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Mulberry and Non-mulberry Silkworm Pupae as an Animal Feed

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ABSTRACT

The animal requires certain essential nutrients in their diet in order to achieve the desired growth and development which leads to income generation. The dietary feed which are available in the market for fishes and monogastric animals such as poultry, pig etc. are quite expensive and are not easily available. Silkworm pupae meal, which is a waste of the sericultural industry, is a highly nutritious and cost-effective product that can fulfil the dietary requirement and successfully utilized as a feed for these organisms. The present review displays the utilization of silkworm (both mulberry as well as non-mulberry) pupae as an alternate source of protein in fish, poultry, and pig feeding.

Key words : *Fish feed, Silkworm pupae, Poultry feed, Pig feed, Waste*

Introduction

Proper nutrition is a critical factor for success in aquaculture, poultry and piggery. Fish meal is generally considered as an excellent dietary protein source for many fish species (Hertrampf and Piedad-Pascual, 2012) and it typically represents approximately 50% of the variable production cost (Craig, 2017). The most dominant protein sources in poultry feed are fish meal and soybean meal where feed cost in poultry farming is approximately 60% to 80% of the total cost (Elahi *et al.*, 2022). In pig diets, the most conventional protein source is soybean meal (Veldkamp and Vernooij, 2021) and feed alone represents 70% to 75% of the total cost of production (Olomu and Oboh, 1995). Since, farming of fish, poultry and pig is highly prevalent among the rural society, it becomes a major concern for them as these feeds are quite expensive and not easily available. Therefore, there is a need for an alternative feed source which is cheap, efficient, highly nutritious as well as sustainable. Although various plant-based proteins had been tried to replace fish meal, there were shortcomings as often the plant proteins possess anti nutritional factors as well as less efficient protein digestion (Yaghoubi *et al.*, 2016).

Over the last decade, studies on the replacement of fish meal or soybean meal with insect meal have emerged with promising results. Due to poikilothermic behaviour, insects are potentially highly sustainable and are distinguished by a high feed conversion efficiency, require low quantities of water and land to be farmed and many of them can be successfully grown on organic side streams, converting low-value organic by-products into high-value protein (Van Zanten *et al.*, 2014). Dipteran insect, black soldier fly (*Hermetia illucens*) and house fly (*Musca domestica*); larvae of Coleopteran insect, mealworm (*Tenebrio molitor*); adult Orthopteran insects from the Acrididae (locusts and grasshoppers), Gryllidae

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(crickets), and Tettigoniidae (katydids) families; and pupae of mulberry silkworm *Bombyx mori* (Lepidoptera) are some of the fish feed ingredients in partial or complete substitution for fish meal, with regard to their nutritional attributes, ease of rearing, and biomass production, similarly in case of broiler and laying hen feed including some other common insect meals (earthworm meal, vermi-humus, bee meal and termite meal) in partial substitution for fish meal and soybean meal at different levels is found to be successful (Elahi *et al.*, 2022). Black soldier larvae meal in growing pig diets (Makkar *et al*., 2014) were found to be effective.

Silkworm can be classified into two categories *viz.,* mulberry (*B. mori*) and non-mulberry or *vanya* including eri, *Samia ricini*; muga, *Antheraea assamensis*; tropical tassar, *A. mylitta* and temperate tassar, *A. proylei.* Silkworm pupa, a waste product of silk reeling industry is a great source of protein, fat, minerals and vitamins, has a protein content of about 21.5% which is higher when compared to other typical animal products and due to high content of essential amino acids present in silkworm pupae proteins, these proteins are often termed as complete proteins (Wu *et al.,* 2021) hence, can be used as an alternative dietary source of protein for animal nutrition. The protein content of silkworm pupae on a dry weight basis has been found to be as high as 49% to 54% (Nowak *et al*., 2016). Apart from that they also contain 24% to 33% of crude lipid (Karthick Raja *et al.,* 2019). It was reported by Mishra *et al.* (2003) that proximate compositions for non-mulberry and mulberry silkworm pupae were in the range of : total protein (12% to 16%), total fat (11% to 20%), carbohydrate (1.2% to 1.8%), moisture (65% to 70%) and ash (0.8% to 1.4%). India is the second largest producer and world's largest consumer of silk and the only country that produces all the four kinds of silk, indicates that there is ample scope for the utilization of silkworm pupae, a chief by-product of this industry, as a feed ingredient for cultivation of fish, poultry and pig.

