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Algal oil: A sustainable alternative of essential fatty acid (EFA) for aquafeed

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Introduction

Aquaculture is the fastest growing food producing sector in the world, providing critical sources of income and nutrition for millions of small-scale fish farmers and their communities. In recent decades, aquaculture has undergone a significant global expansion, with an average annual growth rate of 8-10% (Sarker et al., 2016). Access to sustainable and affordable fish feeds is a key determinant for productive and profitable aquaculture. Fishes or any animals require a balanced diet with essential nutrients for optimal growth which varies by several determinants like species, sex, age, environment and developmental stages. Nutritionally balanced aqua feed plays a crucial role for growth of aquatic organism and survivability (Manam, 2023).

Selection of appropriate feed ingredients are essential for developing nutritionally balanced feed which promotes well-being of the targeted organism. Fish oil and fish meal are two of the most demanded ingredient used for aquaculture. Production of fish meal and fish oil is around 2.443 mmt and 1.738 mmt respectively (IFFO, 2023) among which around 40% of fish meal and 75% of fish oil are utilized in aquaculture sector (Nasopoulou et al., 2012). Demand of these ingredients create a huge pressure on environment which forces the industry to identify alternative sources of ingredients which are sustainable. Plant-based proteins, insect-based meals, microbial proteins, and synthetic amino acids are important ingredients in terms of sustainable resources. These ingredients reduce reliance on marine resources and aquaculture carbon footprint, supporting optimal growth, immune function, and reproductive health. Essential amino acids (EAAs) and essential fatty acids (EFAs) are crucial components in aquafeeds, supporting growth, health, and performance in aquatic species (Sawicka et al., 2020).

EAAs are the building blocks of proteins that fish cannot synthesize internally, therefore their inclusion in aquafeeds is crucial for the success of aquaculture operations (Jia et al., 2022). EAAs are essential for protein synthesis, enzyme and hormone production, immune function, reproductive health, metabolic processes, cell development, stress resistance, and improving skin, scales, and mucosal health of fish. Key EFAs include omega-3 and omega-6 fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA). The interaction between amino acids and fatty acids is critical for balanced nutrition in aquaculture, ensuring that EAAs are not diverted from growth to metabolic functions. Deficiencies in either EAAs or EFAs can lead to impaired growth, poor reproductive performance, and increased susceptibility to diseases. Therefore, aquafeed formulations must ensure the right balance and quantity of these essential nutrients (Glencross, 2009; Sawicka et al., 2020)

Alternative protein sources like plant proteins and insect meal are being used to reduce fishmeal reliance, while algal oil and plant oils are being explored as sustainable sources of omega-3 fatty acids. This article has covered an overview of essential fatty acids and essential amino acids as sustainable aquafeed ingredients (Sawicka et al., 2020).

Essential Fatty Acid its types

Essential Fatty Acids (EFAs) are found in plant oils, algae and marine aquatic sources. Eicosapentaenoic Acid (EPA), Docosahexaenoic Acid (DHA), and Linoleic Acid (LA) are found in plant oils, nuts, seeds, and fish. DHA is essential for brain and eye development, while LA is found in vegetable oils. EFAs are essential for overall growth and development. Essential fatty acids (EFAs) are essential lipids for human health, which cannot be synthesized by the body. They are primarily found in the diet and are essential for brain function, inflammation reduction, heart health, skin and eye health. The two main types of EFAs are: (a) Omega-3 fatty acids, found in plants like flaxseed, chia seeds, and walnuts, are crucial for brain function and heart health. (b) Omega-6 fatty acids, found in vegetable oils and animal products, are essential for immune function, brain health, and cell growth. However, an imbalance with omega-3s can promote inflammation (Sardesai, 1992).

