Nutritional Innovation: Enhancing Fish Feed Resources for Economic Gain

Ayesha Shafqat*[1], Nadia Nazish[1,*], Muhammad Abdur Rehman[1], Nimra Razzaq[1], Mehwish Hadiat Ullah[1] and Rabia Awan[1]

[1]Department of Zoology, University of Sialkot, Sialkot, Pakistan
*Corresponding author: ayeshashafqatjanjua@gmail.com; nadia.nazish@uskt.edu.pk

Abstract

The aquaculture industry appeals for innovative facilities to optimize fish feed supply;as a result of fish industry's efficient growth in terms of economic stability and sustainability. This chapter concentrates on nutritional innovations techniques that are expected to enhance fish feed by focusing on serious challenges including; feed costs, obtaining raw materials in a sustainable manner, and growing the availability of nutrients. Apart from innovative feed additives that could enhance growth performance and decrease the feed conversion ratios (FCR), the main focus of the dispute is the introduction of extra alternative sources of protein, such insect meals and algae. The economic impact of these innovations is assessed in terms of revenues, reduced expenses, and sustainability over time in addition to promoting the ecological benefits of significantly reducing dependence on common fishmeal and plant-based proteins. Through studies on analyzing the effective implementations within various aquaculture atmospheres, the practical application of these innovations is displayed. These strategies have the perspective to recover the aquaculture sector by improving economic viability and sustainable development as well as opportunities for the stakeholders and research analysis. Ultimately, these nutritional innovations are fundamental for meeting the growing demand for fish all over the world.

Keywords: Fish feed, Nutritional innovation, Aquaculture practices, Alternative protein sources, Feed conversion ratio (FCR), Sustainability, Insect meal, Nutrients, Algae-based feed.

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Introduction

The aquaculture industries 344 have developed at a rate never witnessed before over the last 3 decades, at this time it is an essential supply of food for millions of people globally. The Food and Agriculture Organization (FAO) estimated that fisheries industry was contributing to almost 46% of the worldwide consumed fish in the year 2020 (Smith et al., 2010). This practice is predicted to continue as the global population increases and dietary preferences improve and shift towards consuming more seafood. The recent statistics indicate that; in order to fulfill the rising demand for fish protein, aquaculture production needs to increase by 30% by the year 2030 (Hunter et al., 2017).

The historic dependence on both fish oil and fishmeal from wild-caught fish is the main obstacle. Despite the significant amount of protein and nutritious amino acid profile of these nutrients, environmental issues, pricing increases, and competing for marine resources are making their utilization more and more difficult (Kim et al., 2019). Fishmeal employment, which rose in the late 1990s, has declined as a result of overfishing of important species. The aquaculture sector must therefore look at substitute feed ingredients that might lessen dependency on fishmeal while preserving the nutritional value and growth potential of farmed fish (Ong et al., 2021).

i. Overview of Fish Feed Composition

Fish feed is typically composed of a variety of ingredients designed to meet the nutritional needs (Table 1) of specific fish species. The primary components of fish feed include:

- Protein Sources: Vital for general health, growth, and development. Because of its great digestibility and well-balanced amino acid profile, fishmeal has long been regarded as the gold standard in protein content, ranging from 25% to 50% as listed in the Table.1. Small pelagic fish, including sardines and anchovies, are processed to create fishmeal, which contains vital amino acids that support healthy growth in a variety of fish species (Pandey, 2013).
- Lipids: Vital for vital fatty acids and energy. The omega-3 fatty acids (Table 1), that are abundant in fish oils, are essential for the growth and well-being of numerous species of fish when given in adequate amounts, approximately up to 10% to 15% (Table 1). Omega-3 fatty acids are essential for cellular function, inflammation control, and general health, especially EPA (eicosapentaenoic acid) along with DHA (docosahexaenoic acid) (Deng et al., 2011).
- Fat: A crucial part of fish feed, fat offers a concentrated energy source and promotes fish development and general health. There are two types of lipids: saturated and unsaturated. Unsaturated fats, especially omega-3 and omega-6 fatty acids, are essential for a number of

physiological processes. These fatty acids are important for the formation of cellular membranes, hormone synthesis, and the control of inflammation (Parker, 2011). Fish oils are frequently utilized in aquaculture as a source of important fatty acids, particularly EPA (Eicosapentaenoic acid) alongside DHA (docosahexaenoic acid), that are needed for many fish species' proper growth and development. To support energy needs, increase feed efficiency, and improve the nutritional value of farmed fish, fish feed must have enough fat levels (Table 1) (Abowei & Ekubo, 2011).