Mulberry silkworm pupae as a fish feed

Silkworm pupa of *B. mori* is considered to be a highly proteinaceous feed constituent having high values of essential amino acids *viz.*, valine, methionine and phenylalanine along with higher nutritional value (Asimi *et al*., 2017). Researchers have developed a recommended inclusion levels of meal of silkworm pupae in the diet of various aquatic species: 30-50% for major and minor carps, 5-15% for trout, 50-60% for masher, 75-100% for catfish, 30-40% for ornamental fishes and 5-20% for shellfishes which assures to provide better growth performance compared to fish meal (Karthick Raja *et al.,* 2019).

Silkworm pupae (SWP) meal could be used as a replacement for fish meal up to 75% without affecting growth rate, feed consumption ratio, protein efficiency ratio and apparent net protein utilization in the diet of catfish, *Heteropneustes fossils* bloch fingerlings (Hossain *et al*., 1991); highest growth rates in case of silver barb fingerlings (*Barbonymus goninotus*) were observed when fed a diet with about 38% of total dietary protein replaced by silkworm pupae meal (Mahata *et al.,* 1994). Salem *et al.* (2008) concluded that Nile Tilapia, *Oreochromis niloticus* when fed on a diet containing 66.66% *B. mori* pupae meal was found to be economically higher to the other tested diets and hence, it reduced about 18.79% of feeding cost per unit of fish over the control diets. In case of snakeskin gourami, *Trichopodus pectoralis*, a diet containing 15% of *B. mori* protein did not affect fish growth, however, higher levels than 22% reduced both protein digestibility as well as fish growth (Jintasataporn *et al.,* 2011); whereas, low levels of silkworm protein caused oxidative stress in Jian carp (Ji *et al.,* 2013). Growth performance and feed utilization values of ornamental fish, *Maylandia estherae* were significantly superior when fed with diets containing 60% silkworm pupae meal and there was an importance in blood and physiological parameters in fish fed with pupae meal compared with control diet, while 80% level of pupae meal showed lower performance (Nisha *et al.,* 2014). Oso and Iwalaye (2014) evaluated the various level of *B. mori* meal as substitute of fish meal on growth performance and ingredient utilizations of *Clarias gariepinus* juveniles revealed that replacement of *B. mori* meal at 25%, 50%, 75% and 100% showed best performance over the control. Kurbanov *et al.* (2015) studied the effect of replacement of fish meal with *B. mori* pupa protein on the growth of *C. gariepinus* fingerling demonstrated that partial replacement of fishmeal with pupa protein produced better growth performance than those fed with single fishmeal as the growth rate was higher in group fed a mixture of fishmeal and pupa protein (highest was 50:50) and lower in those fed 100% of pupa protein or fishmeal; their study also reported that growth parameters in pupa protein meal fed fish group showed better than in control group. Incorporation of silkworm

pupae in diets of rainbow trout, *Oncohynchus mykiss* up to 10% of fish meal could meet the essential requirements however, beyond 10% reduced the growth adversely and increased the Feed conversion ratio (FCR) (Shakoori *et al.*, 2016). *Labeo rohita*'s growth performance was significantly higher when they were allowed to feed on different levels of silkworm (*B. mori*) pupae meal diet and out of the different levels of silkworm pupae meal, 40% level was suitable for aquaculture (Radha and Geetha, 2018).

