Utilization of Fish Waste and By-Products for Fish Meal Production as a Potential Feed Ingredient, Fish Waste to Valuable Products: Recent Applications and Research Update

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Abstract Fishmeal is an important component in animal feeds for a variety of reasons. They serve as a primary protein source for animal feeds. In addition to acting as a strong attractant in feed, it is nutrient-dense and provides a highly digestible source of amino acids and essential omega-3 fatty acids. Fishmeal remains one of the most nutritionally balanced components for aquafeed, piglet, and pet diets, despite fast ingredient innovation around the world. Protein is required in all types of animal feed, and the quality of protein distinguishes one ingredient from another. Essential amino acids must be provided in the meal to promote growth. Plant-based concentrates and meals may be high in protein, but they lack some critical amino acids like lysine, methionine, and cysteine, which are abundant in fishmeal. The excellent fatty acid profile of fishmeal is another reason for utilizing fishmeal as a feed ingredient. When raw fish is processed into fishmeal, the majority of the fish oil is removed, leaving between 6 and 10% fat by weight in the meal. This percentage supplies important polyunsaturated fatty acids, particularly vital omega-3 fatty acids (EPA and DHA). Fishmeal output, which is crucial to the animal feed industry, has remained relatively steady year over year, while demand continues to increase rapidly. The amount of ocean-caught fish meal has dropped, while the amount of fishmeal

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S. Maqsood et al. (eds.), *Fish Waste to Valuable Products*, Sustainable Materials and Technology, https://doi.org/10.1007/978-981-99-8593-7_13

made from processing wastes, filet trims, and offal has increased. Around 30% of the fishmeal produced globally is made from trimmings that have been up-cycled into sustainable fishmeal, contributing to 51% of all fishmeal produced globally. To meet up the demand for fish meals for the feed industry, efficient utilization of fish wastes, bycatch, and processing wastes for fish meal production via energy-efficient technologies are needed.

Keywords Fish waste · Fish meal · Aquafeed · Poultry feed · Animal feed · Wet rendering · Dry rendering · Waste utilization · Fish by-products

1 Introduction

Nutritionists perceive fishmeal as a superior, highly digestible feed ingredient that is preferred for inclusion in the diet of most animal production, particularly cattle, poultry, swine, fish, and shrimp. The calorie content of fishmeal is high per unit weight, and it is a great source of protein, lipids, minerals, and vitamins with less amount of carbohydrates. Fishmeal has been used as an additive in feed formulation to enhance the growth and performance of farmed animals (Ashbrook 1917). It is mostly prepared from small, wild-caught marine fishes that are bony and oily and considered unfit for direct human consumption due to their low market values. Since the majority of these fish are caught for the sole purpose of producing fishmeal and fish oil and it is regarded as "industrial" fish. On the other hand, by-catch from other fisheries and discards like head, skin, trimmings, etc., from fish processing industries are also used as raw material for fish meal production. In general, 90% of fish meal is produced from oily fish species such as sardine, anchovy, capelin, and menhaden whereas, white fish offal from cod and haddock contributes less than 10%. Currently, the fish meal supply is constant between 6.0 and 6.5 million tons per year (FAO 2019). Approximately, 4–5 tons of raw material are required to produce a ton of dry fish meal. Countries such as Peru, Chile, China, Thailand, Iceland, Norway, Denmark, the United States, and Japan contribute one-third of the world's fishmeal production. Fishmeal supplements showed a synergistic effect with plant and animal proteins in the feed, which promotes growth and enhances disease resistance by boosting the immune system. The increasing demand for fish meal as a feed additive has created competition in the animal feed industry and is becoming an expensive protein source. Several reports have been documented to partially or fully replace the fish meal with a less expensive and widely available protein source in feed formulation. In this chapter, global trends, nutritional value, and effective production techniques of the fish meal were reviewed. Furthermore, the potential benefits of fish meal supplements in livestock, poultry, and aquafeed feed were revisited. Finally, present challenges associated with the application of fish meal and its alternative solutions were addressed.