- Carbohydrates: Contribute to gut health and act as an energy source. To prevent adverse effects on digestion, fish feed's carbohydrate level should be balanced (Table 1). Compared to terrestrial animals, fish usually have lower carbohydrate consumption (5%-20%), hence the types and amounts of carbohydrates used in aquafeed composition must be carefully considered (Wu et al., 2019).
- Vitamins and Minerals: Fish metabolism and general health depend on 1% to 5% of vitamin and mineral intake (Table.1). Growth impairment and heightened vulnerability to illnesses can result from deficiencies in certain nutrients. For several physiological functions in fish, the four vitamins A, D, and E, as well as a variety of B vitamins are essential (Miles & Chapman, 2015).

Table 1: Summarizes the components of fish feed along with their approximate percentage ranges in typical formulations (Lall & Dumas, 2022)

Component	Description	Approximate Percentage Range
Protein Sources	Essential for growth and health; traditionally fishmeal is the gold standard.	25% - 50%
Lipids	Important for energy and omega-3 fatty acids (EPA & DHA).	10% - 15%
Fats	Provides additional energy; includes both saturated and unsaturated fats.	10% - 20%
Carbohydrates	Serve as an energy source; need to be balanced to avoid digestion issues.	5% - 20%
Vitamins & Minerals	Essential for metabolic processes and fish health; deficiencies can impair growth.	1% - 5%

ii. Challenges in Traditional Fish Feed Ingredients

The aquaculture industry faces several challenges associated with traditional fish feed ingredients:

Resource Scarcity: The increasing lack of high-quality fishmeal is one of the main issues facing the aquaculture sector. Because of their high protein content, small pelagic species including anchovies, sardines and menhaden are the main source of fishmeal (D'Abramo, 2018). On the other hand, populations of wild fish over the world have experienced declines as a result of over fishing, habitat loss and climate change. These conditions result in a continuous drop in fishmeal yield; which raises issues over the long-term sustainability of the fish supply; due to the fact there are only a smaller number of small pelagic fish available (Boyd et al., 2020). As aquaculture market continues to grow with the increasing demand for seafood, additional strain on the availability of fishmeal will get more intense (Columbo & Turchini, 2021).

Furthermore, it is suggested that environmental changes particularly fluctuating water temperatures and oxygen levels due to climate change is likely to contribute to the shortage of fishmeal resources (Rodde et al., 2020). The fishing industry may be subjected to the potential drop in fish populations brought on by ocean temperatures. The increasing population is also adding to the demand on freshwater fish stocks as the global demand for fisheries and foods high in protein is predicted to increase significantly by 2030 (Tran et al., 2021).

Cost Fluctuations: The huge market fluctuations in the selling prices of fish oil along with fishmeal provide significant challenges for the aquaculture industry. Fishmeal prices can be controlled by a variety of factors including; changes in the number and the variety of fish species, environmental conditions, demand in the global market and the effects of sociopolitical influences. Fish traders are at concern from this price instability, since they need to balance their operating expenses with the current feed material costs in order to retain revenue (Reis et al., 2021). For instance, many weather conditions like El Niño can have a direct effect on the supply of the fishmeal. El Niño circumstances can often lead to a reduction in the number of fish in the southern Pacific because to changes in underwater currents and temperatures (Pereira et al., 2022). The general availability of fishmeal decreases and the price of fishmeal increase as the supply of fish drops. In a similar way, overfishing and its restrictions including; fishing limits and prohibitions on specific fish species can minimize the supply of fishmeal which raises prices substantially (Beya et al., 2021).

The price of fish products (fish oil and fish meal) it contains changes as an outcome of global economic crisis. The developments in the consumption of seafood, international trade rules along with the currency exchange rates all have an impact on the selling and cost of feed materials. In this regard, the market demand for fish meal has increased primarily due to the growing consumption of seafood in emerging countries such as China and India; that has raised the price of fish meal (Hossain et al., 2022).

Environmental Impact: The use of freshwater fish as feed has adverse consequences on the ecosystems, particularly in regards to habitat destruction and overfishing. These practices create problems for marine ecosystems and put fish species in risk, which has a direct effect on the food chain as a whole (Tornero & Hanke, 2016). Small pelagic fish such as anchovies, sardine fish, and menhaden are crucial to marine ecosystems because they supply food for bigger fish, aquatic animals, and seabirds (Mishra et al., 2023). The nationwide destruction of these species to fulfill the demand of fishmeal may have far-reaching impact. For example, the over fishing of sardines over the Mediterranean Sea has been associated to declines in tuna and seabird populations as their primary source of nutrition has become less abundant (Abbas et al., 2024).