A pelleted diet of silkworm pupae with prawn paste, fish meal and tapioca flour improved the growth of common carp, *Cyprinus carpio* (Jeyachandran and Raj, 1976). Begum *et al.* (1994) revealed a significantly better utilisation of the diet by Indian major carp (*L. rohita*) fingerlings when a diet was provided with inclusion of 50% protein of silkworm pupae and clam meat with fish meal; and ultimately it showed an improvement in the growth rate. While comparing silkworm pupae meal (mulberry) with plant leaf meals (alfalfa), parameters such as feed conversion efficiency, nutrient digestibility and nutrient retention were better for diets based on silkworm meal than for diets based on plant leaf meals (Swamy and Devaraj, 1994). Rangacharyulu *et al*. (2003) revealed fermented silkworm pupae silage when included in formulated diets of a polyculture system having Indian carp (*Catla catla*), mrigal carp (*Cirrhinus mrigala*), rohu (*L. rohita*), and silver carp (*Hypophthalmychthys molitrix*) exhibited better performance in respect of survival rate, feed conversion ratio, and specific growth rate against untreated fresh silkworm pupae paste or fish meal. Hwoan (2010) worked on the effect of fishmeal substitution with various animal and/or plant protein sources in the diet of the abalone, *Haliotis discus hannai* Ino reported that a combination of soybean meal and silkworm pupae meal replaced fish meal, resulted in slightly higher survival rate and better growth performance. A diet for mahseer fingerlings (*Tor khudree*) containing 50% defatted silkworm pupae at 5% body weight had better growth and survival rates than fingerlings fed lesser or no amount of silkworm pupae (Sunder *et al.*, 1993) while, un-defatted silkworm pupae were found to be a suitable fish meal substitute in diets for walking catfish (*Clarias batrachus*) (Borthakur and Sarma, 1998). Alcaraz *et al.* (2021) worked on the physical properties of five extruded diets for gilthead seabream (*Sparus aurata*) containing 0, 2.5, 5, 10 or 15% of non-defatted silkworm (*B. mori*) pupae meal, inferred feed formulated with pupae meal exhibited gain in properties like expansion ratio, hardness and durability, while water absorption index and sinking velocity decreased and the pellets from these diets showed reduction in nutrient leaching or fat leakage, thus, there is a possibility of incorporating silkworm pupae meal up to 15% in extruded fish feed without impairing its physical quality. Asfaw *et al.* (2018) revealed that feeding *B. mori* feces to *O. niloticus* was effective as it was a good source of nutrient and can meet the nutrient requirements recommended especially for their juveniles.

Feeding experiments with shrimp (*Metapenaeus monoceros*) revealed that when silkworm pupae meal was used to replace fish meal, it reduced their digestive efficiency (Vijayaraghavan *et al.*, 1978). Akiyama *et al.* (1984) provided a diet for chum salmon fry (*Onchorhynchus ketas*) supplemented with 5% silkworm pupae meal for over six weeks at the expense of fish meal depicted that it did not show any improvement in growth rate and protein content, but enhanced feed efficiency. Rahimnejad *et al.* (2019) reported that complete substitution of fish meal with defatted silkworm pupae (*B. mori*) meal did not enhance the growth of Pacific white shrimp (*Litopenaeus vannamei*) as total replacement led to shrinkage of hepatopancreatic cells, however, the replacement level was recommended to be restricted to 75%.

Mulberry silkworm pupae as a poultry feed

Wijayasinghe and Rajaguru (1977) worked on effect of silkworm pupae meal in layers rations by replacing fish meal and the study showed an increment in weight as well as production of egg, feed efficiency and reproductive performance due to incorporation of pupae meal in their diet. Kumar *et al*. (1992) demonstrated that with increasing dietary levels of silkworm pupae meal, the dressed weight of broilers increased almost linearly. Khatun *et al.* (2003) carried out research on broiler chicks where they were allowed to feed on a diet in which silkworm pupa meal was included along with the fish meal and it was observed that with the increasing level of silkworm pupa meal in the diet, parameters such as feed conversion ratio, growth performance, carcass produce and profitability also got improved. Due to the high oil and fibre content of silkworm larvae. Rahmasari *et al.* (2014) studied the effect of replacement of fish meal protein with silkworm pupae (*B. mori*) from 25% up to 75% significantly reduced feed

conversion ratio, significantly enhanced egg production without affecting the physical quality of quail eggs. Similarly, in case of laying hens, feed consumption differs markedly higher when fed silkworm pupae meal of 25-75% replaced fish meal protein than that of fed 100% replaced fish meal protein (Mangisah *et al.,* 2004).

Silkworm meal has a pleasant taste and is palatable and acceptable by both laying birds and broilers (Khatun *et al.,* 2003; Loselevich *et al.,* 2004, Khatun *et al.,* 2005). Moreover, in case of hens, their response capacity in the yolk colour of eggs was improved when the silkworm pupa meal was utilised as a nutritional supplement (Priyadharshini *et al.*, 2017). Bandlamori *et al.* (2012) accessed the nutritional composition of hybrids ($CSR_2 \times CSR_4$ and $PM \times CSR_2$) of waste *B. mori* silkworm pupa and reported that the hybrids were good sources of protein containing all 18 amino acids; both the breeds were rich in cysteine and methionine (sulphur containing amino acids) which is essential for the growth of broiler and quality of eggs and hence, the study finally concluded that both these hybrids can be utilised as a source of raw material for the formulation of poultry feed.

