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Nonconventional Feed Resources for Sustainable Aquaculture: A Review

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ABSTRACT: The increasing need for aquafeeds has greatly strained conventional feed components like fish meal (FM), fish oil (FO), and soybean meal (SM), and raising concerns about sustainability, expense, and ecological damage. In order to meet those challenges, nonconventional feed resources have emerged to economically replace conventionally used feeds. Agricultural wastes, insect meal, earthworm meal, blood meal, tadpole meal, and aquatic plants are common examples of NCFRs, which are economically feasible and environmentally friendly, while achieving optimal fish growth, health, and feed efficiency. NCFRs further enhance resource use efficiency, waste recycling, and reduction in reliance on unsustainably harvested marine resources. However, nutrient inconsistency within these NCFRs along with anti-nutritional characteristics, low digestibility values, and policy restrictions must be addressed properly via advance feed processing techniques. This review aims to evaluate the prospects of including NCFRs in aquafeeds in terms of their nutritional profile, agro processing methods, advantages, and difficulties, particularly in the context of sustainable aquaculture development.

Keywords: Sustainability, Aquaculture Nutrition, Insect meal, By-products, Waste Utilization.

INTRODUCTION

Fish farming is often categorised into extensive, semi-intensive and intensive farming. The fast-paced growth of the aquaculture sector has led to an abrupt increase in intensive farming where the fishes are reared at high stocking density and are completely reliant in the feed provided. According to FAO (2022), total aquatic animal production is expected to reach 202 million tonnes by 2030, comprising of 96 million tonnes from capture fisheries and 106 million tonnes from aquaculture fisheries. By 2030, there is expected to be a 26 million metric tons (MT) increase in aquaculture production worldwide, necessitating an extra 40 million MT of feed (Albrektsen *et al.*, 2022; Almas *et al.*, 2020). Enhancing feed suitability and bolstering the global surge in fish production present an important task for aquaculture. For the past 20 years, feed formulation has undergone continuous improvements to increase feed sustainability and efficiency in aquaculture. Fish meal (FM), Soyabean meal (SM) and fish oil (FO) continue to be essential for high trophic level fishes, because these resources sufficiently satisfy the fish needs. The majority of fish species, especially the marine fishes, have essential fatty acid requirements that are met by the lipid profile of FO and FM and offers high-quality, easily digestible proteins with a balanced essential amino acid profile (Oliva-Teles *et al.*, 2015). Global fish production levels, including that of forage fisheries supplying FM and FO, are expected to stay relatively stable. However, aquaculture production and other products used in human nutrition, pharmaceuticals, and cosmetics are on the rise, resulting in a shortage of marine resources for aquaculture (Troell *et al.*, 2014). As a result, the aquaculture sector will eventually not be able to sustain the market value of FM and FO in the coming years.

A significant portion of conventional feedstuffs, such as fishmeal, fish oil and soybean meal, pose a great barrier to the sustainable development of aquaculture due to their availability and cost (Tacon & Metian 2015). Since the wild caught fish stocks are constantly being overfished, fish meal which has been traditionally the major protein source in aquaculture feeds is becoming harder to get and causing fears of overfishing and ecological sustainability (FAO, 2022). In recent years, the use of soybean meal as a substitute plant protein has gained acceptance; however, the production of soybeans competes with human food and it uses a great deal of land and water, thus doing more harm than good. Soyabean meal used to be considered a viable option but now poses as a threat and exacerbates socio-environmental issues (Gatlin *et al.*, 2007).

In light of these, attention is gradually shifting towards nonconventional feed resources (NCFRs) which could serve as potential alternative of protein and energy sources. NCFRs, are feeds that aren't typically found in markets or among the standard ingredients used to produce commercial fish feed (Abowei & Ekubo 2011; Madu *et al.*, 2003). They are cheap by-products from agriculture, farm feeds and processing industries serving as a form of waste management tool. They are not commonly used in large in fish feed production due to reasons such as being not well known or understood, not readily available, no thoughts of commercialising them, being toxic or poisonous. These include all types of feedstuffs from animal such as silkworm, maggot, termite, grub, earthworm, snail, tadpoles etc. and plant wastes and wastes from animal sources and processing of food for human consumption such as animal dung, offal, visceral, feathers, fish silage, bone, blood (Devendra, 1992).

Agricultural by-products, aquatic macrophyte, insect protein, and processed animal waste are some of the novel and unconventional feed ingredients that tend to encompass a wide variety of ingredients that can be used more sustainably and effectively (Madu *et al.,* 2003). These NCFRs have the potential to bring down the cost of fish feed because they are not only underutilized but are also available locally, therefore presenting an alternative for minimizing feed cost while reducing dependence on conventional protein sources (Abowei & Ekubo 2011).

The application of NCFRs is in accordance with the principles of circular economy, ensuring resource efficiency by recycling organic waste and minimizing environmental pollution. For example, black soldier fly larvae and housefly maggot insect protein is a high-protein substitute for fish meal, characterized by reduced environmental footprints and improved feed conversion rate (Van Huis *et al.,* 2013). Likewise, crop residues and aquatic plants like duckweed and water hyacinth are valuable protein and fibre resources and facilitate waste management and nutrient recycling in aquaculture production (Pratiwi & Andhikawati 2021).