Nutritional Deficiencies: Many alternative feed ingredients have nutritional limits, even if they may provide solutions to the problems of resource scarcity, economic changes, and environmental effect. In particular, one of the most accessible substitute ingredients, plant-based proteins, frequently lacks some important amino acids and could have anti-nutritional elements that might impair fish health and growth (Teh & Sumaila, 2013).

The unsuitable amino acid profile of plant-based proteins is one of their main nutritional drawbacks. Because it offers a balanced amino acid profile that includes all necessary amino acids including methionine, lysine, and tryptophan, fishmeal is highly regarded in aquaculture diets (Rasal & Sundaray, 2020). However, the amounts of these vital amino acids, especially methionine, are lower in many protein sources made from plants including soybean meal. Methionine is essential for fish development, immunological response, and protein synthesis. Fish that don't get enough methionine may grow more slowly, have weakened immune systems, and be more prone to illness (Musharraf & Khan, 2019).

iii. Importance of Nutritional Innovation in Aquaculture

The significance of nutritional development in aquaculture is becoming more widely acknowledged; especially in light of the difficulties experienced by conventional fish feed sources. The sustainability and financial feasibility of fish farming can be greatly increased by advancements in feed composition, ingredient supply, and processing technology (Abate et al., 2016).

Types of Feed additives

Moist feeds: Compared to dry pellets, moist diets have a greater water content. They are more appetizing and nutrient-dense since they are frequently prepared with fresh ingredients like fish or squid. Due to their shorter shelf lives and greater expense, these feeds are not frequently utilized on a wide basis, however they could be utilized for certain high-value species, such as sea bass (Tacon et al., 2024).

Live feeds: There is a wide variety of live fish feeds.

- Fish larvae: Fish larvae and fry are commonly fed Artemia (Brine Shrimp) in hatcheries. They improve the early growth of juvenile fish and are high in nutrients (Hasan et al., 2023).
- Daphnia: Also referred to as water fleas, these insects are fed to tiny fish and fry.
- Tubifex Worms: A popular live food source that gives aquarium fish protein and lipids.
- Rotifers: They are tiny creatures that make high-quality food for young fish larvae (Johan et al., 2023).

Frozen and Freeze-Dried Feeds: Aquatic creatures such as brine shrimp, krill, bloodworms, and others are examples of frozen and freeze-dried feeds. Both freshwater and marine organisms benefit greatly from these diets, which maintain their nutritional content. Versions that have been freeze-dried are particularly practical for storage (Oba et al., 2023).

Plant-Based Feeds: In aquaculture, plant-based feeds which include components like soybean meal, gluten, wheat and peas are used in place of fishmeal and fish oil. They support aquaculture's sustainability while offering protein and energy (Kuebutornye et al., 2024).

Specialty Feeds

a) Medicated feeds: These include antibiotics or additives to treat particular fish illnesses.

b) Color-Enhancing Feeds: Carotenoids such as astaxanthin are used in recreational fish farming to increase the color vibrancy of fish (Hossain et al., 2023).

Supplements:

In ponds and other open water systems, supplemental feeds are utilized to supplement natural food sources. They complement the diet of fish in less restrictive circumstances but are not meant to be the only source of nourishment (Craig & Helfrich, 2009).

Alternative Protein Sources

Investigating substitute protein sources for or in addition to fishmeal is one of the most promising directions for nutritional innovation. Insect meal, algae, as well as single-cell proteins are emerging substitutes that have shown promise in producing high-quality protein with less of an adverse effect on the environment.

- Insect Meals: Low-value substrates can be transformed into high-quality protein by raising insects like mealworms and black army flies on organic garbage. In addition to providing nutritional advantages, using insect meals for aquaculture waste reduction and are consistent with the circular economy (Velichkova et al., 2024).
- Algal Feeds: High in proteins, fats, vitamins, and minerals are both macro and microalgae. They can be included into fisheries to improve fish health and feed efficiency, and their cultivation uses few resources (Yossa et al., 2021).
- Single-Cell Proteins: High-protein biomass can be produced by cultivating microorganisms including fungi, bacteria, and yeast on a variety of substrates. These single-cell proteins have the potential to be useful feed ingredients, especially when resources are scarce (Iqbal et al., 2020).

Advanced Feed Formulation Technologies

In order to optimize the utilization of substitute ingredients in fish feed, cutting-edge feed formulation technologies must be developed.

