Innovative Feed Technology in Aquaculture Production in Nigeria

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ABSTRACT

Auaculture is the fastest growing food sector in Nigeria which has the potential to meet the increasing demand for fish and ensure food security. The success of aquaculture heavily relies on the quality and efficiency of the feed provided to fish. High quality fish feed is important for the success of aquaculture because it significantly affects fish health, growth, and the sustainability of aquaculture operations. One of the significant challenges in aquaculture production is the high cost and limited availability of sustainable fish feed. In recent years, there has been a growing interest in the development of innovative feed technology that can help to improve the efficiency and sustainability of aquaculture production in Nigeria. These technologies include the use of sustainable alternative feed ingredients, advanced feed processing methods, implementation of automated feeding systems and the use of functional feed additives. Traditional fish feed are typically based on fishmeal and fish oil, which are expensive and in limited supply. Sustainable alternatives to fish meal such as plant-based proteins, insect meals, single-cell proteins, and microalgae improve feed sustainability, reduce costs of feed production and reliance on wild fish stocks. Advancements in feed processing, including extrusion, pelleting, and encapsulation improve feed digestibility, reduce nutrient losses, and enhance feed conversion efficiency. Technological innovations in automated feeding systems such as AI-driven sensors, drones, and automated feeders minimize waste, improve feed conversion ratios, and reduce operational costs. The inclusion of functional feed additives, such as prebiotics, probiotics, enzymes, and immunostimulants enhance feed digestibility, boost immune function, and promote growth performance in fish. Continued research and investment in feed innovation will be important for the long-term success of the aquaculture sector in Nigeria.

INTRODUCTION

Aquaculture is the practice of cultivation of aquatic organisms, including fish, molluscs, crustaceans, and aquatic plants in controlled environments (Kaleem and Bio Singou Sabi, 2020). Aquaculture is the fastest-growing food production sector, which accounts for over 50 percent of global fish production and benefiting millions through the provision of nutrition, food security, sustainable livelihood, and poverty reduction (Galappaththi *et al*., 2020). Nigeria is the largest fish consumer in Africa and among the largest fish consumers in the world (Adelesi, 2019). The aquaculture sub-sector is considered a very viable alternative to meeting the nation's need for self-sufficiency in fish production. The majority of the aquaculture production in Nigeria is based on freshwater fish such as catfish, tilapia and carp which are the most commonly cultivated species in the country (Omeje *et al*., 2020). The success in aquaculture operations

depend on the quality of fish feeds since it determines the survival and growth of the fish (Jamabo *et al*., 2019).

Quality fish feed production in aquaculture is one of the major determinants of significant growth, efficiency in feed utilization, and flesh quality of the fish produced (Ogueji *et al*., 2020). Fish feed represents almost 65–70% of the cost of production in aquaculture setting with protein (fish meal) being the most expensive nutrient in feed formulation (Aragão *et al*., 2022). The production of high quality feed is one of the significant obstacle that hinders the rapid growth of aquaculture in Nigeria (Udo and Dickson, 2017). A major component in sustainable aquaculture is fish feed development and discovery of novel feed ingredients (Ragaza *et al*., 2023). As more than half of the cost in aquaculture production comes from feeds, different feed reduction schemes have been employed and adopted. Research is being done to find innovative sources of fish feed with the right nutritional values that can replace or augment conventional aquaculture or fish feed (Kaleem and Bio Singou Sabi, 2020).

