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Review Article

A Review of Fishmeal Replacement with Animal By-Products in Aqua Diets

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Abstract

Fish meal is primary ingredient source of protein in aqua feed production. However, the shortage in world fish meal production and demand for fish meal in feeds for livestock and poultry is probably to reduce the dependence on fish meal as a single protein source in aquafeeds. Therefore, aqua nutritionists have made several attempts to partially of completely replace fish meal with low cost and locally available ingredients. The poultry by-product meal (PBM) and silkworm pupae meal (SWP) are locally available waste raw materials obtained from poultry rendering plants and silk production factories. Therefore, this review article has discussed the feasibilities or infeasibilities of fish meal alternatives in various commercial finfish and shellfish diets.

Keywords: Animal by Products; Fish Diets; Fishmeal Replacer; Poultry by Product Meal; Silkworm Pupae Meal

Introduction

Aquaculture is one of the fastest expanding food production systems in the world. As a result, global fish production reached up to 179 million tons and out of which 82 million tons contributed from total aquaculture production in 2018 [9]. Rapid development of aquaculture industry highly depends on aquafeed and the feed cost represents nearly 60% of the production cost [24]. Fish meal is a primary source of protein in aqua diets due to its well-balanced amino acids and fatty acids profile, high protein content, palatability, digestible energy, vitamins and minerals. However, the shortage of fishmeal production worldwide, demand and competition for its use to other livestock and poultry feeds has further increased the fishmeal prices. During the past decades, there has been research interest in the identification and utilization of alternatives to partially or completely replace the fish meal with less expensive, locally available protein sources in feed formulation. Animal by-products such as poultry by-product meal (PBM) and silkworm pupae meal (SWP) derived from animal rendering plants and sericulture waste recycling processes respectively are used as ingredients in fish feed industry [30,37].

Therefore, this article has reviewed with the impacts of animal by-products on growth performance, nutrient utilization, digestive enzyme activities, haemato - biochemical analysis, immune status and whole-body composition of various commercial finfish and shellfishes.

Animal by-products

Poultry by-product meal

Poultry by-product meal (PBM) is ground rendered clean carcass of slaughtered poultry such as necks, feet, undeveloped eggs and intestines, exclusive of feathers, except some amount as might occur unavoidably in good processing practices [5]. About, 70% of liveweight of a laying hen and broiler are used as human consumption. The waste such as head, feat and intestines amount to 19.7% in laying hens and 16.5% in broilers.

Manufacturing process

Wet rendering is the conventional manufacturing procedure for processing the PBM. The raw materials such as waste of slaughtered poultry parts are cooked under steam pressure at 110°C to 130°C for 3 to 6 hours. Subsequently, the raw material is dried and ground after removing fat. The pathogenic bacteria like salmonella which are killed at above 82°C for 20 mins are eradicated. After the wet-rendering process, the PBM is golden to brown in colour with fresh poultry fragrance. Finally, the PBM is properly treated with antioxidants and stored in plastic bags [16].

Nutritional composition

Variation in proximate compositional quality is common in PBM which largely depends upon the variability in raw material composition, quality and processing specifications such as temperature, time and pressure. As a result, there will be deficiencies in certain essential amino acids, higher ash content and variability in digestibility [7]. PBM is comparatively less expensive than fish meal [38]. PBM emerged as one of the most promising alternative ingredients for fishmeal due to its high crude protein content of 58-65% [51], high digestible crude protein value (87% to 91%) [3], essential fatty acids, vitamins, minerals, palatability and protein quality [5].