- Enzyme Supplementation: Adding enzymes to aqua-feeds can boost nutrient absorption and the digestion of plant-based proteins. Complex proteins and carbohydrates can be broken down by enzymes like phytase, protease, and amylase, increasing the bioavailability of nutrients for fish.
- Extrusion and Pelleting: The most popular type of fish feed is extruded pellets. The components are boiled and then shaped into pellets. Because extruded pellets slide on water, they are perfect for fish that eat near the surface, such as salmon and tilapia (Samuelsen et al., 2022).
- Sinking Pellets: These types of pellets are ideal for bottom-feeding animals like prawns and catfish since they sink gradually. Crumbles: Tiny, crumbled pellets used to feed fry or young fish. Smaller fish can easily swallow them (Samuelsen et al., 2022).
- Fermentation: The nutritional value of feed materials can be raised by using fermentation processes. The process of fermentation can improve amino acid compositions and decrease anti-nutritional factors by employing particular strains of microbes, increasing the feeds' ability to support fish growth (Xu et al., 2021).

iv. Regulatory and Market Considerations

As the aquaculture sector develops, market and regulatory factors play a critical role in directing the creation and uptake of novel nutritional techniques. These factors include sustainability certifications, feed ingredient regulations, and market trends influenced by consumer preferences for products with ethical and sustainable sources (Wanja et al., 2020).

Regulatory Frameworks: Although regional regulatory frameworks for aqua feed ingredients differ greatly, most of them attempt to guarantee the nutritional sufficiency, sustainability, and safety of feeds utilized in aquaculture. To accommodate novel feed ingredients like insect meals along with single-cell proteins, regulatory bodies are modifying their regulations in a number of jurisdictions (Føre et al., 2018). The European Union has strict guidelines on feed additives. The European Food Safety Authority (EFSA) is a fundamental authority in determining the safety and nutritional value of all the novel feed additives. The EU has certified the use of insect-based proteins in aqua feeds because to their potential to enhance aquaculture's primary level sustainability. New feed additives must undergo rigorous safety testing as well as risk assessments before getting clearance, which may further slowdown the regulatory process (Raja et al., 2019).

The United States Food and Drug Administration regulate the ingredients used in animal feed in accordance with the Federal Food, Drug, and Cosmetic Act. The FDA Centre for Veterinary Medicine (CVM) evaluates the risk and effectiveness of feed additives utilized in aquaculture. Like the EU, the U.S. regulatory approval procedure may need a long time and requires considerable evidence on the safety check, nutritional necessities, and environmental effect of innovative feed additives. Though, countries like China which produces the greatest quantity of farmed seafood in the world have more lenient rules and regulations that are fast developing to meet the needs of a rapidly growing fish industry (Roheim & Zhang 2018). As the consumer demand for alternative proteins sources, the global cooperation and management of regulatory guidelines will be necessary to ensure the quality and safety of fish feeds. The corresponding standards would encourage international trade in feed ingredients and stimulate the best widespread adoption of environmentally friendly practices (Giacomarra et al., 2021).

Market Trends: Consumer expectations for sustainability, accountability, and health are having a growing impression on market developments in the aquaculture industry. As a greater number of consumers become more familiar of the environmental and social effects of fish aquaculture, they demand that farmers and retailers be held more responsibly. One of the most important market changes over the past few decades has been the rising demand for seafood that is sustainable. In addition to the customers, more of them are searching for fish products with achieved certification. This practice which is an element of an additional change in the food industry towards sustainability; is being driven by consumer demand for goods that decrease environmental effects, carbon footprints, and promote moral actions. Large retailers and eateries are establishing challenging sustainability goals for their seafood the supply chain in response to this demand (Sheng & Wang, 2021).

Aquaculture market trends are also being influenced by health-conscious consumers. Many people believe that fish is a good source of protein because it is high in omega-3 fatty acids that are good for the heart and brain. However, some consumers prefer farmed seafood because feed components may be more precisely monitored, and they are concerned about toxins like mercury, dioxins, or PCBs in wild-caught fish (Menozzi et al., 2020). As an organic supply of omega-3 fatty acids, innovative feed additives like algae appeal especially to consumers who are health-conscious. Higher quantities of EPA and DHA, that are critical for human health, can be found in algae-based feeds, improving the nutritional needs of farmed fish. When manufacturers promote their seafood as sustainable and health-promoting, this nutritional benefit can be a major selling feature (Borgwardt et al., 2019).