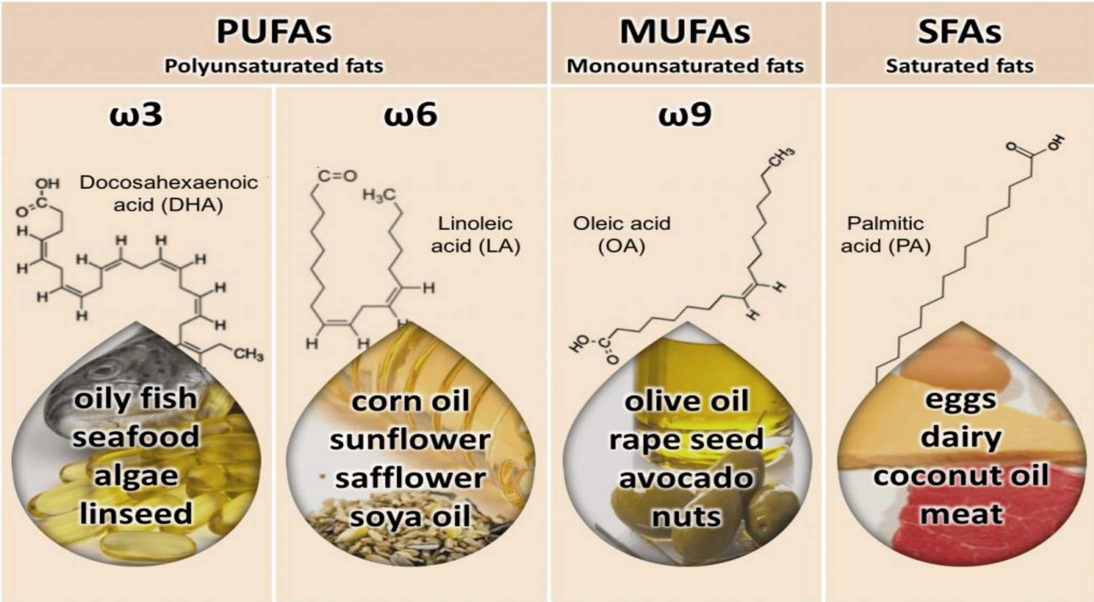

Figure 1. Common sources of EFA (Watson, 2023)

3. Importance of EFA in aquaculture

There is various use of EFA in aquaculture as fish cannot synthesize it. The physiological benefits of algal oil are mentioned below.

3.1. Growth and Development: EFAs, especially EPA and DHA, are crucial for aquatic animal growth and development, supporting cell membrane integrity, muscle development, body composition, weight gain, and feed efficiency.

3.2. Reproductive Health: EFAs are crucial for reproductive processes, ensuring proper gamete production, fertility, and egg hatchability, and deficiency can lead to poor reproductive performance and lower offspring survival rates.

3.3. Immune Function: Omega-3 and omega-6 fatty acids regulate immune responses and inflammation, improving disease resistance in fish and shrimp, reducing mortality from infections and stressors like poor water quality.

3.4. Stress Tolerance: EFAs, particularly DHA, enhance resilience to environmental stressors like temperature fluctuations and handling, thereby ensuring stability under stress conditions.

3.5. Energy Source: EFAs are a crucial energy source in aquafeeds, providing a concentrated form of calories for fish and shrimp metabolic demands, thereby optimizing feed conversion ratios and promoting sustainable production.

3.6. Sustainable aquaculture: EFAs are essential for human consumption in species like salmon, tilapia, and shrimp, improving flesh quality and health benefits. They are crucial for larval development, regulating fat metabolism and deposition, and preventing fatty liver syndrome. Alternative sources like microalgae and plant-based oils are being explored for aquaculture sustainability, ensuring long-term viability of operations (Marques et al., 2023; Kaur et al., 2014).

4. Algae as a source of EFA

In addition to being a great source of oil, algae are being studied and used more and more in the manufacturing of biofuels, dietary supplements, and other industrial uses. Algae are two types micro algae and macro algae for sources of lipids, as described in table 1. The composition of Essential Fatty Acids in most common algae are discussed in table 2.

Table 1. Common algae as a source of lipid

Types of algae most common sources for lipid (Gupta and Gupta, 2020; Ahluwalia and Khosa, 2003; El-Beltagi et al., 2022)	
Micro algae	**Macro algae**
a. Green algae: *Chlorella sp., Dunaliella sp., Nannochloropsis sp., Spirogyra sp., Oedogonium sp., Botryococcus braunii etc.* b. Diatoms: *Nitzschia sp., Thalassiosira sp., Phaeodactylum sp., etc.* c. Golden Algae: *Prymnesium sp., etc.* d. Blue green algae: *Spirulina sp., etc.*	a. Red algae: *Porphyra sp., Gracilaria sp.* etc. b. Brown Algae: *Kelp sp., Sargassum sp. etc.* c. Green Algae: *Ulva sp., Codium sp., Rhizoclonium sp., Azolla sp.*, etc.

Table 2. The composition of EFA in most common algae (Huerliman et al., 2010; Jiang and Gao, 2004; Zhila et al., 2010; Santigosa et al., 2020)

Fatty acids	***Nannochloropsis salina***	***Phaeodactylum tricornutum***	***Botryococcus braunii***	***Schizochytrium sp.***
C16:0 (palmitic acid)	37.5%	25.8%	21.0%	29.6%
C18:0 (stearic acid)	0.9%	1.3%	2.9%	2.2%
C18:1 (oleic acid)	11.9%	—	3.2%	—
C18:2 (linoleic acid)	1.5%	5.1%	13.6%	0.01%
C18:3 (Alfa linolenic acid)	—	2.0%	33.0%	0.05 %
C20:4 n6 (arachidonic acid)	3.3%	1.6%	—	1.9%
C20:5 n3 (eicosapentaenoic acid)	15.3%	13.1%	—	15.7%
C22:6 n3 (docosahexaenoic acid)	—	—	—	39.8%

5. Types of lipids extracted from algae

Algae can be an excellent source of lipids. There are various types of lipids that can be extracted from algae which are highly usable in aqua-nutrition industry. Various types of algal lipids are classified in the figure 2.