PBM is a rich source of crude protein (53.85%, 52.90% and 67.13%), ether extract (23%,18.35% and 13.52%) and ash content (18.20%, 20.14%, 13.34%) as reported by [8,37,49] respectively. The raw poultry by-product meal has rich source of essential amino acids (%): phenylalanine (2.65), arginine (5.43), leucine (5.00), lysine (4.17), methionine (1.46), isoleucine (2.67), histidine (1.47), threonine (2.81), valine (3.08) and non-essential amino acids: glutamic acid (9.55), alanine (4.62), taurine (0.31), tyrosine (2.15), glycine (6.53), aspartic acid (5.95), cysteine (0.66), serine (3.01), proline (5.63). Similarly, poultry by product meal has total fatty acids of 1019.70 mg/g which includes EPA and DHA at 0.13% and 0.24%, respectively of total lipids.

Poultry by-product meal in aqua diets

Poultry by-product meal-pet food grade (PBM-PFG) (crude protein-66%) can effectively replace up to 80% of fish meal in the commercial diets of Pacific white leg shrimp, *Penaeus vannamei* [5]. Total replacement of fish meal with PBM might be constrained by lower nutrient digestibility and limiting essential amino acids, especially lysine and methionine. Therefore, 66.7% PBM protein could replace fish meal without affecting *P. vannamei* growth performances [4]. Similarly, good quality of terrestrial poultry by product meal can successfully replace more than half of the protein from marine fish meal in the diets for humpback grouper [35]. [48] suggested that high quality PBM could replace 100% of fish meal in diets for Gibel carp without negative impact on growth performance and feed utilization. [19] has demonstrated that combination of poultry by product meal and blood meal supplemented with methionine and lysine could replace up to 66.7% of dietary fish meal protein in Gibel carp. [50] suggested that without amino acid supplementations, PBM could safely replace up to 25% of fish meal protein in the diets for black sea turbot without loss in growth performance, nutrient utilization and nitrogen retention. [41] reported that chicken intestine meal can successfully replace fish meal up to 100% without addition of any amino acid in grass carp (*Ctenopharyngodon idella*) diet.

[32] suggested that juvenile cobia can be fed using 100% PBM protein without negative effect on growth and fillet qualities. However, 60% of PBM protein is recommended for better growth and efficient feed utilization. Similarly, [53] reported that up to 60% of dietary fish meal protein could be replaced by supplementation of PBM in cobia diets with no significant effect on the growth performance. [29] indicated that complete replacement of fish meal with PBM in sunshine bass diets are feasible and their economic analysis suggest that the replacement of fish meal with PBM may result in reduced revenue over feed costs. [38] recommended a combined poultry by-product and feather meal as a suitable and fish meal sparing ingredient in diets for rainbow trout. [15] reported in the spotted rose snapper that, up to 90% of the fish meal protein in formulated diets can be replaced by good quality PBM without any negative effects on health and growth performance. [21] has reported that PBM can partially substitute the fish meal without negative effects on growth performance and feed utilization of juvenile black sea bream. Moreover, the optimal replacement level of PBM in black sea bream is 28.30%. [47] has demonstrated that fish meal level could be reduced to 24% by inclusion of a blend of PBM and feather meal in diets of giant croaker. [13] suggested that

fish meal can be substituted up to 50% chicken by-product meal without retardation in growth, feed utilization, haematology and non-specific immune responses of olive flounder.

Nile tilapia is able to efficiently utilize minerals from animal by-products better than plant protein products, and the poultry by-product meal seems to be an interesting ingredient to compound diets for this species due to its higher nutrient digestibility and P availability, contributing to reduction of waste outputs in aquaculture production [11]. [8] reported that 53.85% crude protein content of local, full fat and commercial poultry by product meal can totally replace fish meal in practical diets of Nile tilapia. Average apparent amino acid availability (91.2%) and protein digestibility (89.7%) of PBM was higher than Average apparent amino acid availability (88.9%) and protein digestibility (88.6%) of fish meal. As a result, PBM has been identified as alternative of *O. niloticus* diets and it can be utilized efficiently to improve growth responses [11]. [14] suggested that high-quality poultry by-product meal-pet grade (PBM-PG) could completely replace fish meal protein in diets for fingerling Nile tilapia without affecting growth performance. PBM-PG is apparently a viable alternative ingredient in tilapia fingerling diets.