2 Global Status of Fish Meal Production

The production of fishmeal represents a large but dwindling share of global fisheries. Whole fish or leftovers from the fish processing industries are used for the production of fishmeal. Primarily, small pelagic fishes including *Peruvian anchoveta* (which accounts for the largest part), menhaden, blue whiting, capelin, sardine, mackerel, and herring are utilized as whole fish. Fishmeal and fish oil production vary in accordance with variations in catches of certain species, particularly anchoveta, which is influenced by the El Nino-southern oscillation that influences stock abundance. FAO report documented that *Peruvian anchoveta* catches reduced from 18 million tons (2018) to 16 million tons (2020), respectively. This equates to around 20% of overall marine catch fisheries. The gradual decrease in fishmeal supply has been accompanied by the increasing demand due to the expansion of the aquaculture industry, as well as pig and poultry farming, pet food, and pharmaceutical industries. According to the International Fishmeal and Fish Oil Organization (2020), approximately 86% of fishmeal was utilized in aquafeed, 9% in pig feed, 1% in poultry feed, and 4% in pet food. Whereas, 73% of fish oil was intended for aquaculture, 16% for human consumption, and 11% for other applications (including pet food and biofuel).

In 2030, it is anticipated that the production of fishmeal will increase by 11–13% as compared to 2020. The proportion of fish catches conversion into fishmeal is expected to decrease from 18% in 2020 to 17% in 2030, respectively. However, the production of fishmeal is anticipated to rise due to the overall growth in capture fisheries and the utilization of fish waste from processing sectors. The total fishmeal produced from fish waste is anticipated to rise from 27% in 2020 to 29% in 2030. According to IFFO, by-products from processing industries contribute to 27% of the world's total production of fishmeal in 2020. Fishmeal is regarded as the most nutrient-dense and easily absorbed component in animal diets and aquafeed. However, there has been a noticeable decline in their inclusion rates in feed formulation as a result of supply and price volatility and steadily rising demand from the feed industries. In recent days, fishmeal and fish oil are being utilized more and more selectively at particular points in the production process, such as for diets for hatcheries, brood stock, and finishing, while their inclusion in grower diets is declining. Therefore, nutritionists have been working to replace fishmeal, particularly with insect meal without compromising nutritive benefits (Hua et al. 2019).

3 Production Process of Fish Meal

The most common and commercial methods to produce fish meal include the wet reduction process also known as wet rendering and the dry reduction process or dry rendering. The process methods for the production of fish meal will be selected based on the type of raw materials (whole fish, by-catch, or by-product) and lipid content (fatty or lean fish). The wet reduction process is the traditional method for the production of fishmeal. The process involves cooking the raw material, pressing of cooked material, and finally drying it to a lower moisture content suitable for transportation and storage without bacterial and mold growth. The separation of oil and water from the solid portions is the fundamental processing step for producing high-quality fishmeal. Firstly, raw material passes through a lengthy, steam-jacketed screw conveyor cylinder for cooking. The cooking temperature is around 95 to 100 °C for 15 to 20 min. The cooking process denatures and/or coagulates the protein and ruptures the cell wall of tissue thereby oil and water can be separated from the fish muscle. This crucial step sterilizes the raw material and helps to remove the mixture of water, oil, and soluble protein in the form of "liquor." Secondly, the pressing operation aids to separate the cooked material into two distinct phases. After being cooked, the liquid (press liquor) is extracted by pressing, leaving behind a solid residue known as "press cake." Pressing can be done using a screw press. The double screw press is the most preferable compared to the single screw press which removes the maximum amount of oil and water from the press cake. Approximately, the press cake contains about 45–55% moisture and 2–3% oil after passing through the screw press. Then, press liquor is centrifuged to separate oil and stick water. The extracted oil is refined more than twice before being delivered to storage tanks. It is crucial to stabilize the oil to preserve its quality before storing it in the storage tank. The extracted oil should not be exposed to air, heat, or light while being stored. Stick water is a term that refers to the liquid that remains after the separation of oil and suspended particles from the press liquor (about 65% of the raw material). Stick water contains vitamins, minerals, leftover oil, and soluble and undissolved proteins (20%). Stick water is evaporated until it reaches the consistency of a thick liquid that contains 30–50% solids. This substance can be added back to the press cake or it can be marketed as "condensed fish soluble." Consequently, one has the option to buy a "press cake" meal or a "full" dinner (where all of the solubles have been added back). Pressing is frequently skipped when a small quantity of oil is present in raw material, e.g., lean fish. The solid press cake turns into large lumps after pressing, which reduces the efficiency of drying. The fluffing process must be carried out before drying to break down the lumps into small particles (<1 cm). Finally, the drying can be done using a direct drier (flame drier) or indirect drier (steam-heated drier). The temperature of hot air is around 600 °C, however, particles of press cake reach only 80 °C due to evaporative cooling produced by rapid evaporation of water from their surface. The wet meal was dried in a dryer to < 10% moisture content within 15–20 min.