Innovative feed techniques refer to the development and implementation of novel approaches to feed formulation, processing, and delivery in aquaculture. Innovative feed techniques play a vital role in the advancement of aquaculture, which is the fastest-growing food production sector globally. These technologies aim to improve the nutritional quality of feeds, enhance feed conversion efficiency, reduce environmental impacts, and ultimately increase the productivity and profitability of aquaculture operations. Fishmeal and fish oil are the main components of fish feed (Hameed *et al*., 2022). Traditionall aquaculture has relied heavily on fishmeal and fish oil derived from wild-caught fish, raising issues of overexploitation and environmental degradation (Olufemi, 2024). The rising costs and limited availability of fishmeal have led to investigations either to reduce or replace the content of fishmeal with more economic protein sources of plant and/or animal origin (Kaleem and Bio Singou Sabi, 2020). The need for cheap, protein-rich feed is a universal requirement, relevant to both large and small producers.

New alternatives, including plant-based proteins, insect meals, and microbial proteins, are being developed to replace these traditional feed components. These sustainable feed options not only reduce the industry's reliance on wild fish but also lower production costs and environmental impacts (Goswami *et al*., 2023). Hameed *et al*. (2022) reported that amongst all these novel ingredients, insects have greater potential to replace fishmeal due to its nutritional value and eco-friendly approach. Digital technologies and automation play an increasingly important role in modern aquaculture feed techniques (Olufemi, 2024). Sensors, drones, and artifcial intelligence are being used to monitor water quality, fish behavior, and feed distribution in real-time (Liu *et al*., 2025). Automated feeding systems can dispense feed based on the specifc needs of fish, reducing overfeeding and improving feed effeciency (Olufemi, 2024). Fish feed ingredients often require novel processing technology to improve feed digestibility and fish growth (Sarker, 2023). Advanced feed processing technologies such as extrusion, pelleting, and encapsulation improve nutrient availability, feed digestibility, leading to better feed utilization and minimal waste production. Functional feed additives, including prebiotics, probiotics, and immunostimulants, are increasingly incorporated into aquafeeds to improve fish health, enhance growth performance, and boost disease resistance (Onomu and Okuthe, 2024). This study therefore, provides overview of the innovative feed technologies in aquacuture production in Nigeria.

BENEFITS OF INNOVATIVE FEED TECHNOLOGIES IN AQUACULTURE

Innovative feed technologies play a vital role in the aquaculture industry by improving the efficiency and sustainability of fish production. These technologies encompass a wide range of advancements in feed formulation, processing, and delivery systems that aim to optimize nutrient utilization, reduce environmental impact, and enhance the overall health and growth of aquatic species.

Feed efficiency: Advanced feed formulation and automated feeding technologies maximize nutrient uptake, and enhances feed efficiency by preventing overfeeding and ensuring optimal feed intake. This leads to higher feed conversion ratios and lower feed wastage, ultimately resulting in cost savings for aquaculture operations (Goswami *et al*., 2023).

Sustainability: Innovative feed technologies contribute to the sustainability of aquaculture by reducing the reliance on wild-caught fish for feed ingredients. With the development of alternative protein sources, such as insect meal, algae, and single-cell proteins, aquafeed manufacturers can decrease the pressure on marine resources and promote a more environmentally friendly approach to feed production (Olufemi, 2024). This helps to address the issue of overfishing and minimize the ecological impact of aquaculture.

Improved health and growth of farmed fish: The inclusion of advanced ingredients and additives, such as enzymes, immunostimulants, probiotics, and prebiotics, into aquafeeds enhance the digestibility of nutrients, promote better growth performance, boost the immune system and disease resistance in fish (Onomu and Okuthe, 2024). This leads to lower mortality rates and improved overall well-being of the animals, resulting in higher quality products for consumers.

Cost-effectiveness: Fish production is hampered by the increasing costs of feeds due to the ever rising cost of fish meal. Substituting fish meal with cheap, yet highly nutritious ingredients in fish feeds is cost-effective (Irungu *et al*., 2018). Alternative feed ingredients such as plant-based proteins, insect meal, and single-cell proteins offer cheaper, sustainable alternatives to fishmeal, reducing the cost of production and improving the profitability of aquacuture.