[27] indicated that PBM is a viable alternative ingredient in Nile tilapia diets on cage culture system and can be included up to 30% in the diet without any deleterious effects on growth response and blood biochemical parameters. [1] has demonstrated and proven that 50% of fishmeal protein could be replaced by PBM protein without any negative effects on growth performance in Nile tilapia diets along with the supplementation of lysine, methionine and threonine. [51] documented that fish meal can be replaced with 100% poultry by-product meal in the diet of Nile tilapia *O. niloticus*, without compromising growth performance, nutrients utilization and blood contents. [10] revealed that poultry by-product meal in the diet of GIFT tilapia could be used as main protein sources to substitute fish meal up to 40% of dietary protein without negative impact on growth performance and feed utilization. Similarly, PBM completely replace the fish meal protein in GIFT tilapia diets, without any negative impacts on growth performance, feed utilization, whole-body proximate and amino acid composition and haemato-biochemical composition [56].

Silkworm pupae meal

The mulberry silkworm pupae is one of the major by-products of silk industry. Silkworms are the caterpillars of moth species raised for the production of silk. Mulberry silk contributes to around 90% of the world silk production. When the silkworm enters the pupa phase, it builds a protective cocoon made of raw silk. At the end of pupation, the pupa releases an enzyme that creates a hole in the cocoon and the moth emerges. In order to produce silk, the pupae are killed by boiling, drying or soaking in NaOH before they produce the enzyme [6,23]. The spent pupae are obtained after reeling of silk and it is the major by product from silk industry [6].

One kg of raw silk can be produced from 8 kg of wet silk worm pupae (2 kg of dry pupae) [28]. After revealing the silk thread production, spent pupae are waste material often discarded in the open environment or used as fertilizer [45]. The extracted meal of silkworm pupae is used for the production of chitin, the long-chain polymer of N-acetylglucosamine which is the main component of the exoskeleton [39]. Silkworm pupae meal found to be a suitable feed ingredient for livestock notably monogastric animals such as poultry, pig and fish due to its high protein content [42]. Fresh spent silkworm pupae are easily spoiling due to its high moisture content, so spent pupae are generally sundried and ground [46,43,23].

SWP is a protein-rich feed ingredient with a high nutritional value. Its crude protein content ranges from 52 to 72%, while for the defatted meal it can be higher than 80%. The lysine is 6-7% in 100 g crude protein and methionine plus cystine levels is approximately 4%. Non-defatted pupae meal is rich in fat, up to 37%. Silkworm oil contains a high percentage of polyunsaturated fatty acids, notably linolenic acid (18:3), with values ranging from 11 to 45% of the total fatty acids [31; 20, 43]. China is leading silk producing country in the world and India is the second largest producer of silk. Disposal of silkworm pupae meal is a big problem in the silk factories. The silk producers after reeling out silk used to throw the dead pupae at outdoors, creating nuisance and health hazards [44]. Therefore, due to high protein content and local availability, silkworm pupae meal can be used as an animal feed ingredient. So, the utilization of this resource as feed ingredient is a great way to reduce the environmental impact of silk production.

Nutritional composition of silkworm pupae meal

Silkworm pupae meal (SWP) has 52.3% of crude protein and 27.8% of crude lipid [22]. According to [25] SWP has 50.02% crude protein, 27.85% crude lipid, 4.93% crude fibre and 10.69% ash. [30] reported that defatted silkworm pupae meal has crude protein content of 75.94%, crude lipid of 8.4%. ash of 6.3% and with the essential amino acids (%): arginine (2.94), histidine (1.86), isoleucine (2.23), leucine (3.90), lysine (3.92), methionine (2.08), phenylalanine (4.17), threonine (2.67), valine (3.12) and non-essential amino acids (%): alanine (2.77), aspartic acid (6.25), cysteine (0.57), glutamic acid (7.17), glycine (3.10), proline (2.60), serine (2.55), tyrosine (3.76) and minerals such as phosphorus and calcium at 1.44% and 0.26%, respectively.