The dry reduction process is a batch operation and is normally used for the production of fishmeal from non-oily fish and fish offal. In this process, the raw material is coarsely grounded via a hacker or mixer. The grounded material was cooked in a steam-jacked cooker and it also acts as a drier which is referred to as cooker-drier. After drying, the fish meal is cooled to room temperature by the cooler. Then, fish meal was subjected to milling, sieving, and packed in polyethylene line jute bags or polyethylene line HDPE woven sacks. This process was not been commercially used in recent times due to high production costs. The produced fish meal is a dry product that has a brownish-grey color. The fishmeal may become burned and lose some of its nutritious content if the drying process is not adequately regulated or if it is over-dried. It is recommended to store the fish meal in a cool, dry location away from animals and birds.

4 Nutritive Value of Fishmeal

Fish meal is an essential component of the diet for the majority of aquaculture species as well as many land-based farm animals due to its high quality and balanced nutrients, particularly essential amino acids, key fatty acids, vitamins, and minerals. Fish meal is well-known for its nutritious richness, excellent digestibility, and palatability.

4.1 Proteins in Fish Meal

On average, the high-quality fishmeal has a crude protein content of about 60–72%. Protein is a necessary component of any diet; however, its nutritional value depends on the balance of its amino acids and absorption. Fishmeal is a well-known protein supplement in animal feeds due to its amino acid composition. The limiting amino acids such as lysine and methionine are typically lacking in the proteins found in cereal grains and other plant concentrates. However, soybean and other legume meals are excellent sources of lysine and tryptophan but are deficient in sulfur-containing amino acids (methionine and cystine). Even when adequately prepared, plant-based proteins typically do not have the same level of digestibility as fishmeal, and their use in diets is frequently constrained since it reduces feed intake and development rates. Fishmeal has an overall protein digestibility level exceeding 95%. In contrast, depending on the species of plant, the digestibility of plant-based proteins varies substantially from 77 to 96% due to the presence of non-digestible carbohydrates (oligosaccharides) or structural fiber components (cellulose). The application of fish meal as supplementation is preferable more than plant proteins due to the absence of nutritional inhibitors or anti-nutritional elements. Anti-nutritional factors are harmful and interfere with nutrient digestion, absorption, or metabolism. For instance, the trypsin-inhibitor, a naturally occurring anti-nutritional component in raw soybean retards the action of the digestive enzyme trypsin from breaking down meal proteins in animals' intestines. Chickpea lectrogens prevent collagen formation, which is the prevalent protein in connective tissue and offers structural support. Another antinutritional component in cottonseed meal/oil named gossypol negatively affects animals by decreasing fertility.

4.2 Lipids in Fish Meal

Even though the majority of the oil is removed during the processing of fish meal, the leftover lipid accounts for about 6 to 10% of the total weight, however, it can range from 4 to 20%. Fish lipids are easily absorbed and are a great source of n-3 fatty acids such as linolenic acid, eicosapentaenoic acid, and docosahexaenoic acid. Small-size algae and zooplankton that are eaten by fish transmit the n-3 fatty acids through the food chain. In general, essential fatty acids are required for growth and reproduction as well as appropriate larval development. Also, PUFA seems to support the immune system in fighting off and reducing the stress response and disease agents. Beneficial phospholipids, fat-soluble vitamins, and steroid hormones are also present in fishmeal. However, species, physiology, sex, age, and feeding habits impact the amount and quality of oil in the fish meal. All animals, including fish, shrimp, poultry, pigs, and ruminants like cows, sheep, and goats can easily digest the lipids in fishmeal and fish oil. The digestibility of lipids in these animals is more than 90%.

