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REDUCING THE ENVIRONMENTAL IMPACT BY USING A SUSTAINABLE PROTEIN SOURCE IN FISH DIET - INSECT MEAL. A REVIEW

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Abstract

Due to the growth intensification in the aquaculture industry it is desirable to ensure fish production and improve it in a sustainable manner. It is known that the protein source from fish diet is represented by the fish meal wich is very expensive. Obtaining fishmeal requires quite a lot of pressure on fish stocks in the natural environment due tu overfishing, which leads to a drastic reduction of stoks. For this reason, it is desirable to find sustainable alternative sources that can replace the protein from fish meal. Therefore, was tried the replacement with soy, sorghum or wheat meal, but their production involves a very large cultivation area. Recently, was made some research on the fish growth and welfare effect in case of replacement of fish meal with insect meal. In conclusion, it has been demonstrated that the insect meal has a much higher nutritional value and has a low impact on the environment (low footprint, less water and feed consuming), but the selection of optimal insect species for the production of protein for fish feed represents a considerable challenge.

Key words: *environmental impact, insect meal, overfishing, sustainable protein source.*

INTRODUCTION

In recent years the aquaculture sector has experienced an intensive production in a very rapid way in the worldwide to contribute to food security. The world population has consumed more farmed fish than captured fish (FAO, 2016).

Fisheries and aquaculture production reaches an all-time high of 214 million tons in 2020 (FAO, 2022). Also, aquaculture production has a huge potential for expansion for increased fish supply, which is an important high-quality source of animal protein for human food (Munguti et al., 2021). This exponential growth has also led to the experimentation of certain aspects related to the economic and ecological issues as the supply of fishmeal and fish oil included in fish diet which is constantly decreasing (Tschirner & Kloas, 2017). Therefore, putting a lot of pressure on the fish population contributes to the production of fish meal and oil that goes into fish feed endangers the sustainability of wild fish fauna. This leads to an increased costs related to the production of fish feed, with a direct effect on the economic profitability of fish farming (FAO, 2016). But, the consistent use of fish meal in aquaculture has not only threatened the sustainability of fisheries ecosystems but has also increased fish demand, and thus affecting profit margins of the fish farmers (Ogello et al., 2014).

Research on novel ingredients for fish feeds, such as microalgae and other single cell proteins, macroalgae, and insect meals, has proliferated recently and will continue to expand (Naylor et al., 2021; Dumitrache et al., 2022). Over time, plants have been introduced into the diet of fish, to replace a part of fish meal, as a source of protein such as soybeans, peas, etc. However, it is known that the composition of the fish diets can have a very big impact on the environmental sustainability as it is necessary to evaluate feed materials and whether or not an alternative is possible that would be more effective and have less impact on the environment.

Therefore, the marine stocks harvested from the wild for fishmeal production are decreasing and from ecologic and economic points of view, the plant-based protein sources are no longer sustainable (FAO, 2016). From this reason, was made different research to look an alternative source of protein to replace fish meal in fish diet, more exactly to improve fish production but also to maintain environmental sustainability.

In fish nutrition were used different plant meals such as SBM, copra meal, sunflower meal, cotton meal and pea meal, but are not parts of natural fish diets, and therefore, their protein contents and AA profiles are not well balanced for fish. Animal by-products such as blood meal, hydrolysed feather meal, bone meal and meat meal have also been used in fish nutrition (Campos et al., 2017; Moutinho et al., 2017). Also, it is known that the protein source from fish diet is represented by the fish meal which is very expensive. Obtaining fishmeal requires quite a lot of pressure on fish stocks in the natural environment due to overfishing, which leads to a drastic reduction of stocks. For this reason, it is desirable to find sustainable alternative sources that can replace the protein from fish meal.

The aim of these paper is to present the alternative protein sources used to replace the fish meal from fish diet with that from vegetable plants or insects and the effect of this on the fish growth and welfare.

VEGETABLE PLANTS USED AS PROTEIN SOURCE IN FISH DIET AND THEIR IMPACT

Over the years, attempts have been made to replace fish meal with meal from terrestrial plants more precisely in order to find an alternative source of protein for fish feed as a strategy to contribute to aquaculture sustainability and to reducing the production costs. But in recent years, research has shown that replacing fishmeal with plant-based meal can have negative effects on fish growth and welfare.

Most plant used as protein source contain a variety of biologically active antinutritional elements, which may negatively affect the feed intake, digestion and absorption of nutrients, and fish health status (Hardy, 2010; Glencross et al., 2020).