The utilization of NCFRs in aquafeeds faces several challenges despite its potential benefits. Challenges such as variation in the nutrient content, the presence of potential anti-nutritional factors, digestibility problems, and regulatory concerns need to be addressed to achieve their full utilization in commercial fish feed products (Dedeke *et al.,* 2013). Improvements in feed processing technologies such as fermentation, enzymatic hydrolysis, and extrusion have been explored to improve the nutritional value and digestibility of unconventional feedstuffs (Drew *et al.,* 2007; Rojas and Stein 2017).

As compared to the augmented pressures on conventional feed sources, the applications of NCFRs offer a promising direction towards sustainable aquaculture. This review discuss the possibility of NCFRs and their nutrient composition, processing, and impacts on fish production efficiency, health, and growth.

ANIMAL-BASED NONCONVENTIONAL FEED INGREDIENTS

The incorporation of animal NCFRs in aquaculture has been seen as a shift from the traditional protein sources to tadpole meal, house fly larvae, animal droppings, earthworm meal, blood meal, krill meal, insect protein, and silkworm pupae meal in aquaculture. These are known to contain considerable amounts of protein, essential amino acids, and beneficial lipids leading to improved weight gain and feed conversion ratios (Abowei & Ekubo 2011).

Earthworm meal: Earthworm meal can be used as a cost-effective alternative to fish meal in aquaculture (Musyoka *et al*., 2019). They are soil dwellers that feeds on decaying leaves and other organic materials, which they subsequently excrete as worm caste. Commercial production involves the heaping of human and animal waste in areas with sufficient soil moisture or in swamps. Suitable earthworms are introduced which breeds in it while utilising the detritus as nutrients. After around six months, they are harvested by pulling up the earth and releasing the earthworms. They are processed by oven drying, smoking, pulverising and known to contain around 52% of crude protein and 18% of crude lipid (Beg *et al.,* 2016; Bhuvaneshwaran *et al*., 2019; Dedeke *et al.,* 2013).

Tadpole meal: Tadpole meal can also be used as a high protein source in fish feed processing (Sogbesan *et al*., 2009). Tadpoles can be raised in the same way as fish and harvested before they turn into frogs. They are then processed by drying in oven or smoking. Tadpole meal is reported to contain around 45-50% protein. They can be added whole to adult fish for immediate use, or grounded and combined with other ingredients at a ratio of 40-50%, subject to availability (Hindatu & Solomon 2017).

House fly larvae: Houseflies can be used in place of fish meal as an alternative protein source depending on nutritional value and availability (Abasubong, 2024). They thrive on decaying organic matter which can be prepared using fish or prawn waste mixed with finely ground maize or soybean powder, groundnut cake or palm kernel cake along with water and kept in the open for a few days. The maggots can be harvested when the quantity is satisfactorily high by diluting the paste and harvesting the larvae using a fine mesh sieve. After washing the maggots thoroughly, they can be processed by oven drying, smoking, pulverising or fed to the fish as a whole. According to numerous feeding tests conducted on a variety of aquaculture species, housefly maggot can increase growth and feed conversion ratio in fish diets without putting them through physiological stress. Incorporation of housefly maggot meal into fish diets has been found to help in reducing the feed cost. This is particularly beneficial in developing countries where fish meal is costly (Abowei & Ekubo 2011).

Blood meal: Blood mean can also be used in fish feed as a replacement of fish meal. Slaughterhouse wastes which also includes blood is highly digestible. It has high quality protein and is a good source of lysine and histidine (El-Haroun and Bureau 2007). According to Agbebi *et al*. (2009), juvenile *Clarias gariepinus* can have their fishmeal completely (100%) replaced with blood meal without experiencing any negative effects on growth, survival, or feed conversion. However, the amount of fishmeal replacement varied depending on the species and the size and feeding habits of the fish (Dedeke *et al*., 2013).

Animal droppings: Animal faeces, particularly the pig and chicken droppings, can be added to ponds as an organic fertilizer to encourage the growth of plankton. However, they can also be used as a direct source of food by collecting their faeces early in the morning while avoiding contamination with their urine. They can also be collected and left in the open to build up fly larvae. Animal wastes are known to contain 30% crude protein (Abowei & Ekubo 2011). ***Insect protein:*** Marine insects are an inherent part of the diets of the majority of wild fish and crustaceans. Mealworms, black soldier fly larvae meal and cricket meal are common examples of insect protein sources that are thought to be novel feed additives boosting the aquaculture feed. Black soldier fly larvae can convert organic waste into protein. They have a crude protein content of 40–44%, a calcium content of 7.56%, and a higher concentration of the majority of essential amino acids than soy meal. Furthermore, it is not known to carry any potential disease (Van Huis *et al.*, 2013).