AREAS OF INNOVATIVE FEED TECHNOLOGIES IN AQUACULTURE

One of the key challenges facing aquaculture producers is the development of sustainable and efficient feed technologies to support the growth and health of farmed species. In recent years, there has been a growing focus on the development of innovative feed technologies that can improve feed efficiency, reduce environmental impact, and enhance the nutritional quality of aquaculture products.

Innovative feed technologies in Aquaculture include the following:

1. Development of alternative ingredients in feed formulations
2. Use of functional feeds
3. Advances in feed processing technology
4. Implementation of automated feeding systems

Development of alternative ingredients in feed formulations

One of the most promising innovations in aquaculture feed technology is the use of sustainable alternative ingredients to replace traditional fishmeal and fish oil. Fishmeal and fish oil are valuable sources of protein and essential fatty acids which can be expensive (Udo and Dickson, 2017) and environmentally unsustainable. Traditionally, aquafeed has been primarily composed of fishmeal and fish oil, which are derived from wild-caught fish (Olufemi, 2024). However, the overexploitation of marine resources, rising costs and the increasing demand for aquafeed have led to the need for sustainable and cost-effective alternatives. Innovative feed technologies focus on utilizing alternative protein sources such as plant proteins, insect meal, algae and single-cell proteins to reduce the reliance on fishmeal and fish oil while maintaining the nutritional requirements of aquatic organisms (Olufemi, 2024).

Alternative Protein Sources in Aquaculture

Plant proteins: Plant proteins have gained popularity as a sustainable alternative to animal-based proteins in feed formulations. Fishmeal has frequently been replaced in aquaculture with plant proteins (Hameed *et al*., 2022). Soybean meal (44% protein content) and groundnut cake (43% protein content) are commonly used plant protein source in fish diets due to their high protein content and amino acid profile. These plant proteins are rich in essential amino acids and can provide a cost-effective and sustainable source of protein for aquaculture species. Rawles *et al*. (2018) reported that among the plant-based diets, soybean is considered the best to replace fishmeal due to its cost-effectiveness and nutritional value.

Insect meal: Insect meals are also being increasingly used as novel protein sources for fish diets. Insects are a rich source of protein, fat, and other nutrients, making them a promising feed ingredient for aquaculture. The protein part of insects' diets ranges from 50–82% (dry matter basis), comparable to fishmeal ranging from 60–72% by weight (Hameed *et al*., 2022). Insects such as housefly larvae (*Musca domestica*), black soldier fly larvae (*Hermetia illucens*), cricket (*Acheta domesticus*) and mealworms (*Tenebrio molitor*) are rich in protein and can be reared on organic waste water, making them a sustainable and environmentally friendly protein source for aquaculture (Irungu *et al*., 2018). Insect meal not only provides a sustainable source of protein but also helps to reduce food waste by utilizing organic by-products as feed for insects. Several studies reported that a significant effect has been observed in the growth performance of fish when fed with an insect-based meal (Hameed *et al*., 2022).

Microlgae: Microalgae have good nutritional profiles, which have emerged as good candidates for use in aquaculture (Oswald *et al*, 2019). Microalgae are rich in essential nutrients, such as omega-3 fatty acids, vitamins, and minerals, making them a valuable feed source for aquaculture. Spirulina and Chlorella are two types of microalgae that are commonly used in feed formulations due to their high nutritional value. Mucroalgae cultivation also has the potential to reduce the environmental impact of animal agriculture by utilizing wastewater as nutrients (Aragão *et al*., 2022) for algae growth.

Single-cell proteins: Single-cell proteins are a relatively new alternative ingredient that are frequently used as feed ingredients for fish due to their nutritional value (Udo and Dickson, 2017). Single-cell proteins are microbial proteins produced from microorganisms, such as yeast, bacteria, and fungi. Bacteria and yeast have the highest potential to replace fishmeal due to their good nutritional value. Bacteria and yeast have good amino acid profiles comparable to fishmeal and the protein content ranges from 50–80% and 45–55%, respectively (Hameed *et al*., 2022). These microorganisms can be grown on a variety of substrates, including agricultural byproducts and waste water, making them a sustainable and cost-effective protein source for aquaculture.