In 2011, Montero & Izquierdo, but also Merrifield et al., reported that a hight level of vegetable ingredients present in fish diet have a negative impact on the fish health and growth performance due to the nutritional imbalances or to the presence of some antinutritional elements. In some study was showed that soybean meal can induce the enteritis in case of fish meal replacement strategies from fish diet.

For example, based on the morphological alterations found in the liver and distal intestine of gilthead seabream juveniles, a possible negative effect of long-term feeding with diets containing more than 34% of carob seed germ meal was suggested (Martínez-Llorens et al., 2012), due to content in tannins in carob seed germ.

Studies in other species, like common carp and gilthead seabream reveal a similar pattern of soybean-induced enteritis but at much higher levels of inclusion when compared to Atlantic salmon (Uran, 2008), suggesting a different species susceptibility towards vegetal ingredients. The symptoms described for fish in which the diet have a high inclusions of soybean meal were: a decrease in digestive enzymes activities, an inhibition of adsorption of brush border enzymes, alterations on the intestinal

morphology (shortening of the intestinal mucosa folds, supranuclear vacuoles in enterocytes), inflammation process, fat deposition in liver and enterocytes, loss of intestine selectivity and lower resistance to diseases due to the decrease in the immunity (Ribeiro et al., 2014).
In 2020, Johny et al. reported that the introduction of wheat meal in 30% concentration in fish diet affected the intestinal and liver health of Atlantic salmon after 63 days of feeding. The symptoms were similar to gluten sensitivity in humans.
In case of Lates calcarifer species, fed with a diet in which the fish meal was replaced with 75% by lupin meal for 60 days, was observed a liver steatosis, a necrosis in kidney and a low growth performance (Siddik et al., 2021). This is because lupine contains phytic acid, tannins, saponins and lectins, substances considered to be antinutritional factors.
Fishmeal replacement, by a mix of plant proteins negatively affected the immune status of the turbot juveniles (mix: wheat gluten, soybean meal, and soy protein concentrate, the replacement was up to 50%) (Bonaldo et al., 2015) and decreased the plasma immunoglobulins, blood monocytes, and gut interleukin-10 (IL-10) mRNA expression in case of European seabass (mix: meal, wheat meal, wheat gluten and corn gluten) (Azeredo et al., 2017).
Unlike to land plants, the macro- and microalgae have been considered alternative ingredients, due to their high growth rates and non-competition of arable lands for cultivation. Macroalgae encompass algae that are multicellular and macroscopic and, depending on the species, their nutritional value is quite different (Aragao et al., 2022).
Generally, plant-based protein derivatives are limited regarding to the essential amino acids' composition, presence of endogenous anti-nutritional factors that reduce their efficiency of utilization in fish (Hossain et al., 2003). Also, they have low palatability (Refstie et al., 2000), high ash and fibre contents (Olvera-Novoa et al., 2002), which in high levels inclusions in fish diet reduces digestibility and protein conversion by fish as well as pellet quality of the feed (Mugo-Bundi et al., 2013; Ogello & Munguti, 2016). For example sunflower has inadequate lysine, phenylalanine, methionine, phosphorus, high fibre levels, low energy and poor palatability (Ogello et al., 2017) and soybean is limited due to the low levels of methionine and cost ineffectiveness (Gamboa-Delgado et al., 2013).
All these aspects contribute to the reduction the bioavailability of nutrients in the fish, decrease the efficiency of utilization, increase the feed conversion ratio, culminating with the reduction in economic success (Hossain et al., 2003). Therefore, non-conventional protein sources, such as insect meal, have gained interests to provide an alternative protein source due to its nutritional values that are close to that of fish meal (Fadaee, 2012).

INSECT MEAL USED AS ALTERNATIVE PROTEIN SOURCE IN FISH DIET AND THEIR IMPACT

Unlike to the plants used in fish nutrition, insects which are farmed under controlled conditions can be a viable alternative protein source in fish diets.
Insects, as well as other animals, are good sources of protein, lipids, vitamins and minerals (sodium, iron, potassium and zinc), but the amounts of these nutrients will vary according to the diet and the stage of the animal (Nogales-Merida et al., 2019). This makes the use of insects, in the fish diet, a sustainable source.
Insects are an excellent source of protein due to content in amino acids; their levels of protein range from 25% to 75 %) (Finke et al., 2015). From all insects, those from *Orthoptera* has the maximum protein values, ranging from 60% to 77% (Barroso et al., 2014). When insect protein is compared with plant and meat proteins, it is found that insects contain a substantial amount of good-quality protein due to balanced amino acid proportions (Rumpolds et al., 2013).

