**Aquafeed Innovation: Utilization of Molluscan and Crustacean By-products for Sustainable Fish Nutrition**

**Abstract**

The growing need for sustainable aquafeeds has accelerated the quest for alternative protein sources to substitute fishmeal, which is expensive and eco-unfriendly. Molluscan and crustacean byproducts such as snail and shrimp shell, clam, crab meal, and mussel shell and powder provide a good source of proteins, essential fatty acids, chitin, and minerals that support growth, immunity, and health of fish. These by-products, commonly viewed as waste, have the potential to drive the circular economy through minimizing environmental effects while enhancing feed efficiency. This review explores the nutritional quality, bioactivity, and processing of molluscan and crustacean by-products, highlighting their benefits and challenges in aquafeed formulation. Despite differences in nutrient content and limitations in processing, their use in aquafeeds has enormous potential for encouraging low-cost and sustainable aquaculture. Further research is needed to refine processing methods, evaluate safety, and facilitate large-scale use in commercial feed manufacturing.

**Keywords:** Aquafeed, Byproducts, Waste utilization, Fishmeal, Chitin

**Introduction**

Aquaculture is one of the fastest-growing food sectors, providing 49 % of the global fish, crustaceans and molluscs supply with significant contributions towards food security and economic growth (Action, 2020). However, nutrition, sustainability, and sourcing economically balanced fish feed for the growing demand of farmed fish is of major concern today. The primary protein source in aqua-feeds is fishmeal, which is mostly obtained from wild and thrash fish. This practice leads to overfishing and destruction of the ecosystem. Furthermore, due to the volatile and high pricing of fishmeal, researchers are motivated to find alternative cheaper protein sources that do not adversely affect the health and growth performance of the fish (Olsen & Hasan, 2012; Tacon & Metian, 2015).

Byproducts of mollusc and crustacean, such as snail and shrimp shells, crab meal, mussel powder and other byproducts, are a richer source of proteins, essential amino acids, polyunsaturated fatty acids, chitin and other minerals like calcium and phosphorus. These are usually considered waste in the food processing sector for other industries. These waste products greatly assist in improving the nutrition and health aspects of farmed fishes (Eggink et al., 2025; Malaweera & Wijesundara, 2013). Using these ingredients helps to lower the value of fishmeal dependency in aqua-feed and significantly enhances the valorization of waste which supports the principles of the circular economy.

Utilization of byproducts derived from molluscs and crustaceans for fish feed formulation has shown promising results in a number of studies. For example, shrimp and clam meats supplementation were shown to improve growth performance and immune functions alongside disease resistance in *Oreochromis niloticus* and *Labeo rohita* (Begum et al., 1994; Fall et al., 2020). Furthermore, altered pigmentation, gut health, and stress tolerance in fish have been associated with the presence of bioactive components such as astaxanthin and chitin contained in byproducts of crustaceans and molluscs (Lim et al., 2018). The process of utilizing molluscan and crustacean by-products as ingredients in producing fishfeed involves multiple steps, ranging from the collection of raw materials to processing and addition to formulated feed. Figure 1 presents the process highlighting key steps for maximizing their nutritional potential in aquafeed.



Figure 1. Processing of molluscan and crustacean byproducts into aquafeed

Although there are benefits, several challenges still exist on how best to efficiently utilize the byproducts of molluscs and crustaceans in aquafeeds. Variability in nutrient makeup, the existence of anti-nutritional factors, and lack of adequate processing to improve digestibility and bioavailability need to be addressed properly (Beltran et al., 2001). Also, in order for large scale industrial application to take place, cost and regulatory compliance need to be evaluated to guarantee sustainable and safe standards.

This review provides a comprehensive analysis of the feasibility of using molluscan and crustacean byproducts as major components in fish feed formulation. It explores their nutritional value and processing techniques as well as their effects on fish health and growth, and the challenges linked with incorporation into commercial aquafeeds. By properly utilizing these underutilized resources, the aquaculture industry can move towards cost-effective feeding strategies and sustainable supply of fish feed.