USE OF FUNCTIONAL FEED ADDITIVES

Feed additives are dietary ingredients that are incorporated into feed formulations not only for the usual provision of basic nutritional requirements as offered by traditional feed, but also to improve growth, immune responses, and disease resistance in fish (Onomu and Okuthe, 2024). Functional feeds are formulated to provide specific health benefits to aquatic species, such as improved growth, disease resistance, and stress tolerance. These feeds often contain additives such as probiotics, prebiotics, immunostimulants, and enzymes that promote gut health, improve nutrient absorption, and enhance disease resistance in farmed fish.

Functional feed additives in Aquacuture Production

Prebiotics: Prebiotics are non-digestible feed ingredients that stimulate the growth and activity of beneficial bacteria in the gut, such as Lactobacillus and Bifidobacterium. They can improve gut health, increase nutrient absorption, and boost immune function in animals (Onomu and Okuthe, 2024). In aquaculture, natural sources of prebiotics include ginger, onion, garlic, chives, tomatoes, and honey.

Probiotics: Probiotics are live microorganisms that confer health benefits to the fish when administered in adequate amounts. They help maintain a healthy gut microbiota by inhibiting the growth of pathogenic bacteria and promoting the growth of beneficial bacteria. Probiotics have been shown to improve growth performance, feed efficiency, disease resistance and boost immune function in fish by promoting favourable gut microflora (Onomu and Okuthe, 2024). For example, *Lactobacillus* spp., yeast such as *Saccharomyces cerevisiae* and *Bacillus* spp. are commonly used as probiotics in aquaculture to enhance the gut health of fish.

Enzymes: Enzymes are biological catalysts that facilitate the breakdown of complex nutrients into simpler forms that can be easily absorbed by aquatic animals. They play an important role in improving feed digestibility, nutrient utilization, and growth performance (Sarker, 2023). Enzymes such as proteases, lipases, and carbohydrases are commonly used in aquafeeds to enhance nutrient digestibility and reduce feed costs.

Immunostimulants are substances that enhance the immune response of fish, making them more resistant to pathogens and diseases. They can be natural compounds or synthetic molecules that activate the immune system and improve disease resistance. Immunostimulants such as β-glucans and nucleotides have been shown to enhance the immune response and disease resistance of fish.

ADVANCES IN FEED PROCESSING TECHNOLOGY

Advances in feed processing technology have also contributed to the development of innovative feed formulations for aquaculture. New technologies have been developing to process the ingredients that can improve the feed efficiency/feed conversion ratio, digestibility, and protein efficiency (Sarker, 2023). Technologies such as extrusion, pelleting, and encapsulation are used to enhance the physical and chemical properties of feeds, ensuring better feed intake and nutrient absorption by the target species. These techniques can be used to produce feeds with improved digestibility, palatability, and stability in water. These processing technologies can also be used to incorporate bioactive compounds such as antioxidants, antimicrobials, and growth promoters into feeds, further enhancing their nutritional value and health benefits for farmed fish.

Advances in Feed Processing Technology

Extrusion: Extrusion processing exposes ingredients to high temperatures and pressures over a short period of time (Sarker, 2023). This process not only improves the digestibility of nutrients but also enhances the palatability of the feed, feed intake, nutrient digestibility, and growth of fish. Extrusion also increase the availability of protein in feed ingredients, leading to better growth performance in fish. Additionally, extrusion can also be used to produce floating fish feeds, which are highly digestible and reduce feed wastage in aquaculture operations (Hu, 2022).