4.3 Mineral and Vitamins in Fish Meal

A good quality fish meal typically has an ash content of about 17–25%. Higher mineral content, particularly calcium, phosphorus, and magnesium are present in fishmeal. Most of the ash in fishmeal is made up of calcium and phosphorus. Unlike phosphorus found in plants, which is not readily available to most animals. Whereas, fish meal contains phosphorus largely found in the organic form known as phytate. Furthermore, phosphorus in plants is not easily absorbed by monogastric animals (those with a one-compartment stomach, such as pigs, dogs, and humans). Whereas, the microbial community in the rumen's stomach allows ruminants (cows, sheep, and goats) to use the phosphorus in phytate. Fish origin and composition, meal processing technique and product freshness are a few variables that might affect the vitamin content of fishmeal. Fishmeal has comparatively low fat-soluble vitamin content due to the removal of oil during the production process. Cobalamin, niacin, choline, pantothenic acid, and riboflavin are among the B-complex vitamins that are rich in fish meal with moderate concentration.

4.4 Fishmeal Quality Analysis and Its Management

One of the most important criteria for meeting the nutrient requirements of growing animals is the quality of fishmeal. Because the growth performance of the animals depends on the quality of the fishmeal. Generally, the quality of the fishmeal is determined by the freshness of the fish and processing conditions (De Koning 2002). Some analytical methods, such as total volatile nitrogen and free fatty acids, are used to express the quality. The total volatile nitrogen content depends on the temperature and duration. The enzymes generated by the free fatty acids initially increase to their maximum and then decrease, so the FFA is not used as a stable index. Because the long-chain FFA is turned into short-chain volatile and water-soluble FFA. Additionally, phospholipid levels are also used to detect the quality of fishmeal. Normally, the fresh fish (wet) phospholipid level ranges between 0.5 and 0.8%. During processing, most of the phospholipids end up with the meal (Sandfeld 1983; De Koning et al. 1990, 1985). Apart from that, some of the general points should also be remembered while processing fishmeal. (a) Raw material quality; (b) processing temperature; (c) fat stability; and (d) plant, machine, and utensil hygiene. The following physical properties of the fishmeal are very important for preparing good quality feed: The color of the fishmeal should be light brown to dark brown in color. The odor of the fishmeal should be free from rancidity. Fine granules and powder form are important texture properties of the fishmeal, and it should also be free from any contamination. Based on the above quality parameters and the physical properties, normally there are three grades of fishmeal available.

Nutrients	Grade 1	Grade 2	Grade 3
Moisture (% maximum)	10	10	10
Crude protein (% minimum)	60	50	40
Crude lipid (%, maximum)	8	10	11
Salinity (%, maximum)	2	3	5
Ash (%, maximum)	2	3	4
Hard and sharp solid materials	Not permitted		
Total volatile nitrogen (mg/100 g, maximum)	150	250	350

Source (FAO, Feed and Feed Ingredient Standards)

Proper management practices should be used to produce fishmeal of higher grade. One of the most crucial steps in maintaining freshness is handling the raw materials. The biological breakdown of raw materials is typically slowed down by cooling and icing them. Moisture must be kept out of the fishmeal. To prevent condensation and drip at night, which would lead to localized mold growth and lumping in the fish meal, the inner surface of the roof should, if required, be insulated. Ceilings should also be installed in the stores. Fishmeal should only be kept outdoors in arid areas. Whether treated with an antioxidant or kept after curing, the fish meal must be kept from excessive self-heating. Because of this, the width of bulk storage units shouldn't be greater than 5 m (FAO 1971).

4.5 Unknown Growth Factor in Fish Meal

It had been hypothesized that fishmeal has unknown growth factors that remain unexplained, frequently referred to as UGF. In numerous feeding trials, animals fed diets with a comparable amino acid composition to a fish meal have developed less well than those fed with fishmeal itself. Despite this fact, the UGF component has not been isolated yet. In some reports, it has been documented that carefully supplemented plant protein diets have shown similar outcomes as comparable to fishmeal. The UGF trait might be attributed to the dietary balance rather than the presence of some unidentified component. Fishmeal from commercial sources is unlikely to be able to keep up with the anticipated growth in global production of aqua and animal feeds. Aquaculture has recently consumed about 46% of the yearly fishmeal production; this percentage is anticipated to rise over the next ten years as demand for aquaculture products rises. The best possible use of fishmeal in animal diets is to reduce feeding costs, which contribute 40% or more of operating costs. In recent years, fishmeal has become one of the most expensive feedstuffs due to its high concentration of protein. Since 2000, the price of high-quality fishmeal ($\leq$65% protein) has varied between $385 and $554 per ton and it is 2.0–3.5 times more costly than soybean meal.