**Nutritional Composition of Molluscan and Crustacean Byproducts**

Molluscs and crustaceans byproducts are extremely nutritious and contain bioactive ingredients which greatly help in fish growth, health, and performance in aquaculture. With shells and soft tissues from snails and shrimp, crab, mussels, oysters, squid, and clam, these byproducts form the viscera and exoskeletons are commonly sourced from seafood processing industries. These byproducts are very valuable as constituents of aquafeeds, due to the presence of high levels of protein, essential fatty acids, chitin, and other important minerals. Furthermore, bioactive compounds present in theses byproducts are known to enhance the metabolism, immunity, and pigmentation of farmed fish.

*1. Protein Content and Amino Acid Profile*

The fish meal substitutes, such as shellfish meals obtained from mussels, oysters, and clams, contribute about 50 to 70% of crude protein. Depending on the mollusc and crustaceans species used, the processing methods of such byproducts influences the final protein concentration (Mohammad & Yusuf, 2016; Muntean et al., 2024). It has been found that crustacean byproducts such as crab and shrimp waste provides between 30-60% of protein, based on processing and extraction methods (Ashraf et al., 2024; Jeyaprakashsabari & Aanand, 2021).

Essential amino acids such as lysine, methionine, arginine, and taurine are present in these byproducts. Notably, amongst all these components, taurine is dominant in squid and mussel meals of molluscan byproducts. It helps in osmoregulation, formation of bile salts, and especially, during neurological development in a carnivorous fish such as seabass and salmon, which have minimal capabilities for taurine biosynthesis (Kotzamanis et al., 2020).

*2. Lipid Content and Essential Fatty Acids*

Byproducts of molluscs and crustaceans are known to be a good sources long-chain polyunsaturated fatty acids (LC-PUFA) like eicosapentaenoic acid (EPA, 20:5n-3) and docosahexaenoic acid (DHA, 22:6n-3) (Abedi & Sahari, 2014). These are needed for fish growth, and proper neural as well as immune system development. Several studies reports the presence of large quantities of polyunsaturated fatty acids (PUFAs), primarily EPA and DHA, in shrimp and crab waste. Such PUFAs positively influence the feed conversion ratios (FCRs) and disease resistance while enhancing reproductive output among aquaculture species (An et al., 2023).

Squid liver oil, which is derived from the processing of squid, is another remarkable lipid source as it has 20–30% of crude fat with high DHA and EPA content. These fatty acids aid in reducing oxidative stress, improving the function of cell membranes, and thus increasing the health status along with survival of fish larvae and juveniles (Hossain et al., 2024).

*3. Chitin and Its Bioactive Property*

The byproducts of crustaceans, primarily shrimps and crabs, are an excellent sources of chitin, a bioactive polysaccharide which possesses appreciable value in aquaculture. Both chitin and its derivative, chitosan have been frequently studied for biomedical and immune-stimulating as well as prebiotic applications. Inclusion of chitin in fish diet increases the gut health through enhancing the beneficial gut microbiota and boosting mucosal immunity which aids in disease resistance (Gopalakannan & Arul, 2006).

Chitin has been shown to enhance growth performance and reduce feed wastage through improvement of digestive enzyme function and nutrient uptake. In addition, chitin and chitosan are effective at reducing pathogenic infections in aquaculture systems due to their antibacterial properties (Qin et al., 2014).

*4. Mineral Content: Calcium, Phosphorus, and Trace Elements*

By-products of molluscs and crustaceans have great potential as sources of minerals like calcium (Ca) and phosphorus (P) which are important for the development of bones, osmoregulation, and enzymatic activities in fish. Cross-linked calcium phosphate that occurs in molluscan shells and crustacean exoskeletons, together with the calcium to phosphorus ratio in these materials, increases their suitability as dietary supplements for prevention of skeletal deformities and effective bone mineralization in rapidly growing fish species (Malaweera & Wijesundara, 2013; Suprijanto & Widowati, 2024).

