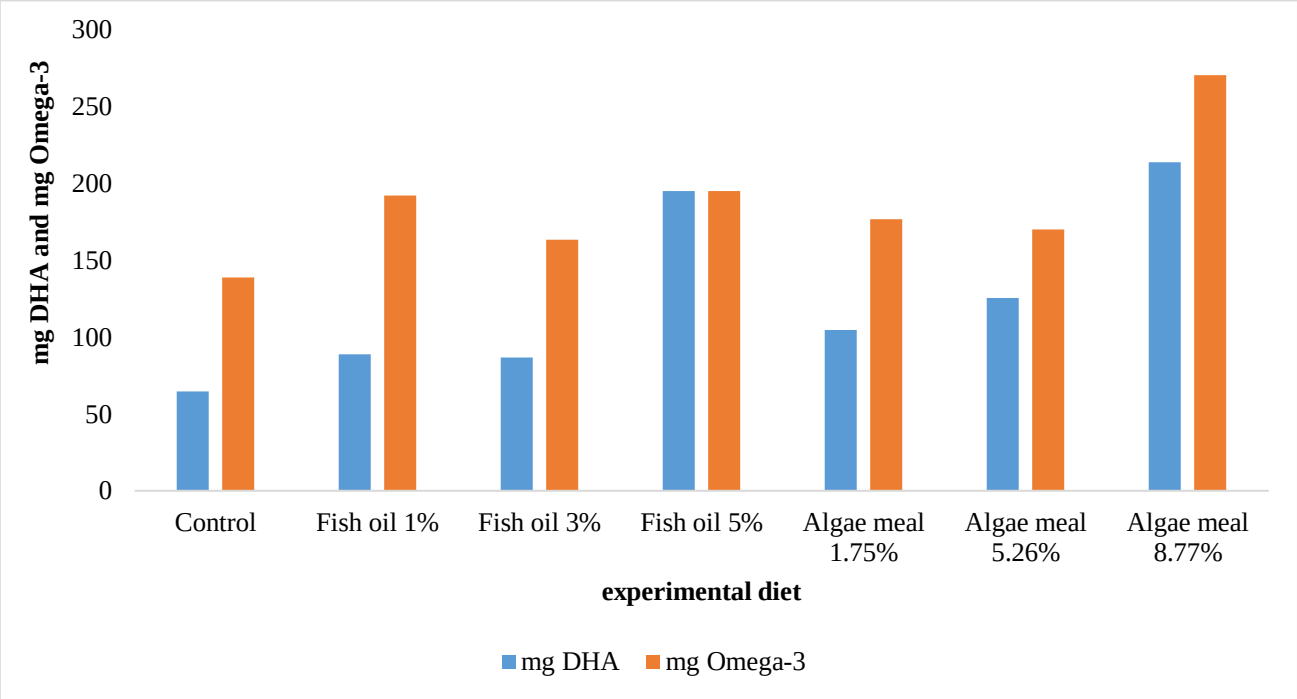

Fig. 7: Nutritional fatty acid profiles of mg DHA and mg Omega-3 in tilapia fillet. Source: Stoneham *et al.*, (2018)

VIII. CONCLUSIONS

Microalgae play an important part in the aquatic food chain and are widely employed in the rearing of aquatic creatures such as mollusks, shrimps, and fishes at various stages of development. Due to their chemical makeup, they can be utilized to improve the nutritional value and immunity of fish feed, and hence serve a key role in aquaculture. Algae collection, drying, and pelletization require substantial time and effort, though. Costs associated with cultivation would need to be taken into account. Before definitive conclusions can be formed on the future use of algae as fish feed, it is necessary to conduct additional farm-based cost-benefit analyses that account for these expenses. Algae as dietary additives contribute to an increase in the growth and immunity of cultured fish due to the efficient assimilation of dietary protein, enhancements in physiological activity, stress response, starvation tolerance, disease resistance, and carcass quality, as demonstrated by numerous research studies. In general, when algal meal was employed as a partial replacement for fish oil, moderate growth responses and improved immunological responses were observed. Algae can only meet 10-15% of the protein requirements in test diets without impairing development and immunity. In addition, this microalgal diet reduces mortality during the larvae's most vulnerable periods and improves their survival.

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