5 Fish Meal as Feed Ingredients

Fishmeal is a great source of digestible energy for farmed animals including pigs, sheep, cattle, poultry, and fish. It has a gross energy of 21.9 MJ kg of dry matter and is nutritionally dense. Due to high digestibility, fishmeal is frequently used to improve feed conversion ratio (FCR) and faster growth rate in young pigs and poultry. Further, reduction in unabsorbed nutrients leads to lower levels of nitrogen and phosphorus excretion. Many of the micronutrients in fishmeal are known to have positive effects on the health and welfare of farm animals, as well as the quality of the final product.

5.1 Fish Meal in Aquafeed

The finfish and crustacean aquaculture sector are still highly dependent upon marine capture fisheries for sourcing key dietary nutrient inputs, including fish meal and fish oil. This dependency is particularly strong within compound aquafeeds. The inclusion level of fishmeal in aquafeeds varies between the same species, e.g., 5–40% in shrimp, 20–50% in salmon, 15–55% in trout, 40–80% in eel, 7–70% in marine fishes, 5–20% in tilapia, 1–5% in milkfish, 5–25% in freshwater prawn, 0–20% in Chinese carps, and 3–40% in catfish. This variation depends greatly on stocking density, water and feed management, natural food availability, species differences, etc. Fishmeal is a proteinaceous flour added as a primary protein source in aquafeed. However, the inclusion of fishmeal as the primary protein source in compounded aquafeeds is now threatening feed manufacturers to depend on it. Accordingly, feed formulators look for alternative feedstuffs that can replace fishmeal with no adverse effects on fish performance (Daniel 2018). In the meantime, fish wastes meal is readily available, less expensive than fishmeal, considered to be suitable, and have a sustainable supply for replacing fishmeal in commercial aquafeeds (Baeza-Ariño et al. 2016).

The efficacy of using trout-offal as a protein ingredient in gilt-head bream (*Sparus aurata)* diets was researched by Kotzamanis et al. (2001). Trout-offal (intestine, frames, heads, skeletons, and fins) was finely minced and thoroughly mixed with the other dietary components to form a homogenous paste, then pelleted out. The study concluded that trout-offal is a suitable, non-polluting alternative for fishmeal in seabream diets. European sea bass (*Dicentrarchus labrax*) was evaluated with different animal protein sources as dietary fishmeal replacers including fermented prawn waste liquor at 30% in juvenile feeds (Nor et al. 2011), and a mixture of shrimp and tilapia protein hydrolysates in combination with poultry by-products meal at 15% (Robert 2014). For other marine fish species, tuna muscle by-product powder replaced 50% of dietary fishmeal. Meanwhile, whole tuna by-products replaced 30% without reducing the growth performance of olive flounder (*Paralichthys olivaceus*) (Uyan et al. 2006; Kim et al. 2014a, b). Recently, Muttharasi et al. (2019) suggested that *Rastrelliger kanagurta*, *Sphyraena barracuda*, and *Fenneropenaeus* indicus disposal meals can be used as complete fishmeal alternates to obtain low-cost feeds for farmed carp, *Cyprinus carpio*. In addition, Saleh et al. (2020) concluded that tilapia by-products replaced 30% of fishmeal in the European sea bass (*D. labrax*) diet without compromising fish growth or health.

5.2 Fish Meal in Animal Feed

Fishmeal is also fed to dogs, cats, pigs, cattle, and other terrestrial animals. Typically, fishmeal makes up around 10% of pigs' diet. In pig starter fed, soybean meal was substituted with menhaden fishmeal had better growth performance and average daily feed intake in weanling pigs (Stoner et al. 1990). Pigs fed with a diet incorporated with fishmeal (22.5%) resulted in higher weight gain as compared to soybean meal and rapeseed meal (Kyriazakis and Emmans 1993). Sanderson et al. (2001) documented that the inclusion of fishmeal in the daily diet is an effective way to enhance protein adsorption and deposition in young cattle. Heifers fed with a diet supplemented with fishmeal showed higher average daily gain as compared to those fed with a diet containing urea and soybean meal (Oldham and Smith 1982). Further, milk yield was noticed higher in early lactating cows when fed with the fishmeal-added diet (Miller et al. 1972). Intake of fishmeal at 1.19 kg/day from a diet supplemented with 5% of fishmeal resulted in increased milk and protein yields of Holstein cows within