Silkworm pupae meal: Fishmeal and dried silkworm pupae are known to have similar nutritional values with 52-72% of crude protein with a well- balanced amino acid profile rich in valine, methionine and phenylalanine (Hăbeanu *et al.,* 2024). Although silkworm pupae meal may be an excellent replacement for fish meal, it is also being targeted for human consumption (Wu *et al*., 2021). On the international market, dried silkworm pupa currently costs far more than FM. Furthermore, compared to using silkworm pupae meal in aquafeeds, the industrial use of bioactive peptides derived from silkworm pupae is much more lucrative as a source of highly valuable proteins and bioactive peptides (Altomare *et al.*, 2020). Hence, it is currently not economically feasible to replace FM with silkworm pupae meal.

Meat and bone meal: They are known to have high protein with around 55-60% crude protein, exhibiting a well-balanced amino acid profile (Moutinho, 2015). They are rich in digestible minerals, such as phosphorous and calcium and also lacks anti-nutritional factors (Suloma *et al.*, 2013). However, it has high ash content which limits it's used in fish diets (Bureau *et al.*, 1999).

Krill meal: It contains approximately 33%–55% protein with balanced amino acids, 25% lipids (40% of which are phospholipids), omega-3 fatty acids (EPA and DHA), and astaxanthin. It is also rich in soluble substances such as TMAO, free amino acids, nucleotides, and chitin. It acts as a feeding stimulant, increases palatability and helps in fast growth (Kaur *et al.*, 2022).

Integrating these NCFRs resources in fish feed poses a number of challenges to their basic composition's variability, the costs associated with their processing, and even their possible contamination. However, the increasing use of these materials enhances sustainability and decreases the reliance on traditional fish meal diets and can serve as a viable alternative to fish meals.

PLANT-BASED NONCONVENTIONAL FEED INGREDIENTS

The use of plant-based NCFRs helps a great deal in replacing the conventional fish feed while reducing the expenses associated with fishmeal and soybean meal, making them a more economically viable choice (Ivan *et al.*, 2024). Macrophyte plants such as hydrilla, lotus, waterlettuce, duckweed, and water hyacinth along with azolla and certain unusual pulses such as mucuna, winged beans, broad beans, and bread beans have been studied for their possible use in aquaculture as plant-based NCFRs (Abowei & Ekubo 2011; Pratiwi & Andhikawati 2021).

Leaf protein: Leaf proteins can replace fish meal in aquafeeds due to the presence of high protein content and essential amino acids. Studies have shown that leaf meals such as amaranth and cassava leaves can substitute fish meal partially without affecting fish growth, nutrient retention, or feed efficiency. This suggest that leaf proteins could potentially replace fish meal in aquaculture in a sustainable, low-cost manner (Ngugi *et al.*, 2017; Olude *et al*., 2023.

Aquatic macrophytes: They are viable alternatives to fish meal in aquafeeds due to their high protein content, essential amino acids, and bioactive compounds (Naseem *et al.*, 2021). They are rooted flowering plants growing along the edges of water bodies, rooted flowering plants with submerged leaves (hydrilla), rooted flowering plants with floating leaves (lotus), free floating plants (water lettuce, duckweed, water hyacinth, etc). Aquatic macrophytes such as water hyacinth contains most of the essential nutrients required, it can be used as one of the raw material replacing fish meal. It also contains secondary metabolites enhancing its property as an antibacterial agent (Pratiwi & Andhikawati 2021).

Unconventional pulses: These include a wide variety of legumes that are used as cover crops but are not eaten because they may contain toxic substances such as trypsin inhibitors and hydrogen cyanide which can be eliminated by heat processing techniques like toasting, steaming, boiling, and drying. The notable ones are broad beans, winged beans, mucuna beans, etc. They're a great binder as they contain 50–60% carbohydrates but low in protein with18–20% and 3–10% of fat (Abowei & Ekubo 2011). Unconventional pulses can potentially be used in fish feed as a low cost NCFRs.

These plant-based NCFRs are important supplementary nutritional sources for fish as growth supportive nutrition is crucial for the health and growth of the fish. With the use of proper processing techniques, their digestibility along with nutrient uptake can be improved which results in better feed conversion. The use of technology in aquaculture feeds helps promote more eco-friendly ways to farm fish as there is less reliance on traditional feed material. The use of these resources also helps reduce waste and improves the use of available resources, hence providing additional support for environmental sustainability.

CONCLUSIONS

NCFRs offers the potential to improve aquaculture's sustainability by decreasing the reliance on conventional ingredients such as fishmeal and soybean meal. These feed alternatives not only come from agricultural waste, aquatic vegetation, and animal proteins like insect larvae and earthworm meal, but also promote the principles of circular economy through waste valorisation and eco-friendliness. Although challenges with nutrient variability, anti-nutritional components, and digestibility are present, newer feed processing technologies like fermentation, enzymatic hydrolysis, and extrusion can improve their nutritional value and digestibility. The aquaculture industry's shift towards more affordable and greener practices, all while preserving food security, can help counter their ecological challenge NCFRs aid in value addition, however, more investigation in restricting feed formulation, regulatory policies, and long-term impacts on the fish's health and growth performance is essential. For the increased adoption and commercialization of these alternate feed resources, more integration between researchers, lawmakers, and industry experts is necessary.

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