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EDITORIAL

Novel Protein Ingredients in Aquafeed

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Abstract: As the fastest-growing food producer in the world, aquaculture plays a crucial role in ensuring global food and nutritional security. Nearly 70% of the aquaculture production is represented by fed aquaculture, in which the provision of nutritionally balanced formulated aquafeed is compulsory. Fish meal and fish oil derived from wild-captured small-pelagic fish are major components of aquafeed. Unsustainability in wild-captured fish, escalating market demand, uncertainties in future supply and prices are forcing fish nutritionists to evaluate and utilize alternative novel ingredients for aquafeed. By-products of fishery and aquaculture, insect meals, food waste, macroalgae, and a variety of single-cell organisms have been identified as potential ingredients in future aquafeed and it will ensure the sustainability of fed aquaculture. This editorial note discusses the utilization of alternative novel protein ingredients in aquafeed to ensure an economically and environmentally sound future for the aquaculture industry.

Keywords: Fish meal, Insect meal, Single-Cell-Organisms, fed-aquaculture nutrition,

Introduction

The aquaculture industry has been recognized as one of the key contributors to global food security and nutrition in the twenty-first century. The global population rises together with other critical issues such as land and water scarcity, pushing the aquaculture industry to accelerate production to meet the increasing demand. Aquaculture production basically comes under two categories ‘‘unfed’’ and ‘‘fed’’. Suppling of food from the production ecosystem itself (e.g., filter feeders such as silver carp, and bivalves) is the common practice in unfed aquaculture while supplying high-protein aqua-feed is an essential component in fed aquaculture. Fed aquaculture is the largest component of the sector, and it relies on supplying animals with formulated aquafeed or whole or processed fish.

Historically, fish meal and fish oil derived from wild-captured small pelagic fish are utilized as the major components of the formulated feed. Unfortunately, the intensification of aquaculture production has mounted significant pressure on wild fish stocks. According to Naylor et al., (2009), approximately 10% of fish biomass of capture fisheries is utilized to formulate aquafeed for high-value species in fed aquaculture.

Although fishmeal is considered an ideal source of protein for aquafeed, the aquaculture industry is shifting to search for alternative protein sources to replace fishmeal due to an increase in market demand, prices, and environmental concerns. During the last three decades, a variety of plant protein sources including soybean meal, corn gluten meal, rapeseed meal, and animal by-products such as meat and bone meal, and poultry meal have been tested and used to replace the fish meal component of aquafeed. Although these plant-based protein alternatives served as important components of aquafeed, their usage as protein sources is limited by a combination of factors including the presence of anti-nutritional elements, and difficulty in expanding production without putting additional pressure on land and water. Therefore, finding cost-effective protein sources to meet the increasing demand for aquafeed is critical. This

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editorial considers emerging, novel protein ingredients that could be utilized as alternative sources for the protein provided by fishmeal and highlights the opportunities, and discusses the potential hurdles of using alternative novel feed ingredients in aquafeed.

Novel protein ingredients

Searching and evaluating alternative protein sources to replace marine-derived ingredients from aquafeed and address the cost and sustainability issues is a great challenge in aquaculture. The requirement of identifying and evaluating sustainable ingredients for aquafeed is ever-rising and by-products of fisheries and aquaculture, insect meal, food waste, macroalgae, and a variety of single-cell organisms received attention as emerging protein sources. Attributes of these novel protein ingredients include high nutrient profile, low price, and availability, low or no utilization as a human food, and support to several 2030 Sustainable Development Goals (SDGs).

By-products of fisheries and aquaculture

By-products of fisheries and aquaculture are the raw materials that turn out when fish are processed for human consumption. About 50% - 70% of the fisheries and aquaculture by-products typically consisted of trimmings including head, skin, bone, and viscera, and are considered ‘‘inedible’’. This inedible portion of fish which is removed after processing has huge potential to replace fish meal from aquafeed as those by-products are rich in essential nutrients. Nevertheless, these products are still underused. The inclusion of fishery and aquaculture by-products to replace fishmeal components in aquafeed that contained higher levels of plant proteins exhibited positive results on performances in fish (García-Romero et al. 2014; Gisbert et al., 2018).

Intensification and expansion of the aquaculture industry, create a huge potential and opportunity to utilize the by-products as an alternative for fishmeal in aquafeed. This would accompany several added advantages including environmental sustainability, provision of downstream processing jobs, enhancing economic and social benefits through the utilization of processing by-products and thereby ensuring the long-term sustainability of the aquaculture industry.

Insect meal

Insect meal is becoming an emerging source of protein for fishmeal replacements in aquafeed. A combination of factors including the amino acid and other nutritional composition of insects, the role of insects in the natural diet of fish, and ease of propagation have made them a good candidate in fishmeal replacement studies. It is reported that there is 42% to 63.3% crude protein in insects (Alfiko et al., 2022), and 34% to 74% protein in insect meal on a dry matter basis (Freccia et al., 2020; Gasco et al., 2020). The nutritional value of insect meal is enhanced by its amino acid profile, fatty acid profile, presence of several vitamins, and minerals such as iron and zinc (Gasco et al., 2020). The amino acid profile of insect meal resembles that of fishmeal. In addition, the presence of antimicrobial properties, bioactive compounds, antioxidants, and prebiotics, (Gasco et al., 2020) is also beneficial when utilizing insect meal in aquafeed.