Sustainability Certifications: Aquaculture certifications act as a form of advertising for manufacturers looking to set their products apart in a market that is becoming more and more competitive, in addition to acting as a benchmark for ethical and environmental norms.

- Marine Stewardship Council provides a framework for the sustainable fisheries standard: the MSC standard. This standard makes sure healthy fish stocks, jobs within the aquaculture and to minimize the harm to the marine environment. The MSC certification facilitates consumers to differentiate sustainable products from conventional ones and to promote environment friendly fishing practices (Van et al., 2020).
- Fish traders discovered that getting ASC (Aquaculture Stewardship Council) certification opens up higher-end opportunities and boosts pricing as consumers become more responsive of the social and environmental concerns of the food products they eat (Risius et al., 2019). One of the diverse aspects of aquaculture operations that experience the certification process is the consumption of sustainable feed. In this regard acquiring a certainty in sustainability mayinvolve using alternate proteins such as; insects based, algae, and single-cell proteins that minimize their dependency on fish oil as well as fishmeal from aquatic species are more expected to meet the quality standards (Asche et al., 2021).

The Global Aquaculture Alliance (GAA) also grants the finest Aquaculture Practices certification including the complete supply chain from hatching centers to feeds and farms as well. Social accountability, food safety, livestock security and environmental sustainability are extremely valued by BAP accreditation. These certification programs are supported by significant traders and food service organizations, who are increasingly demanding accredited fish products as a part of their social responsibilities. Therefore, the introduction of innovative, sustainable feed can have a significant impact on the economic viability of aquaculture operations and the application of innovative, environment friendly feed additives (Del et al., 2018).

v. Future Directions for Research

As the aquaculture industry grows, research is crucial to address the unresolved problems with feed composition, environmental sustainability and acceptance among consumers. The development and optimization of feed additives would need an effective approach.

Nutritional Studies

- Although considerable advancements in this sector, further research is required to fully examine the nutritional profiles of the various proteins and how they have an effect on the different fish species. Future research's primary objective should be to determine the standard ratios of alternative proteins to utilize in fish feeds to optimize fish growth, health and feed effectiveness (Jonell et al., 2019).
- An extensive study on the long-term consequences of alternative protein sources (e.g. insect meals) on fish health and productivity rates

is crucial, despite their potential alternate source of fishmeal. Similarly, feeds containing algae have rich omega-3 fatty acids However; the variations in algae species along with the production parameters may impact the feed solubility and protein content (Sigurdsson et al., 2022).

Environmental Impact Assessments

Life Cycle Assessment (LCA) is an organized study of the environmental effects over the life stages of a manufactured product. They offer a diverse technological background that utilizes the newest software and databases in work to guarantee that the LCAs are comprehensive, precise, and cost-effective. Life Cycle Assessment ensure that organizations and dealers can make improved decisions, enhance bottom line performance, processing of supply chains and material preferences to minimize environmental impacts (Assefa and Abunna, 2019). It directs the advancements of initiatives that encourage ecologically mindful behavior, in order to precisely assess these aquaculture settlements, life cycle assessments) are required (Javed & Usmani, 2019).

Consumer Acceptance

An additional main concern that requires further investigation is consumer satisfaction and acceptability. Moreover, alternative proteins supply a high level of assurance towards enhancing the sustainability of aquaculture; marketplace's performance is linked to the opinions of consumers. To completely recognize possible challenges regarding acceptance, it is necessary to do further research on consumer perceptions of seafood produced using different feed supplies (Reis et al., 2021). Consequently, consumers may be reluctant about buying insect or algae-based feeds due to social or psychological reasons, even while they are satisfied about the beneficial environmental consequences of such fish products. To order to gain market acceptance and assurance; consumer education approaches that emphasize the long-term advantages associated with different protein sources would be required (Oba et al., 2023).

Conclusion

For the aquaculture sector to succeed financially and efficiently, nutritional improvement is significant. With developments in feed additives and their composition, aquaculture companies can substantially increase the efficacy of fish feed while concentrating on increased costs and ecological concerns using diverse types of protein such as; insect and algae meals. These developments have significant impact as they lessen reliance on ordinary fishmeal while, likewise increasing profitability through reduced costs and strategic advantages. Recent case studies represent the positive outcomes of these techniques and explain how they can benefit the aquaculture industry. The extensive application of dietary advancements offers potential to fulfill the increasing need for seafood around the world and preserving value production standards as research and manufacturing approaches continue to evolve. Thereby, employing above approaches aquaculture would develop into a profitable and sustainable industry that can flourish despite the global threats.

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