Insect used in fish diet

Black Soldier Fly

The black soldier fly (*Hermetia illucens*) represents one of the best options currently used as an alternative source of protein in the fish diet and due to his nutritional value is one of the most investigated insect species (Chen et al., 2021). They balanced nutritional composition makes it an ideal and possibly significant alternative to fish meal.

The content in bioactive compounds such as lauric acid, chitin and antimicrobial peptides, make them to have nutraceutical properties which contribute to improve the fish growth (Surendra et al., 2020). Also, the protein of black soldier fly has a good protein solubility, water binding capacity, and lipid binding capacity (Bußler et al., 2016). The introduction of BSFL meal in fish diet did not show any adverse impact on fish development (Cummins et al., 2017; Dumas et al., 2018).

The use of this insect makes it sustainable due to the fact that it can utilize organic wastes as the substrate, such as animal dung (Moula et al., 2018; Parodi et al., 2021) and plant waste, which includes vegetables and fruit wastes (Meneguz et al., 2018) and algae (Liland et al., 2017). In case of Nile tilapia BSFL meal was found to have a greater growth response and feed conversion ratio than fish meal (Aini et al., 2018).

Common Housefly

Housefly (*Musca domestica*) maggot meal has a high nutritional value as an insect protein source. The housefly contains a substantial number of proteins, lipids, and carbohydrates similar to fishmeal, improving fish growth (Makkar et al., 2014). Housefly larvae are less expensive, have healthy nutritional contents, and are easier to produce.

Houseflies can quickly digest food waste and cattle dung waste, which is organic, using nutrients from waste to reduce the volume of waste in its entirety. Wang et al. (2017), observed that the supplemented diet of Nile tilapia with 75% maggot meal had no substantial adverse effects on the fish growth and development. But, in other study the replacement of fish meal with maggot meal (100%) had no any negative impact on Nile tilapia fingerlings (Ogunji et al., 2008) and African catfish (Okey Aniebo et al., 2009) without damaging growth or nutrient utilization ability or causing oxidative stress fingerlings (Ogunji et al., 2008). Also, several feeding studies on various fish species have shown that adding housefly maggots meal in fish diets may boost growth and FCR while limiting physiological stress, also the fish diet which contain housefly meal is also less expensive (Ogunji et al., 2021).

Cricket

Cricket (*Acheta domesticus*) meal contains a significant amount of crude protein (64.9%) and lipids (17.4%) with a good proportion of amino acids, including lysine and methionine, which are deficient in a plant-based diet (Jeong et al., 2021). Recent studies reported that 8.7% of chitin is present in cricket meals, and its supplementation in the fish diet can improve the interaction of chitosan glucosamine with bacterial cell walls (Phesatcha et al., 2022).

In fish diet cricket meal has the potential to partially or completely replace the fish meal (Jeong et al., 2021). In case of African catfish, the replace of fish meal with cricket meal in 100% proportion in concentration show better growth performance than the control diet (Taufek et al., 2018). In other study the substitute of fish meal with 50% cricket meal in red Nile tilapia diet not significantly affecting growth performance or feed consumption (Finke et al., 2015).

Locust

Locusts are among the most commonly consumed insect species, they are a protein source for the chickens and fish (Van Huise et al., 2013) because they have up to 70% protein content in dry matter basis. Several studies have shown that replacing 20% fish meal with locust meal did not influence digestibility and growth performance of catfish and Nile tilapia (Alegbeleye et al., 2012). But the replacement with 50% locust meal has led to optimal results in terms of growth.

Mealworm

Mealworms (*Tenebrio molitor* - TM) are simple to produce, have a low environmental impact, are easily to manipulate, have a good nutritional content and are highly efficient.

Research shows that TM meal is an innovative protein source that can partially substitute fish meal in rainbow trout (Belforti et al., 2015), European sea bass (Gasco et al., 2016), gilthead seabream (Piccolo et al., 2017) and blackspot seabream (Jeong et al., 2021). Also, a 100% replacement of fish meal with yellow mealworm meal enhances the Pacific white shrimp lipid content but does not affect the growth rate and feed conversion ratio (Panini et al., 2017). But it must be considered that the meal worm has a low concentration of calcium so primarily feeding fish with mealworms might result in calcium deficiencies and body deformities, despite this, the mealworm insect is an excellent choice to replace fishmeal (Makkar et al., 2014).

Silkworm

Silkworm meal contains 56% protein and is obtained by drying and grinding the larvae uncoiled boiled cocoons (Tomotake et al., 2010). Researches showed that replacing fish meal with 10% silkworm meal can be successfully substituted in the diet of salmon and olive flounder (Lee et al., 2012), and with 50% in African catfish fingerlings diet conduct to an increase in growth rate and feed utilization efficiency (Kurbanov et al., 2015).