Silkworm pupae meal as a fish meal replacer in aqua diets

The silkworm pupae meal derived from reeled silk is also a potential fish meal replacer because of its high nutritional value similar to fishmeal, as it revealed that 50% of the fish meal protein in Jian carp diets can be replaced with silkworm pupae meal without compromising growth performance and the health status of the fish [22]. Fishmeal protein was totally replaced with silkworm meal in the diet of common carp (*Cyprinus carpio*) without any negative impact on fish growth performances [25]. In a comparison between silk worm pupae meal and plant leaf meals (*alfalfa and mulberry*), feed conversion efficiency, nutrient digestibility and nutrient retention were better for diets based on silkworm meal than for diets based on plant leaf meals in common carp [40]. In rohu, non-defatted silkworm pupae and defatted silkworm pupae resulted in significantly higher protein digestibility values than fishmeal [54]. In silver barb (*Barbonymus gonionotus*) fingerlings, highest growth performance was observed in fish fed a diet replacing about 38% of total dietary protein by silkworm pupae meal [55].

Mahseer (*Tor khudree*) fingerlings fed a diet containing 50% defatted silkworm pupae at 5% of body weight had a better growth and survival than fingerlings fed no or lower amounts of silkworm pupae [36]. Silkworm pupae meal could be used as a substitute for fishmeal up to 75% of protein in Asian stinging catfish (*Heteropneustes fossilis*) diets without adverse effect on growth [17]. Non-defatted silkworm pupae meal was found to be a suitable fishmeal substitute in diets for walking catfish (*Clarias batrachus*). Digestibility of the crude protein in silkworm meal was found to be similar to that in fishmeal [2]. In Japanese sea bass (*Lateolabrax japonicus*), the energy digestibility (73%) of non-defatted silk-worm pupae meal was lower than that of poultry by-product meal, feather meal, blood meal and soybean meal but comparable to that of meat and bone meal. Crude protein digestibility (85%) was also lower than that of poultry by-product meal, blood meal and soybean meal but was comparable with that of feather meal and higher than that of meat and bone meal [22].

[34] reported that only 10% of FM can be replaced with silkworm pupae meal without any adverse effects on the values of the feed conversion ratio (FCR), specific growth rate (SGR), weight gain per cent (WG), condition factor (CF), survival rate (SR), protein content, lipid content, or net protein utilization (NPU) of Rainbow trout (*Oncorhynchus mykiss*). [26] demonstrated that 100% silkworm pupae meal replacement displayed improved weight gain, specific growth rate, feed conversion ratio, protein efficiency ratio (PER) along with high protein and lipid carcass composition in *Clarias gariepinus*.

Silkworm pupae meal as fish meal replacer in tilapia diets

Tilapia (*Oreochromis mossambicus*) was able to utilize the protein of both defatted and non-defatted silkworm pupae meal with high apparent protein digestibility of 85-86% [18]. Moreover, [33] reported that silkworm pupae meal can profitably replace fish meal even up to 66.66% in Nile tilapia diets without any negative effects on growth performance, feed conversion, nutrient utilization, protein efficiency and economic efficiency. Additionally, silkworm pupae meal can completely replace the dietary fish meal protein in GIFT tilapia diets, without any negative effects on growth, nutrient utilization, whole-body proximate and amino acid composition and haemato-biochemical composition [57].

Conclusion

Fish meal replacement with less expansive and locally available ingredients evaluation in commercial aquatic fish and shellfish species is not the recent trend. However, this review will support and update the information on animal by-products on growth, nutrient utilization, whole-body chemical composition and digestive enzyme activities of various fish and shellfish species.

Conflict of Interest

No conflict of interest was reported by authors.

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