Pelleting is another widely used feed processing technology that involves compressing feed ingredients into pellets using a pellet mill. Pelleting helps to improve feed efficiency by reducing feed wastage and improving nutrient utilization by fish species. Pelleting can also improve feed conversion efficiency, handling and storage of feed, leading to reduced feed spoilage and improved feed hygiene (Hu, 2022).

Encapsulation is a relatively newer feed processing technology that involves coating feed ingredients with a protective layer to shield them from degradation during feed processing, storage, and digestion (Choi *et al*., 2021). Encapsulation can be used to protect sensitive nutrients such as vitamins, enzymes, and probiotics from degradation during feed processing and storage. The encapsulated nutrients are effectively preserved, maintaining their bioactivity and nutritional value until they are released at the desired site of action within the fish (Misra *et al*., 2023). This technology has been shown to enhance the shelf life of feed ingredients and improve their release in the digestive tract, leading to better nutrient absorption.

AUTOMATED FEEDING SYSTEMS

Innovative feed technologies also encompass the use of automated feeding systems (Olufemi, 2024). Automated feeding involves the precise delivery of feed based on the nutritional requirements of the fish and the environmental conditions of the aquaculture system. By utilizing AI-driven sensors, drones, and automated feeders, farmers can monitor the feeding behavior of their stocks in real-time and adjust feed rations accordingly. This not only improves feed efficiency and reduces waste but also minimizes the environmental impact of aquaculture by preventing excess nutrients from entering the water.

Automated feeding systems in Aquaculture

Sensors play a viral role in automated feeding systems by monitoring various parameters such as feed intake, body weight, and fish behavior (Liu *et al*., 2025). For example, electronic feeders equipped with sensors can track individual fish feeding patterns and adjust feed rations accordingly. This allows farmers to tailor feed programs to meet the specific needs of each fish, leading to improved feed efficiency and overall animal health.

Automated feeders are another key component of precision feeding systems, as they enable precise and consistent feeding schedules. These feeders can be programmed to dispense specific amounts of feed at designated times, ensuring that farmed fish receive the right amount of nutrients at the right time (Olufemi, 2024). This not only reduces feed wastage but also helps prevent overfeeding or underfeeding, which can have negative impacts on fish growth and performance.

Drones are emerging as a valuable tool in aquaculture management, particularly for monitoring fish health and feeding behavior. Some advanced drones are capable of distributing feed efficiently over large ponds, reducing the labor-intensive nature of manual feeding. The integration of drone technology into aquaculture operations reduces operational costs, and ensures efficient feed distribution across large areas.

Artificial Intelligence (AI): Artificial Intelligence (AI) improves fish feeding system in aquaculture by optimizing feeding schedules, reducing feed wastage, and improving fish growth rates. AI contributes to the formulation of personalized feeding programs tailored to meet the nutritional requirements of individual fish, improves growth rates, overall health and well-being of fish (Kaur *et al*., 2021). AI-driven systems analyze large datasets collected from sensors, cameras, and feeding records to determine the optimal feeding strategy for different fish species.

Challenges of adopting innovative feed techniques in aquaculture production in Nigeria

Despite these advancements, challenges remain in achieving widespread adoption of innovative feed techniques in aquaculture production in Nigeria. High initial costs, limited technical expertise, and regulatory hurdles can deter small-scale farmers from embracing new methods (Aragão *et al*., 2022). The financial

burden of implementing these technologies often limits their widespread adoption. Additionally, Many fish farmers lack the technical expertise to operate and maintain advanced feeding systems.

CONCLUSION

Innovative feed techniques have the potential to advance aquaculture production in Nigeria by improving the efficiency, sustainability, and profitability of the industry. By exploring the use of alternative feed ingredients, advanced feed processing technology, automated feeding systems and feed additives to enhance the nutritional quality of feeds, aquaculture producers can overcome the challenges of high feed costs and limited availability and help to meet the growing demand for fish in Nigeria. Continued research and investment in innovative feed techniques are essential for the growth and development of the aquaculture industry in Nigeria.

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