Silkworm meal (*B. mori*) can used successfully as a low-cost protein constituent in the broiler finisher ration by replacing the soybean meal since pupae meal did not affect the performance of broiler and carcass quality (Ullah *et al.,* 2017). Miah *et al.* (2020) conducted a study on partial replacement of soybean meal and oil with full-fat silkworm (*B. mori*) on growth performance and meat quality of Rhode Island Red × Fayoumi crossbred chickens and reported this partial replacement with full-fat silkworm meal ensured a satisfactory result in growth performance and carcass traits and therefore, providing meat with a healthier *n*-6/*n*-3 ratio. Yhoung-Aree *et al.* (1997) suggested that broilers when allowed to feed on a diet containing deoiled silkworm pupae meal treated with 70% acetone for a time period of 12 hours improved their performance. Zotte *et al.* (2021) evaluated the effect of the dietary inclusion of full-fat or defatted silkworm pupa meal on the apparent digestibility of nutrients, feed choice and faecal microbiome in meat-producing Japanese quails (*Coturnix coturnix japonica*) where they received three experimental diets: a control, a diet containing 12.5% full-fat silkworm pupae meal and a diet containing 12.5% defatted silkworm pupae meal and the results of the digestibility trial exhibited that the DM intake and excreta production were higher in both silkworm pupae meal group than that of control; apparent digestibility of DM, organic matter, CP, ether extract, starch and energy was lower in both silkworm pupae meal groups than in the control suggesting the possible implication of chitin and 1-DNJ; however, in case of feed choice test, results showed that quails mostly preferred the control diet; in terms of microbiome analysis of the excreta, families such as Streptococcaceae, Rikenellaceae and Eubacteriaceae and taxa at species level such as *Lactobacillus delbrueckii, Aneurinibacillus thermoaerophilus* and *Bacillus thermoamylovorans* scored higher in full-fat silkworm pupae meal supplemented quails.

Mulberry silkworm pupae as a pig feed

Coll *et al*. (1992) inferred that replacing soybean meal with un-defatted *B. mori* pupae meal had no effect on growth performance and carcass parameters in growing and finishing pigs. Ramamoorthi and Mercy (2003) carried out an experiment to assess the effect of dietary inclusion of silk worm pupae meal replacing fish meal protein at three levels (0, 50 and 100%) on the growth performance of Large White Yorkshire Pigs reported that silkworm pupae meal does not have any adverse effects on the growth rate and cumulative feed conversion efficiency and can replace unsalted dried fish partially or completely in swine. In another study on effect of silkworm pupae meal and enzyme supplementation on blood constituents in crossbred growing pigs had been done by Medhi *et al.* (2009), where they determined the incorporation of silkworm pupae meal with or without enzyme supplementation had no adverse effects on different biochemical constituents of blood in crossbred (Hampshire × Assam local) growing pigs and pupae meal especially up to 7% level do not have any toxic effects. Medhi (2011) also reported that average values of all the blood constituents in thirty-six crossbred (Hampshire × Assam local) finishing pigs of about 5-7 months age when fed different levels of silkworm pupae meal replacing fish meal with or without enzyme supplementation was found to be statistically *at par*. Three diets *viz.,* a control (standard concentrate mixture) and the other two diets consisting of mulberry silkworm pupae @ 50% and 100% replacing the fish meal were provided to the growing crossbred piglets of 3-3.5 months, evaluated that significantly the highest feed consumption was recorded in control

followed by 50% and 100% level of silkworm pupae meal, feed conversion ratio at the end of the experiment was lowest in 50% followed by control and 100%, non-significant but highest body weight gain were observed for control followed by groups at 50% and 100%, and the average cost per kg body weight gain was observed to be Rs 54.02, Rs 50.72 and Rs 45.72 for control, 50% and 100% group respectively (Kumar, 2015).

Non-mulberry silkworm pupae as a fish feed

Deori *et al.* (2014) investigated the antioxidant activity of pupae of the muga and eri silkworm and concluded that these pupae could be used as natural antioxidants on food products. A study was conducted on growth, food conversion and body composition of fingerlings of *Cirrhinus mrigala* fed on a diet containing muga silkworm pupae by replacing the fish meal on iso nitrogenous basis and revealed that they had better growth rate, food conversion ratio and nitrogen assimilation; the study suggested that muga silkworm pupae could be a possible application as a nutritionally balanced low-cost artificial diet in fish culture (Sengupta *et al.,* 2004). Olaniyi and Babasanmi (2013) suggested that, the 100% silkworm pupae meal (*Anaphe infracta*) diet enhances better growth performance in African cat fish.

