New Trends in Aquaculture Feed Production

Subjects: Agriculture, Dairy & Animal Science
Contributor: Edo D'Agaro, PierPaolo Gibertoni, Stefano Esposito

Fish plays a crucial role in global human nutrition as a source of essential nutrients. Marine-derived ingredients (fishmeal and fish oil) are of critical importance in fish feed production. Fishmeal primarily provides protein for fish growth but is also a valuable source of micro-nutrients such as vitamins, minerals, and lipids. In addition, fishmeal contributes to improved feed digestibility and palatability, particularly in weaning diets for many species.

Keywords: aquaculture ; rainbow trout ; production

1. Extraction of Active Ingredients from Molluscs and Algae

The extraction of active ingredients from plant and animal products is a rapidly evolving research area [1]. From 2000 to 2020, the production of algae and molluscs doubled. In 2020, the production of algae and bivalve molluscs represented 43% of the total aquaculture sector by volume and 7.6% by edible weight [2]. Since 2000, the cultivation of algae (especially macroalgae) has increased steadily [3]. Global aquatic plant production tripled from 10 MT of wet biomass in 2000 to over 32 MT in 2020. A total of 31–38% of 32 MT of algae production is used by humans (99% in Asia) [2]. In 2020, macroalgae production was 4.6 MT. Many algae are used in the food industry as an additive for the production of nutraceuticals (source of polysaccharides), pharmaceuticals, cosmetics (source of hydrocolloids), and fertilisers and feed ingredients. Recently, fucoxanthin, a potent anti-inflammatory, has been extracted from some brown algae [4]. The production of microalgae such as *Spirulina* spp., *Chlorella* spp., *Haematococcus pluvialis*, and *Nannochloropsis* spp. is highly developed in some countries [5]. In 2020, the world production of microalgae amounted to 130,000 t. In 2020, the demand for dried microalgae in Italy was 200 t. Meal obtained from algae can be used in fish diets [5]. Generally, the nutritive value of brown algae is lower than that of red and green algae due to the lower protein content. The algae production process can be improved by means of a "biorefinery" approach. In this method, active ingredients from the algae are produced using large photobioreactors and are then extracted sequentially, thereby reducing waste, energy inputs, and environmental damage. New technological advances allow algae to be grown on a large scale in coastal and offshore locations. Disease prevention and management and optimisation of environmental parameters during the cultivation phase (nutrients, light, and temperature) are some of the aspects that are still under development. In intensive plants, bacterial and viral diseases are particularly frequent, and disease management costs can represent up to 50% of variable costs. New varieties are needed to improve production and profitability to improve yield, disease resistance, and nutritional characteristics. Microalgae can replace fishmeal and fish oil in fish feeds. However, some technical, biological, and economic difficulties related to the production of high-quality microalgal biomass limits its practical use. According to some recent studies, a level of macroalgae inclusion with rates >10% results in adverse effects on trout growth. Some bacteria and yeasts have a high potential as alternative sources of protein. However, their use is still limited due to high production costs.

Shellfish production includes approximately 65 species, mainly bivalves (clams (*Venerupis decussata*), oysters (*Ostrea Edulis*), scallops (*Pecten jacobaeus*), abalone (*Haliotis Linnaeus*), and mussels (*Mytilus galloprovincialis*). Bivalve mollusc farming does not require the use of feed. The active ingredients extracted from molluscs are used in various sectors, such as the production of fertilisers, building materials, pharmaceuticals, and nutraceuticals [6].

2. Use of Insects in Fish Feed

Insects represent a potential alternative source of animal protein in the production of fish feed [7][8]. The growth cycle of insects is very rapid, and several breeding cycles can be implemented throughout the year [8]. The protein, fat, and vitamin contents in insects vary according to different factors, such as species, sex, developmental stage, and growth environment. Insect meal is a good source of protein (40–75 g/100 g DM) and minerals [7]. Protein digestibility (77–98%) varies in relation to several factors, such as the presence of the exoskeleton and the content of essential amino acids [9]. The average lipid content varies from 13 to 33% of DM depending on species, sex, and developmental stage [9]. The average omega-3 and omega-6 fatty acid compositions of yellow mealworms (Tenebrio molitor) are similar to those of several fish species. Insects contain some bioactive compounds, such as antimicrobial peptides (e.g., amino-rich peptides), fatty acids (e.g., lauric acid), and polysaccharides (e.g., chitosan and chitin) [10]. The most interesting insect meals for the fish feed industry are those obtained from yellow mealworms, black soldier flies (*Hermetia illucens*), common house flies (*Musca domestica*), crickets (*Acheta domesticus*), and grasshoppers (*Tettigonia viridissima*) [8][11]. House crickets (*Acheta domesticus*), mealworms, and migratory locusts (*Locusta migratoria*) were recently authorised as food ingredients in the EU.