Furthermore, other important trace elements such as zinc (Zn), selenium (Se), copper (Cu), are present in molluscan by-products and are also important for some enzymatic processes, antioxidant actions, and functions of immunity. For instance, zinc and selenium are known to improve antioxidant and stress tolerance thus, are useful for fish under intensive aquaculture conditions (El‐Sayed et al., 2023).

**Molluscs and Crustaceans Byproducts Processing and its Utilization in Fish Feed**

Effective processing methods for molluscan and crustacean byproducts must be developed to ensure the byproducts are useful in fish feed formulations and bioavailable in nutrients, easy to digest, and non-toxic. Untreated shellfish and crustacean wastes are composed of non-digestible chitin, heavy metals, and microorganisms which are harmful to fish health (Eggink et al., 2025). Furthermore, these byproducts are very moist and can spoil rapidly, meaning further preservative action is required to keep the feed in good condition. These byproducts, if processed properly, can become stable and nutritious which would benefit and promote the health and growth of fish.

Fermentation is one of the most important bioprocessing techniques which improves digestion by converting chitin, proteins, and lipids into simpler, usable forms (Siddik et al., 2024). It encourages the multiplication of probiotic microorganisms such as *Lactobacillus* spp. and *Bacillus* spp. which enhance gut health and the ability to resist further infections. Additionally, fermentation, through microbial biotransformation, eliminates and transforms harmful substances including some heavy metals and biogenic amines. It has been demonstrated that fermented byproducts based diets increase Feed Conversion Ration (FCRs) and immune responses of tilapia and carp (Dawood et al., 2020; Phinyo et al., 2025).

Another method of processing for molluscan and crustacean byproducts is through enzymatic hydrolysis which involves the use of proteolytic enzymes to break down proteins into bioactive peptides with antimicrobial and antioxidant properties. Hydrolyzed proteins increase the palatability of feed and are advantageous to larval and juvenile fish with undeveloped digestive tracts due to their easily digestible nature (Alves et al., 2020). Hydrolyzed molluscs and crustacean protein is becoming more popular in commercial fish feeds because of their immune-stimulatory effects (Córdova & Garcı́a, 2002; Harnedy et al., 2012). Dehydration and grinding processes like sun drying, oven drying, and spray drying extend the storage life of by-products while retaining their nutrients.

Extrusion is an advanced processing technique that increases the value of these byproducts in fish feed by increasing the degree of nutrient gelatinization, protein emulsification, and the durability of the pellets (Pennells et al., 2025). Acid preservation and silage production using organic acids to ferment unused seafood waste provides economical methods of making digestible fish silage (Gildberg, 2001). Although these methods increase nutrient bioavailability, monitoring chitin digestibility and heavy metal contamination poses a challenge (Gopalakannan & Arul, 2011).

Using the byproducts from mollusc and crustacean processing for fish feed is a novel way of achieving sustainability in aquaculture nutrition. Through the use of fermentation, enzymatic hydrolysis, drying, extrusion, and acid preservation techniques, these bio waste can be transformed into high-value fish feed ingredients that promote the growth and health of farmed fish which will further support the sustainable expansion of aquaculture while reducing seafood industry waste.

**Application of Molluscan and Crustacean Byproducts in Aquafeeds**

The byproducts of molluscs and crustaceans in aquafeeds has been earmarked as an innovative and economical substitute to fishmeal. These byproducts contain high-quality proteins, essential fatty acids, and other bioactive compounds which help in improving growth, feed efficiency and health of fishes. Studies have shown that the utilization of shellfish and crustacean meals improves feed conversion efficiency of a number of aquaculture species and aids in the sustainable practices of aquaculture (El-Sayed, 2023). In tilapia (*Oreochromis niloticus*), growth performance and feed conversion ratios (FCRs) were enhanced with the substitution of fishmeal with mussels, oysters, and clams due to their high digestibility and reasonable level of amino acids.