Non-mulberry silkworm pupae as a poultry feed

Sapcota *et al.* (2003) studied the effect of dietary supplementation of muga silkworm pupae at different levels (0%, 50% and 100%) replacing fish meal on the performance of broilers and reported that the lowest average feed consumption and the best feed efficiency was exhibited at 50% whereas the best performance index was shown by 100% replacement of fish meal with muga silkworm pupae meal. Sheikh and Sapcota (2007) also reported the production per live weight kilogram of broilers was more economical with 100% muga silkworm pupae meal supplemented diets. However, Mahanta *et al*. (2004) recorded that replacement of 50 and 100% fishmeal with muga silkworm pupae showed detrimental effects on certain breeding performances such as ejaculation volume, quantity, and quality of spermatozoa of poultry.

In a study to compare the growth performance of commercial broiler chicks fed giant tasar silkworm pupae, *A. mylitta* meal by replacing fish meal at different concentrations, it was revealed by Sinha *et al.* (2009) that the broiler chicks group fed diet containing 50% de-oiled silkworm pupae meal and 50% fish meal exhibited the best performance in regards of body weight and feed conversion efficiency. Similarly, Dutta *et al.* (2012) conducted an experiment on incorporating different levels of tropical tasar (*A. mylitta*) silkworm pupae meal in powdered form with fish meal to check the growth of Rhode Island broiler chicks and the results established that there was an increase of the maximum weight and better feed conversion rate in 8-week-old chicks fed on a diet containing 50% fish meal plus 50% pupae meal and hence, the study stated that this silkworm powder meal has potential to substitute the costly fish meal used in poultry industry.

Ijaiya and Eko (2009) worked on effect of replacing dietary fish meal with *A. infracta* caterpillar meal on growth, digestibility and cost benefit of starter broiler chickens and reported that cost per kg gain gradually reduced with increasing dietary level of silkworm meal and hence from the investigation, silkworm meal can completely substitute fish meal without compromising the performance as well as economic returns of starter broilers.

It was suggested by Kongsup *et al.* (2022) that addition of eri silkworm (*S. ricini*) pupae at 10% in the diet formulation of broilers gave a higher cold carcass weight and skin yellowness and this formulation did not cause any harmful consequences on growth performance, health status and meat quality and can be used as alternative protein sources for broilers, however, on the other hand, addition of eri silkworm pupae at 15% led to poor outcomes and hence not recommended.

Non-mulberry silkworm pupae as a pig feed

The information available on the use of non-mulberry silkworm pupae in the diet of pig is limited. Choudhury *et al.* (2021) conducted a study on effect of dietary inclusion of dried muga silkworm (*A. assamensis*) pupa meal powder at 0, 2% and 4% by replacing the normal soybean diet on the growth performance of large white yorkshire grower pigs reported that the final body weight and feed conversion ratio were found to be impressive with the supplemented muga pupa diet at 2% and 4% which ultimately affected the feed cost/kg gain and was found to be reduced by Rs 8 and Rs 16 at 2 and 4% level respectively hence, their study unveiled that supplementation of muga pupa powder at 2 and 4% level could improve nutrient digestibility, weight

gain, growth performance, feed conversion efficiency and lower feed cost production in pigs.

Conclusion

Silkworm pupae meals are one of the versatile materials on earth as they are completely natural, highly nutritious, cost effective and has no adverse effect on the production performances hence, can be considered as a better alternative to partially or fully replace fish meal and other plant-based meal. The reviews of the present study revealed that, the silkworm pupae (both mulberry and non-mulberry) are great source of proteins, lipids, minerals and vitamins so could be used as an alternative dietary supplement at different levels in fish, poultry and pig feed for economic production. It also reduces the cost of production without much effecting the growth performance. Though studies on effect of mulberry silkworm pupae as an animal feed has been studied by a number of researchers, there is a limited study in case of non-mulberry silkworm pupae. Therefore, future efforts should be made to study the effect of different non-mulberry silkworm pupae meal as an animal feed to access more benefits from this cheap waste product.

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