10–20 weeks (Adachi et al. 2000). Esteban et al. (2007) reported that fresh fish can be utilized as a substitute ingredient in swine feed along with other conventional protein sources such as soybean meal to partially fulfill protein requirements. Generally, fishmeal is included at a range of 5–20% in dairy cows' feeds to increase the yield of milk due to the presence of balanced amino acids. Beef requires high-quality protein compared to calves to achieve satisfactory rates of growth in a particular period immediately after weaning. Further, fishmeal is generally given to the pregnant ewe to meet the difficulty in late pregnancy, particularly when carrying twins or triplets. Therefore, it is essential to provide a high-quality diet to meet the requirements for developing fetuses. Research has shown that the inclusion of fish meals can result in heavier lambs at birth, therefore its use has welfare benefits for ewes and lambs.

5.3 Fish Meal in Poultry Feed

In order to achieve economic rates of growth or egg production, it is necessary to feed poultry with high-quality diets with high concentrations of essential nutrients. Islam et al. (1997) reported that fishmeal substituted broiler feed (12%) resulted in higher body weight gain, feed intake, and feed efficiency. Feeding fishmeal or fish oil has been shown to increase the PUFA content of poultry tissue without adversely affecting the eating quality. Also, increasing the n-3 content of eggs has been of particular interest which significantly contributes to the additional n-3 required in the human diet. Ockerman (1992) postulated that the use of fishmeal as a supplement increases the n-3 content in the poultry flesh, thus making these tissues to be another source of n-3 fatty acids for the human diet. It is recognized that fishmeal added to poultry feed can reduce infection, improve immune status and reduce inflammation in poultry farming. A desirable ratio of n-6 to n-3 fatty acids is about 4:1. However, commonly used feed has an oversupply of n-6 and an undersupply of n-3 fatty acids e.g., 1:8, 1:11, and 1:10 which causes an imbalance in the diet. The inclusion of fishmeal into the diet increases the n-3 fatty acids thereby the overall desired ratio (4:1) can be obtained. Fishmeal is recognized as safe and natural and is an effective feed ingredient for poultry. The Lion Eggs standards permit the use of fishmeal in pullet and layer diets, although diets for commercial laying hens should be free from any feed material that is likely to produce taint (or toxins) in eggs. It has been recommended that an inclusion of 15 g/kg fish meal in the diet is the maximum used to achieve a favorable taste assessment and unchanged shelf life of the eggs.

6 Replacement of Fishmeal with Alternative Protein Sources

Due to the rising production of aquaculture, the demand for feed resources has increased, especially for fishmeal with a high protein content (Tacon and Metian 2008). Fishmeal has been used as a crucial protein source for both carnivorous and omnivorous species cultured in aquaculture as well as for terrestrial animals and poultry (Sammadar 2018). Considering its increasing demand and decreasing supply urges researchers to search for alternatives to fishmeal in diets (Hardy 2010). The alternative ingredient must have high protein content, good amino acid profile, high nutrient digestibility, and low fiber level (Gatlin et al. 2007).

6.1 Animal-Based Protein Sources

Meat and bone meal is an effective source of protein and minerals for the production of feed. According to Moutinho et al. (2017), the growth and feed efficiency of juvenile gilthead seabream remains unaffected when meat and bone meal replaced 50% of fish meal in the starter diet. Sato and Kikuchi (1997) documented that Japanese flounder substituted with 60% meat meal does not alter weight gain, feed efficiency, and protein efficiency ratio. Grouper (*Epinephelus coioides*) were fed with a mixture of meat and bone meal (4:1) at varied inclusion levels, in which up to 80% of fishmeal replacement had no significant differences in the growth results (Millamena 2002). Yang et al. (2004) studied the effect of meat and bone meal on carp (*Carrassius auratus gibelius*) and concluded that fishmeal can be replaced for up to 50% without affecting the growth rate. For *C. auratus*, feed containing a partial replacement of fish meal with meat and the bone meal alone or in combination with lysine and methionine supplements demonstrated the best growth results (Hu et al. 2008). According to Keramat et al. (2014), poultry by-products have the ability to replace fishmeal in rainbow trout diets by up to 33% without negatively affecting growth performance. Fowler (1991) reported that 50% of fishmeal was replaced with poultry by-products in chinook salmon's feed (*Oncorhynchus tshawytscha*). Kureshy et al. (2000) found that at different inclusion levels poultry by-products could efficiently substitute 67% of fishmeal in the diet of red drum juveniles. Seabass growth was unaffected when replacing fish meal (100%) with turkey meal in feeds (Muzinic et al. 2006). Another study by Bureau et al. (2000) studied the feather meal and bone meals from different origins as a protein source in rainbow trout (*Oncorhynchus mykiss*) diets and showed that it did not affect the protein and energy retention of the fish.