Insect larvae (black soldier fly, common house fly, and yellow mealworms) can be reared in large plants. The larval reproduction systems are similar among the different species. Recent studies have shown that mealworms and soldier flies can be used in the formulation of fish diets because of their excellent palatability and composition in amino acids, lipids, and calcium [12]. Insects can also play a fundamental role in the biodegradation/recovery of several wastes, reducing contamination, and contributing to the sustainability of animal production systems [13]. In fact, insects can be fed agricultural wastes, transforming them into a valuable nutritional resource. Insects can be raised with a reduction of 50–90% in land use compared to conventional livestock farming and with a decrease of approximately 100 times in greenhouse gas emissions. It has been reported in some studies that insect meal may affect the sensory profile of rainbow trout fillets. For some insect species, further investigation and careful economic analysis are needed. The use of insect meal can pose some risks, such as the presence of allergens, chemical contaminants, parasites, and microbiological threats [14]. Currently, there are still limited data available for a thorough risk analysis. In **Table 1** are reported the effects of alternative diets (plant, insect, algae, etc.) on growth and quality parameters in rainbow trout.

Table 1. Effects of alternative diets on growth and quality parameters in rainbow trout.

Protein Ingredient	Inclusion Level (%)	Effects	Reference
Mixed plant meals	**46, 70, 100**	**FBW (reduction) PUFA n-3 (reduction)**	[15]
Schizochytrium limacinum	**5**	**FBW (no difference)**	[16]
Hermetia illucens	**10, 20, 30**	**FBW, SGR, FCR (no difference)**	[17]
Tenebio molitor	**50**	**FBW (no difference)**	[18]
Saccaromyces cerevisiae* and *wickerhamomyces anomalus	**10, 20, 30**	**FBW, FCR (no difference)**	[19]

FBW = Final Body Weight. SGR = Specific Growth Rate. FCR = Feed Conversion Ratio. PUFA n-3 = Polyunsaturated Fatty Acids n-3.

3. Recent and Future Trends of the Sector

The life cycle of rainbow trout begins with brood stock breeding and egg fertilization and continues through the growing phase. Achieving high-quality standards at the first stage (selection of breeding stock and egg production) of the cycle is critical to the entire production process. Recently, in the rainbow trout sector, there has been evidence of a high degree of vertical integration among farms [2]. In particular, several production farms have integrated their activities with brood stock breeding and egg production activities. Female reproductive characteristics (egg diameter, fecundity rate, and number of viable eggs) vary with rearing conditions (temperature, feeding, light cycle, etc.) and genetic selection. Egg quality characteristics vary according to the number of eggs laid and the ability to develop a viable embryo [2]. Recently, automated phenotyping systems, using image analysis technologies (and wireless data transfer), have been developed to determine the presence of dead eggs and/or any embryonic malformations [20]. At the first stage of the production chain, water reuse methods (Recirculating Aquaculture Systems, RASs) allow the farmer a greater degree of control (over production), to reduce water consumption and the release of effluent into the environment. Due to high costs and high energy use, RASs are used only at certain stages of the cycle (particularly in hatcheries where control over environmental conditions is more critical and unit values higher).

Feed conversion ratio (FCR) is the most important parameter for improving the production indices and reducing the environmental impact [21]. Reducing FCR by 10% also results in a 9.5% reduction in the carbon footprint [22]. Recently, several companies have used underwater cameras and sonars to reduce feed waste. The feed industry is continuously working on developing new feed ingredients and improving formulations with higher energy content. While in the 1990s fishmeal and fish oil made up more than 80% of trout feeds, today, conventional marine-derived ingredients make up only 25–30%. As a result, in farmed trout, the content of long-chain omega-3 fatty acids has decreased. Genetic selection and marker-assisted selection have also been used to improve fish growth and health [23]. For example, selected trout show 10–15% weight gain per generation with feeds based on plant ingredients. In addition, supplementing feed with nutraceuticals, prebiotics and probiotics, and plant extracts is used to improve fish growth and immunity and reduce the use of antibiotics. In recent years, researchers have conducted extensive studies to develop new vaccines to control diseases caused by bacteria or viruses. To date, two effective vaccines for IPNV (Infectious Pancreatic Necrosis Virus) and ERM (Enteric Red Mouth) are used in rainbow trout farming.