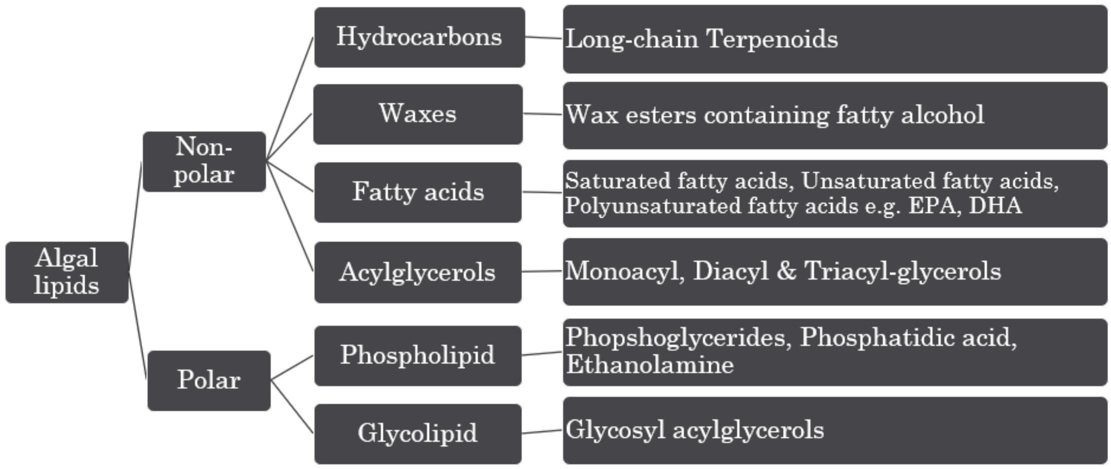

Figure 2. various types of lipids extracted from algae (Kumar et al., 2015)

6. Common extraction methods:

The extraction of algal oil is a complex and costly method. The algae can be extracted by several means but considering the quality and recovery of EFA, few methods can be used. The methods are explained in table 3.

Table 3. Commonly used methods of algal oil extraction and recovery of oil from the algae

Extraction method	Organism	Recovered oil (%)	Fatty acid (% in recovered oil)	References
Solvent extraction	*Porphyridium cruentum*	59.5	Eicosapentaenoic – 79.5 Arachidonic acid – 73.2	(Guerrero et al., 2000)

Supercritical fluid extraction (SC-CO2)	*Nannochloropsis sp.* *Arthrospira maxima,* *Spirulina platensis*	25 40 77.9	Eicosapentaenoic – 32.1 Palmitic acid – 17.8 Gamma-linolenic acid– 13.0 Gamma-linolenic acid – 20.2	(Andrich, 2005) (Mendes, 2006) (Andrich, 2006)
Ultrasonic assisted extraction	*Crypthecodinium cohnii*	25.9	Docosahexaenoic – 39.3 Palmitic acid – 37.9	(Cravotto et al., 2008)
Mechanical cell disruption	*Chlorella protothecoides*	18.8	-	(Shen et al. 2009)

7. Commercial brands dealing with aquafeed supplemented with algal oil:

Understanding the importance of algal oil and its sustainability, several enterprises-initiated standardising of algal oil in aquafeed. Details of the brands are mentioned in table 4.

Table 4. Various commercial algal oil and its use in aqua industry

Veramaris	AlgaPrime DHA	Almega PL
i). *Schizochytrium sp.* is used to extract the oil. ii). 1 ton of Veramaris can eliminate the requirement of 60-ton wild-caught fish. iii). Use of Veramaris can also eliminate the contaminants like dioxins, polychlorinated biphenyl, microplastics etc.	i). *Schizochytrium sp.* is used to extract the oil. ii). It provides 13g of mono- unsaturated fat. iii). 100% replacement of fish oil with AlgaPrime DHA improves 8 times growth in salmonids. iv). Inclusion in feed provides improved organ	i). *Nannochloropsis oculata* is used to extract the oil. ii). It contains 25% of EPA. The product is enriched with the Compounds like carotenoids, omega 7, co-enzyme q10 and chlorophyll which provides additional health benefits. iii). Trail on marine fishes are ongoing.

iv). 6% inclusion in salmonids and 3.5% inclusion in Gilthead seabream provided suitable result.	health, growth, robust skin intestines and gills structure, better anti-inflammatory response, better resistance to handling stress.	