6.2 Plant-Based Protein Sources

The efficiency of various plant protein resources (soybean, linseed, canola, sunflower, cottonseed, etc.) at appropriate levels as a partial or complete replacement for fish meal has been evaluated in fish diets to reduce the cost of feed (Antolovic et al. 2012; Badwy et al. 2008; Soltan et al. 2008). According to Ajani et al. (2016), soybean meal can be used to either partially or entirely replace fishmeal in the diet of *O. niloticus* without affecting growth or nutrient utilization. Rab et al. (2008) studied the effect of soybean meal in the channel catfish diet (*Ictalurus punctatus*) with increasing levels (10 to 40%). The results showed that fish fed with a 30% substitution of soybean meal had desirable fish growth and development. Kasper et al. (2007) replaced up to 47.6% of the fish meal in yellow perch diets with soybean meal won't have an impact on the fish's feed intake, weight gain, feed efficiency ratio, or survival. Zhou et al. (2005) investigated the growth performance of young cobia (*Rachycentron canadum*) fed diets containing varying levels of soybean meal from 0 to 60%. The outcomes demonstrated that the 30% soybean meal can be used without affecting fish growth. Jindal et al. (2007) examined the growth performance of Channa punctatus, in which the fingerlings fed diets containing soybean meal at high (75–100%) inclusion levels exhibit improved live weight gain, percent weight gain, specific growth rate, apparent protein digestibility, protein efficiency ratio, and energy retention.

7 Future Prospects

The diminishing global supplies of wild caught and increasing market price of small pelagic fish due to increasing fishing costs as well as increasing demand for fish products in human diets destined for reduction into fish meal. This directly results in the cost of fish meal and it consequently pressures feed manufacturers for dietary substitution so as to remain profitable. In upcoming years, the application of fishmeal as a protein source in feed will no longer be economically sustainable. Therefore, in agreement with IFFO, fish meal used in the long term will be increasingly targeted as a specialty feed ingredient in the higher-value starter, finisher, and broodstock feeds (Jackson 2009). Utilization of fish waste meal, animal by-products, poultry by-products, and balanced plant-based protein sources can be used widely as a substitution for fish meal. This reduces the cost of feed as well as environmentally friendly techniques.

8 Conclusion

Fishmeal and fish oil, which were once thought of as commodities, are now correctly positioned as important elements in the market. They are increasingly being employed in tailored diets for specialty goods or to suit the more demanding nutritional needs of young or brood animals. Their great significance in animal feeds goes beyond just improving the animal's growth performance, with several micronutrients, in particular, known to support healthy physiological function. The bioavailability of the essential amino acids is excellent, and lysine and methionine are particularly abundant in fishmeal. For a feed ingredient, this is a comparably broad and rich nutritional spectrum that supports growth and ideal physiological function during the most delicate periods of the life cycle. Overall, the advantages of using fishmeal and fish oil in terrestrial animal feed go much beyond their obvious benefits as a source of dietary energy and crude protein. With regard to their potential contribution as functional components to the growth and health of the farmed animal, they are more valuable than the bulk of other ingredients.

Acknowledgements ICAR – National Talent Scholarship for Satheesh Muniasamy from the Indian Council of Agricultural Research, India and PSU President Scholarship for Bharathipriya Rajasekaran from Prince of Songkla University, Thailand were gratefully acknowledged.

Author Contribution **Satheesh Muniasamy**: Conceptualization, Data curation, Writing original draft. **Bharathipriya Rajasekaran**: Conceptualization, Data curation, Resources, Supervision Writing-review & editing. **Bharathi Subramaniam:** Conceptualization, Data curation, Resources, Writing-review & editing. **Subashini Muniasamy**: Conceptualization, Data curation, Writing-review & editing, **Gour Hari Pailan:** Conceptualization, Data curation, Writing-review & editing.

Conflict of Interest The authors have declared no conflicts of interest.

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