References

1. Jędrejek, D.; Levic, J.; Wallace, J.; Oleszek, W. Animal by-products for feed: Characteristics, European regulatory framework, and potential impacts on human and animal health and the environment. J. Anim. Feed Sci. 2016, 25, 189–202.
2. FAO. The State of World Fisheries and Aquaculture. Towards Blue Transformation. 2022. Available online: www.fao.org (accessed on 4 July 2022).
3. Nwoba, E.G.; Parlevliet, D.A.; Laird, D.W.; Alameh, K.; Moheimani, N.R. Light management technologies for increasing algal photobioreactor efficiency. Algal Res. 2019, 39, 101433.
4. Leong, Y.K.; Chen, C.Y.; Varjani, S.; Chang, J.S. Producing fucoxanthin from algae. Recent advances in cultivation strategies and downstream processing. Bioresour. Technol. 2022, 344, 126170.
5. Saadaoui, I.; Rasheed, R.; Aguilar, A. Microalgal-based feed: Promising alternative feedstocks for livestock and poultry production. J. Animal Sci. Biotechnol. 2021, 12, 76.
6. Smaal, A.C.; Ferreira, J.G.; Grant, J.; Petersen, J.K.; Strand, Ø. Goods and Services of Marine Bivalves; Springer: Berlin/Heidelberg, Germany, 2019.
7. Makker, H.P.S.; Tran, G.; Heuze, V.; Ankers, P. State-of-the-art on use of insects as animal feed. Anim. Feed Sci. Technol. 2014, 197, 1–33.
8. Sogari, G.; Amato, M.; Biasato, I.; Chiesa, S.; Gasco, L. The Potential Role of Insects as Feed: A Multi-Perspective Review. Animals 2019, 9, 119.
9. Playne, C.L.R.; Dobermann, D.; Forkes, A.; House, J.; Josephs, J.; McBride, A.; Müller, A.; Quilliam, R.S.; Soares, S. Insects as food and feed: European perspectives on recent research and future priorities. J. Insects Food Feed 2016, 2, 269–275.
10. Gasco, L.; Józefiak, A.; Henry, M. Beyond the protein concept: Health aspects of using edible insects on animals. J. Insects Food Feed 2020, 7, 715–741.
11. Specht, K.; Zoll, F.; Schümann, H.; Bela, J.; Kachel, J.; Robischon, M. How will we eat and produce in the cities of the future? From edible insects to vertical farming—A study on the perception and acceptability of new approaches. Sustainability 2019, 11, 4315.
12. Barroso, F.G.; de Haro, C.; Sánchez-Muros, M.J.; Venegas, E.; Martínez-Sánchez, A.; Pérez-Bañón, C. The potential of various insect species for use as food for fish. Aquaculture 2014, 422, 193–201.
13. Meneguz, M.; Schiavone, A.; Gai, F.; Dama, A.; Lussiana, C.; Renna, M.; Gasco, L. Effect of rearing substrate on growth performance, waste reduction efficiency and chemical composition of black soldier fly (Hermetia illucens) larvae. J. Sci. Food Agric. 2018, 98, 5776–5784.
14. Gałęcki, R.; Sokół, R. A parasitological evaluation of edible insects and their role in the transmission of parasitic diseases to humans and animals. PLoS ONE 2019, 14, e0219303.
15. Lazzarotto, V.; Médale, F.; Larroquet, L.; Corraze, G. Long-term dietary replacement of fishmeal and fish oil in diets for rainbow trout (Oncorhynchus mykiss): Effects on growth, whole body fatty acids and intestinal and hepatic gene expression. PLoS ONE 2018, 13, e0190730.
16. Terova, G.; Rimoldi, S.; Ascione, C.; Gini, E.; Ceccotti, C.; Gasco, L. Rainbow trout (Oncorhynchus mykiss) gut microbiota is modulated by insect meal from Hermetia illucens prepupae in the diet. Rev. Fish Biol. Fish. 2019, 29, 465–486.
17. Antonopoulou, E.; Nikouli, E.; Piccolo, G.; Gasco, L.; Gai, F.; Chatzifotis, S.; Mente, E.; Kormas, K.A. Reshaping gut bacterial communities after dietary Tenebrio molitor larvae meal supplementation in three fish species. Aquaculture 2019, 503, 628–635.

18. Lyons, P.P.; Turnbull, J.F.; Dawson, K.A.; Crumlish, M. Effects of low-level dietary microalgae supplementation on the distal intestinal microbiome of farmed rainbow trout Oncorhynchus mykiss (Walbaum). Aquac. Res. 2017, 48, 2438–2452.
19. Huyben, D.; Nyman, A.; Vidaković, A.; Passoth, V.; Moccia, R.; Kiessling, A.; Dicksved, J.; Lundh, T. Effects of dietary inclusion of the yeasts Saccharomyces cerevisiae and Wickerhamomyces anomalus on gut microbiota of rainbow trout. Aquaculture 2017, 473, 528–537.
20. OECD-FAO. Fish and Seafood. OECD/FAO Agricultural Outlook 2018–2027. 2018. Available online: www.oecd-ilibrary.org (accessed on 4 July 2022).
21. European Union. PEFCR Feed for Food Producing Animals—Draft Version 1.1 for EF Steering Committee; EU: Brussels, Belgium, 2018; pp. 1–4.
22. Maiolo, S.; Forchino, S.A.; Faccenda, F.; Pastres, R. From feed to fork—Life Cycle Assessment on an Italian rainbow trout (Oncorhynchus mykiss) supply chain. J. Clean. Prod. 2021, 289, 125155.
23. D’Agaro, E. New Advances in NGS Technologies. In New Trends in Veterinary Genetics; Intech Editions: London, UK, 2017; pp. 219–251.