A variety of insects representing orders Diptera, Diptyoptera, Hemiptera, Hymenoptera, Coleoptera, and Lepidoptera are used to produce insect meal (Henry et al., 2015). Among them, the common housefly (*Musca domestica*), black soldier fly (*Hermetia illucens*) and the yellow mealworm (*Tenebrio molitor*) are highly tested in fishmeal replacement studies (Iaconisi et al., 2017; Gasco et al., 2020). The amino acid profiles of insects vary with the taxon and species, and the order Diptera shows similar amino acid profiles to that of fish meal (Barroso et al., 2014).

Insects have been utilized in aquafeed in different forms such as meal, pulp (Xu et al., 2020), and insect paste (Weththasinghe et al., 2021). However, a full-fat or defatted meal is the most common form of insect in aquafeed. Although the incorporation of insect meal in aquafeed has been evaluated in many aquaculture species, a limited number of research has been done to evaluate the optimal level of inclusion.

Insect meal successfully replaced the whole fishmeal in Common carp, *Cyprinus carpio* (Zhou et al., 2018), and European seabass; *Dicentrarchus labrax*

(Magalhães et al., 2017), while a partial fishmeal substitution was reported in blackspot seabream; *Pagellus bogaraveo*; (Iaconisi et al., 2017), and Nile tilapia; *Oreochromis niloticus* (Wachira et al., 2021).

The production of insect meal has no competition with human food production. In addition, the short life cycle of insects together with their ability to grow on different substrates has made the insect meal an ideal novel protein ingredient to substitute fish meal in aquafeed.

Single-cell protein (SCP)

A wide range of microbial sources such as yeast, microalgae, and other bacteria and fungi has been evaluated to check their suitability for aquafeed. Many of the single-cell protein products exhibit unique advantages when utilized in aquafeed.

Marine microalgae are a good source of proteins and fatty acids and, thus, there is a huge potential to replace fishmeal and fish oil in diets of high-value fish species including salmonids. Certain marine microalgae such as *Nannochloropsis oculata*, *Isochrysis* sp., and *Schizochytrium* sp. have been identified as potential protein sources for aquafeed as they are rich in eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), protein, essential amino acids, lipids, and minerals. *Isochrysis* sp. is a macroalgae rich in essential amino acids and fatty acids and therefore it has been identified as a substitute for fishmeal and fish oil in rainbow trout diets (Sarker et al., 2020). Lipids extracted from *Desmodesmus* sp. could also be utilized (20%) in the salmon without compromising the growth and fillet composition of fish (Kiron et al., 2016). Further, co-products (leftover biomass oil extraction) of defatted *Nannochloropsis oculata* successfully incorporated for tilapia and Atlantic salmon diets up to 33% and 10% respectively without compromising either the growth or health performances of fish (Sarker et al., 2018). The use of defatted microalgae as a novel protein ingredient in aquafeed provides a unique advantage by supplementing the diet with n-3 polyunsaturated fatty acids (PUFAs).

Yeasts are another potential sustainable ingredient in future aquafeed due to their capability of converting non-food biomass into high-value feedstuff that does not depend on water and arable land (Lapeña et al., 2020a; Lapeña et al., 2020b). It is reported that yeast cells contain 40-55% crude protein, and certain bioactive components important in the growth of fish (Hansen et al., 2019; Rawling et al., 2019). Among different species of yeasts, *Saccharomyces cerevisiae*, *Kluyveromyces marxianus*, *Cyberlindnera jadinii* *Wickerhamomyces anomalus* and *Blastobotrys adeninivorans* have great potential to utilize in aquafeed.

However, only limited research has been conducted to evaluate the suitability of yeast as a protein ingredient in fish feeds and *S. cerevisiae* is the highly studied yeast in aquaculture. Nguyen et al., (2019) showed the possibility of substituting 60% fishmeal protein in freshwater prawn diets with *S. cerevisiae* in a biofloc system. Fronte et al., (2019) reported the possibility of partial replacement of fishmeal (20%) with *S. cerevisiae* without compromising growth in gilthead sea bream (*Sparus aurata*).

Macroalgae

Marine macroalgae generally known as seaweed have the potential to be utilized as a dietary ingredient in aquafeed. In comparison to conventional feed ingredients, macroalgae offer certain benefits other than just a supply of nutrients. It includes pigments, secondary metabolites, and defensive compounds, and hence, marine macroalgae has a beneficial effect on farmed fish. The use of macroalgae and algal extracts in aquafeed has shown positive effects on growth performance, general health, and the immune status of fish.

Although there are beneficial effects of using macroalgae as feedstuff, only a limited number of algal species have been evaluated as potential components in aquafeed. The amino acid composition and the level of protein in macroalgae is species-specific, and therefore it is unfeasible to generalize the usefulness of whole macroalgae as a potential protein source for aquafeed.

Potential hurdles in the utilization of novel feed ingredients

Utilization of novel ingredients in aquafeed cannot be performed in a single step. It requires several steps of nutritional trials which include the evaluation of the nutritional profile, nutritional value, overall palatability, and digestibility of every ingredient. Further, it requires lengthy nutritional trials with formulated feed that incorporates novel feed ingredients. Such feed trials should be conducted not only in the laboratory but also in the field/commercial farms. In addition, additional processing steps are required for certain ingredients to reduce the antinutritional factors and to improve their digestibility, and the Feed Conversion Ratio (FCR). Finally, a comprehensive economic analysis is required to check the cost-competitiveness of unconventional ingredients in aquafeed over conventional ingredients.

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