The supplemented fish diet with 30-50% silkworm pupae registered a successful in case of some fish species (rohu, common carp, mahseer, and rainbow trout) (Sawhney et al., 2014). Also, silkworm meal was found to be an advantageous sustainable feed element in carp (Wan et al., 2017) and rainbow shark (Raja et al., 2020) diets, with benefits for boosting growth performance and specific physiological markers.

But in Jian carp and Nile tilapia the replacement of fish meal with silkworm meal in different concentrations show negative responses as: reduced digestive enzyme activity, heat shock protein activities, and increased oxidative stress (Boscolo et al., 2002; Ji et al., 2015).

Advantages of using insects in aquaculture

Insect production requires six times less feed than conventional livestock to produce the same number of proteins (Randazzo et al., 2021). The greenhouse gas emission from the insects is much less compared to the conventional livestock in the production of food/feed. In the same time the insects can be mass produced using organic waste streams (Gaudioso et al., 2021).

In the wild, fish consume insects, omnivorous fish species eat insects from the bottom of water, while carnivorous fish species consume juvenile life stages of insects (Lopez-Pedrouso et al., 2020). Insects such as the housefly, mealworm, grasshopper, black soldier fly and cricket have been identified as good alternatives to fishmeal (Gasco et al., 2018).

Some research studies with fish fed diets with varying inclusion levels of black soldier fly larvae meal have reported good growth performances similar to those from fish fed on common protein sources such as fish meal. Fingerlings of *Ictalurus punctatus* had a similar weight gain when the diets were supplemented with up to 30% of full-fat black soldier fly larvae meal (BM) (Newton et al., 2005). In case of *Oncorhynchus mykiss* a replacement of fish meal with 25% blak soldier fly meal not have any negative effect on the fish weight gain (St-Hilaire et al., 2007).

Regarding to the investment and the cost–benefit ratio was similar across the diets, suggesting that black soldier fly meal is a suitable and cost-equivalent dietary supplement of fish meal up to 100% in aquafeed for growing tilapia fish in earthen ponds for the market (Wachira et al., 2021).

In case of African catfish supplemented diet with 22% black soldier fly meal conduct to an improvement of growth performance and restored gut microbioma equilibrium. Also enhaced development performance and optimized feed utilization, accompanied by increased antioxidant enzyme activity and contribute to reduced lipid peroxidation in the fish fillet (Fawole et al., 2020).

Benefits of insect meal in aquaculture

Nutritional value - Research has shown that insect – based feeds can provide a balanced amino-acid profile, essential fatty acids, vitamins and minerals necessary for optimal fish health (Chen et al., 2021).

Environmental sustainability - Insects require less land, water and feed resources, emit lower greenhouse gas emissions and generate fewer nutrient-rich effluents. The environmental impact can be reduced by correspondingly increasing insect production, and as a result, insects can compete with conventional ingredients (Smetana et al., 2019). Environmental impact categories of *T. molitor* (Le Feon et al., 2019), *M. domestica* (Roffeis et al., 2020) and *H. illucens* (Maiolo et al., 2020) largely contribute to the food produced in the insect farming industry. Therefore, providing the right substrate for insect growth and increasing plant efficiency will be major contributors to achieving the environmental benefits of insect meal (Smetana et al., 2019; Thevenot et al., 2018). Bioconversion technique for insect production is one of the sustainable solutions to food security. In this sense, waste is a valuable resource for high-quality production protein (insect meal) for the food system. As a result, the technology produces zero waste and reduces the need for expensive protein sources such as soybean meal and fish meal in aqua feed (IPIFF, 2019).

Disease control - Insects possess innate antimicrobial properties, making them potentially valuable in disease prevention and control in aquaculture (Wang et al., 2019).

Economic viability - The cost-effectiveness of insect cultivation for aquaculture feeds is gaining traction (Moreki et al., 2012).

In future must be support the use of insect meal into large scale commercial feed manufacturing and enhance sustainable intensification in aquaculture production.

CONCLUSIONS

In conclusion, it has been demonstrated that the insect meal has a much higher nutritional value and has a low impact on the environment (low footprint, less water and feed consuming), but the selection of optimal insect species for the production of protein for fish feed represents a considerable challenge.

Compared to traditional fish-based feeds, insect cultivation has a significantly lower environmental impact. Insects are highly efficient in converting organic waste materials into valuable biomass.

The replacement of fish meal with insect meal can conduct to the increase of fish growth performance and immunity status improving the welfare status.

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