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NEW PERSPECTIVES ON THE UTILIZATION OF INSECTS AS A FEED SOURCE IN AQUACULTURE

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Aquaculture plays a pivotal role in global food security by producing a significant portion of the world's fish and seafood. However, challenges such as soaring prices of conventional feed ingredients and the over-exploitation of natural resources hinder its production. To address these challenges, innovative strategies, particularly the use of non-conventional feed ingredients, are being explored in aquaculture. This includes incorporating plant-based products, algae, single-cell protein, and insect meal to ensure sustainable food production. Among these alternatives, insects show substantial promise as a substitute for fishmeal. The vast amount of food and agriculture waste, approximately 1.3 billion tons from the supply chain, poses a significant environmental threat. Insects, being small organisms, can thrive on organic waste, offering a solution for bioconversion and nutritional up-cycling. With the ability to recover nutrients from waste aquaculture products and the natural inclination of many fish species to feed on insects, incorporating insects into aquaculture practices emerges as an environmentally friendly approach. This article provides insights into emerging non-conventional feed ingredients, with a particular focus on insects. It delves into the nutritional value of insects, the factors influencing it, potential insect species suitable for aquaculture, the physiological response of fish to insect meal, techno-functional properties of insect meal, and innovative approaches to address potential drawbacks. The review concludes by suggesting avenues for further research into these inventive fishmeal replacements.

Environmental Benefits of Incorporating Insects into Fishmeal Diets

Global environmental challenges, such as the excessive use of natural resources, loss of biodiversity, and escalating pollution levels, have a direct impact on the Earth's climate. This reality is substantiated by scientific reports and data spanning the last few decades

(Almond et al., 2020). Diverse strategies have been implemented to address these environmental issues, with the bioeconomy concept emerging prominently. Bioeconomy is centered on the utilization of food waste or algae (Fraga-Corral et al., 2022). The rapid growth of the world population necessitates a continuous supply of protein while minimizing environmental repercussions (Tilman & Clark, 2014). Recent research indicates that adopting insect-based meals could have a positive environmental impact when carefully selecting the diet. For instance, integrating yellow mealworms into the rainbow trout diet led to a decrease in net primary production use, although it did not alter land use, global warming potential, eutrophication, or energy demand. Conversely, the inclusion of *Hermetia illucens* in the arctic char diet demonstrated notable reductions in environmental impacts, specifically abiotic depletion, global warming potential, acidification, and land use. These findings highlight the potential of insect-based diets to mitigate environmental concerns in aquaculture.

Nutrient Content of Insects

Globally, there exist approximately one million insect species, playing indispensable roles in maintaining the balance of food chains and ecosystems. Despite the prevailing perception of insects as pests among the majority of Europeans, these creatures serve as a dietary staple in 100 countries (De Castro et al., 2018). Insects, constituting the largest class of arthropods, have a rich history as a human food source, with certain species, such as silkworms and honeybees, being successfully domesticated (Lecocq, 2019). Recognized for their high protein content, insects are increasingly considered a valuable alternative to fishmeal, especially as aquaculture production continues to expand. In addition to their protein richness, insects offer a well-balanced amino acid composition and high digestibility, making them suitable substitutes for fishmeal in the aquaculture industry. While numerous insect species have the potential to serve as food, only a select few have been successfully domesticated. The protein content in insects varies from 25 to 75 percent (DM) and is characterized by a favourable amino acid profile (Finke, 2015; Oonincx et al., 2011). The protein factor calculated by multiplying nitrogen content by protein, is established at 6.2, providing a reliable measure for determining crude protein content in insect-based meals. Overall, insects emerge as an excellent protein source for aquaculture, aligning with the increasing demand for sustainable alternatives to traditional feed sources like fishmeal.

Functional Characteristics of Insect Meals

Insect proteins exhibit numerous favourable characteristics that make them suitable for both food and feed applications. However, a crucial step in their integration into food and feed is the assessment of their functional properties (Gravel & Doyen, 2020). The techno-functional properties of insect protein, encompassing solubility, water and oil holding capacity, gelling, and emulsification, dictate the application of various food processing methods to enhance the overall quality of insect-based food products (Villaseñor et al., 2021). Numerous studies have explored strategies to improve the functional properties of insect protein through suitable processing methods (Gravel & Doyen, 2020). Commonly employed techniques include drying, defatting, and extraction, all aimed at enhancing the functional attributes of edible insect proteins (Kim et al., 2022). Fractionation processing, which increases the protein content, has been identified as a method to enhance the functionality of insect proteins, as reported by Kim et al. in 2020 for *Tenebrio molitor*, *Protaetia brevitarsis*, and *Allomyrina dichotoma*. Additionally, enzymatic hydrolysis stands out as another important method for augmenting the functionality of insect proteins (Gravel and Doyen, 2020; Purschke et al., 2018). These processing approaches play a pivotal role in optimizing insect proteins for various food and feed applications by improving their functional characteristics.