Shrimp and crab meal are crustacean byproducts, which have been known to be incorporated into the feeds of carnivorous fishes like salmon, trout and seabass (*Dicentrarchus labrax*). They are known to improve the attractiveness of the feed because of their natural constituents such as free amino acids and nucleotides (Eggink et al., 2025). In addition, the fish feed is enriched with astaxanthin, a carotenoid pigment which improves the flesh and skin colour, and subsequently increases the market value of koi (*Cyprinus rubrofuscus*) (Panjaitan, 2023). In addition to enhancing colour characteristics, the bioactive components of byproducts from molluscs and crustaceans, have been reported to enhance immune responses, gut health, and decrease the rate of bacterial infections in cultured fish (El‐Sayed et al., 2023). The use of these ingredients helps to make fish production healthier and more sustainable by lowering disease incidence and reducing the use of antibiotics.

The use of byproducts of molluscan and crustacean processing also posses an equally important role in promoting environmental sustainability. Using seafood waste as an alternative protein source helps to reduce fishing pressure on wild captured fishmeal, strengthens the circular economy, and decreases organic waste disposal (Tacon & Metian, 2015). Some fish species have been reported to perform well, and in many cases, better when a part of fishmeal is substituted with shell and crustacean meals (Malaweera & Wijesundara, 2013). Byproducts of molluscan and crustacean, thus, show promise as good substitute fish feeds. On the down side, there is still lack of adequate processing and quality control that can eliminate the uncertainty of nutrients, excessive chitin, and heavy metals harmful contamination. Further research and development could make their incorporation into aquafeeds more cost effective, ecologically beneficial, and sustainable for the aquaculture industry.

**Molluscan and Crustacean Byproducts Importance**

Including the by-products of molluscs and crustaceans in fish diets can be economically and ecologically advantageous because it helps tackle seafood waste, lowers pollution, and eases dependence on fishmeal from captured stocks (Tacon and Metian, 2015). In light of concerns regarding the overexploitation and exhaustion of small pelagic fish, some measures such as the use of meiobenthic invertebrates as protein sources help save the environment and, at the same time, aid in marine conservation (Huang et al, 2020). These byproducts are nutritionally beneficial because they are well digested and are abundant in essential amino acids, omega-3 fatty acids, and other bioactive substances which, in turn, enhance fish growth, immunity, and feed efficiency (Ashraf et al., 2024). Moreover, the immune-boosting effects of chitin, peptides, and nucleotides have contributed to lower incidence of diseases and hence lessen the need for antibiotics and chemical additives in aquaculture. These byproducts are readily used and this property leads to lower feed conversion ratios (FCRs) which signifies achieving an acceptable level of growth per unit of feed consumed (An et al., 2023). The integration of molluscan and crustacean by-products in aquafeeds can assist fish farmers to get more profits and at the same time ensure proper environmental care.

**Challenges and Limitations**

Despite the enormous benefits of byproducts of mollusc and crustacea, several challenges hinder the maximum utilization of use of theses byproducts in aquafeeds. Chitin’s inability to be digested is one of the greatest obstacles underpinning the use of crustacean and molluscan byproducts for aquafeeds. Chitin is a tough polysaccharide that needs to go through fermentation or enzymatic treatments to boost nutrient absorption. By and large, heavy metal contamination of molluscs is another challenge. The capital outlays required for enzymatic hydrolysis and fermentation is very high for small-scale aquafeed producers. Future research is needed to optimize these byproducts processing techniques and develop low cost-effective methods for incorporating these byproducts into fish feeds. Future studies should also focus on improving chitin transformability with microbial fermentation and exploring novel bioactive compounds that improve fish health.

**Conclusion**

The substitution of fishmeal with molluscan and crustacean byproducts in aquafeeds is economical and environmentally friendly, while also improving fish growth, immunity, and overall health. The utilization of these byproducts not only reduces dependence on wild fish stocks but also helps in waste reutilization communally known as a circular economy. Nevertheless, issues such as variability in nutrients, anti-nutritional elements, and limitations to processing technologies must be solved in order to be fully optimized. More studies are required to simplify and perfect the processing methods while ensuring safe standards and economically satisfying conditions to help with mass adoption of the products. Incorporating these byproducts into aquafeeds will allow the aquaculture industry to considerably improve the feeding production plans toward sustainable and efficient strategies, thus improving the global food supply without a negative effect on the ecosystem.

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