8. Properties, Benefits and possibilities of algal oil

Due to global and sustainable food demands (Bartek et al., 2021; Kaur et al., 2014):

- Global demand for seafood is increasing, necessitating healthy feed supply.
- Healthy farmed fish and shrimp require Omega-3 essential fatty acids and algal oil can be a sustainable source of Omega-3.
- Higher EPA & DHA levels improve productivity, performance, health, and welfare.
- Algal oil strengthens supply chain against supply volatility and quality variations.
- Aquaculture farmers can provide healthier, sustainable seafood products to consumers.
- Microalgae-based omega-3 sources provide consistent EPA and DHA quality, unlike fish oil, which can vary based on species and season, ensuring a steady nutritional profile in aquafeed.
- Algae grown in controlled environments, produce omega-3s free from contaminants like heavy metals and persistent organic pollutants, reducing the risk of contamination in fish oil.
- 3% reduction of greenhouse gas emission and 27% reduction carbon footprint can be gained within a year using algal oils.

9. Current status of algal oil in Aquafeed:

Algal oil is beneficial for the aquaculture sector, as it offers sustainable ingredients with nutritional value. The oil, extracted from marine algae, high contains fatty acids like EPA and DHA, which improve the survival, growth rate, reproduction, stress, immunity, and flesh quality of aquatic organisms. Current status and inclusion levels of algal oil in aquafeed is mentioned in table 5.

Table 5. Current status of algal oil in Aquafeed

Sl. No.	Fish species	Veramaris inclusion levels	Results in comparison with fish oil	References
1.	*Dicentrarchus labrax*	3.3% and 4.4%	The results showed not significant different between growth and feed performance somatic, indexes or whole-body composition.	Marques et al., 2023
2.	*Sparus aurata*	2.3%, 2.5%, 2.6% and 2.9%	The results support the use of novel dietary formulations and genetic selection in improving sea bream fillet quality in terms of texture and sensorial perception of consumers.	Carvalho et al., 2024
3.	*Salmo salar*	1.2% and 2.3%	The results showed not significant different in growth performance or smoltification-related parameters.	Farris et al., 2024
4.	*Lates calcarifer*	25% replaced with 75% Fish oil	The results supported Substituting Fish oil with Algal Oil and Vegetables Oil significantly affected Viscerosomatic Index, Intraperitoneal fat, carcass lipids, and lipid retention efficiency.	Rahman et al., 2024
5.	*Salmo salar*	1.2% and 2.3%	The results showed dietary of algal oil improved Intestinal, skin, and gill structures, enhancing mucosal barrier function and increasing mucous cell density. Immunolabelling revealed	Islam et al., 2024

			downregulation of HSP70 and upregulation of mucosal defense genes.	
6.	*Sparus aurata*	0.7% and 3.5%	These studied found of sustains growth while maintaining nutritional value, with highest EPA+DHA content and 3.5%, Algal Oil feeds resulting in highest fatty acid deposition, lower dioxins, polychlorinated biphenyls, and good sensory quality.	Santigosa et al., 2021
7.	*Sparus aurata*	2.5%, 2.6% and 2.9%	The results have supported the better on utilizing developing ingredients in aquafeeds, indicating a higher plasticity of digestive enzymes to adapt to dietary changes, potentially improving ingredient digestibility.	Montero *et. al.*, 2023
8.	*Oncorhynchus mykiss*	1%	The trial showed better growth performance in higher in protein (NoPAP) group diet and sensory analysis revealed higher acceptance for fish the NoPAP diet compared with Processed animal protein (PAP) diet.	Vale et al., 2023
9.	*Salmo salar*	4.5%	The experiment results have supported that fish fed plant-based feed without Krill Meal (KM) were lighter, but those with KM had comparable growth and feed intake. Krill Meal addition improved feed intake and growth performance.	Barrows et al., 2023

10	*Dicentrarchus labrax*	2.75%	The study found a significant effect of diet on fish survival after two weeks of high dose and ten weeks of low dose. GALT-associated gene expression analysis showed an interaction between genotype and diet for il-1β in the distal gut. However, the relative abundance of certain taxa varied between experimental groups.	Rimoldi et al., 2023

Conclusion

Aquaculture is advancing as a fastest growing sector in agriculture as the demand for protein is rising with burgeoning population. Being a profitable venture, access to sustainable and affordable fish feed is a key determinant for productive and profitable aquaculture. All living organisms require a balanced diet enriched with critical nutrients where ingredients play a crucial role. Though fish oil is a cheap source of EFA, commonly used in aquafeed but it is having larger impact on environment and fish biodiversity. So, exploration to alternative sources like algal oil should be the major focus of aquaculture industry. Scientific interventions may be instrumental for solving few challenges related to algal oil i.e. high cost, expensive extraction methodology, qualitative value of extracted oil and preservation methods which may open a new era of sustainable ingredient usage for aquafeed.