Potential Insects Used as Fishmeal

Over the past two decades, numerous studies have aimed to reduce the reliance on fishmeal, fish oil, and their by-products in the aquaculture sector. This effort has led to an increased utilization of plant-derived ingredients in fish feed. However, when compared to diets based on fishmeal, the inclusion of these components in aquafeeds puts greater strain on water and land resources and results in increased waste generation. Various protein alternatives have been explored for fish feed, with insect meal and fishery by-products emerging as promising candidates to meet the protein requirements of aquafeed in the coming decades. The successful substitution of fishmeal with insect meal in the diets of numerous freshwater and marine fish species has been extensively reviewed for several aquatic species (Villaseñor et al., 2021).

Use of Insects as Potential Feed Ingredient

The utilization of insects as fish feed ingredients represents a relatively novel approach in the aquaculture sector. Currently, a diverse array of insect species is employed in aquaculture practices, including rat tail maggots (*Musca domestica*), black soldier flies (*H. illucens*), silkworm pupae (*Bombyx mori*), grasshoppers, termites, and mealworms (*T. molitor*), among others. The broader availability across various taxa, coupled with high protein content and favorable lipid profiles, positions insects as promising candidates for replacing traditional fish meal. The potential replacement of fish meal with insect-based diets hinges on the nutritional profile of insects. Insect diets typically exhibit protein contents ranging from 50-82% on a dry matter basis, aligning with the protein content found in fish meal. Insect meal is particularly rich in essential amino acids such as lysine and methionine, with slight variations depending on the insect taxon. Notably, insect meal contains compounds like taurine and hydroxyproline, which are often deficient in plant-based diets. The lipid composition of insects is characterized by a higher concentration of polyunsaturated fatty acids (PUFA) n-6 compared to fish meal. Numerous studies have demonstrated positive outcomes when fish are fed with insect-based diets. These include increased growth rates and higher protein efficiency ratios, as observed in fish fed with *Zophobas variegatus*. Additionally, improved antioxidant activity and recovery from lesions, evident through enhanced haematological parameters like red and white blood cell counts, have been reported in fish fed with insect diets. It's important to note that results may vary based on factors such as fish and insect species, inclusion rates, and processing methods.

Challenges in Utilizing Insects as Fish Meal Alternatives

The exoskeleton of insects is primarily composed of the polysaccharide chitin. Despite the presence of chitinase enzymes, chitin in insects often remains indigestible for most fishes, leading to challenges in utilizing it as a feed ingredient. There have been reports of bioaccumulation of pesticides in fish through the consumption of insects. Additionally, the low content of PUFA in terrestrial insects diminishes their suitability as feed for marine fish. The mass production of insects for aquaculture is still in a developmental stage, emphasizing the need for future studies focused on technological advancements to enhance insect production and better understand the impact of insect meal on fish health. A significant limitation in using insects is the presence of toxic compounds that can adversely affect fish physiology, potentially leading to reduced growth and alterations in hematological

parameters. However, substituting fish meal and fish oil with *H. illucens* meal has shown promise in reducing the levels of certain potentially toxic elements, such as Ni, As, and Pb, in fish feed, ensuring that harmful chemical concentrations remain below permissible limits (Truzzi et al., 2022). Furthermore, the successful incorporation of insect meal into aquaculture practices depends on the acceptance of both aquaculture producers and consumers. Without consumer acceptance, the widespread adoption of insects in the aquaculture sector becomes challenging. Another substantial challenge is accurately evaluating the factors involved in insect production, particularly transitioning from the wild catching of potential edible insects to their large-scale cultivation.

Conclusion

The incorporation of insect meals in fish nutrition represents a promising and sustainable avenue for addressing the challenges associated with traditional feed sources in aquaculture. Through extensive scientific investigation, it is evident that insect-based diets offer a viable alternative that not only meets the nutritional requirements of fish but also mitigates environmental concerns associated with conventional feed production. The diverse array of nutrients provided by insects, coupled with their efficient conversion rates and reduced ecological footprint, positions them as a key player in the quest for more sustainable aquaculture practices. As research in this field continues to evolve, it is anticipated that the integration of insect meals into fish diets will play a pivotal role in fostering a more resilient and ecologically responsible approach to aquaculture, contributing to the long-term health of both aquatic ecosystems and global food security. The ongoing research in this field is expected to yield further insights into optimizing insect-based diets for different fish species, improving production efficiency, and ensuring the economic viability of this alternative feed source.

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