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Silk worm pupal meal: A alternative protein source in aqua feed

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Abstract
In feed fishmeal is the major ingredient, used as protein source because of its nutritional profile. In progression of time fish meal cost has raised enormously due to overfishing, environmental changes, limitation of its raw material supply and it's over usage in feeds of all terrestrial and aquatic meat producing animals, led to increase in feed and production cost. In the search of reducing the feed cost, research on usage of insect meals in animal diets as fish meal replacers either partially or completely has become the novel strategies. Among the different insect meals, silkworm pupal meal is one which is effective and efficient fish meal replacer. It can be used in aquatic animal feeds as pupal meal, deoiled silkworm pupal meal, fermented pupal meal etc., to improve the growth performance and also has a great influence on animal body composition as well as digestive enzyme activity. India is the 2nd largest producer of silk and produces huge amount of silkworm pupae wastes dumped into environment which can be used as protein source in feed. It has a good nutritional profile which is likely near and equal to fish meal, it consists of 50 -80% of crude protein on dry matter, rich in essential amino acid profile and lipid content ranges from 20-40% in freshly spent pupa and less than 10% in defatted pupa. The present review mainly targets on the impact of the silkworm pupal meal in aquatic animal when administered through diets.

Keywords: Feed, fish meal, silkworm pupal meal, aquatic animal

Introduction
Aquaculture has grown in tandem with world fish consumption during the last several decades (FAO 2018) [11]. Aquaculture is predicted to provide 52% of human fish dietary demands (FAO, 2020) [11]. In this regard, cultural practices have strengthened and broadened with significant diversification in terms of species and systems (FAO 2024) [12], and reached an annual average growth rate of 8.61%. Feeding has become the most challenging aspect as the culture practices have become more intensified. Feed, which should cover the nutritional demand of the animal, accounts for 60-70% of the entire operating cost of aquaculture (Boyd and Tucker, 1992) [5], owing to the inclusion of fish meal and fish oil (Hodar *et al.,* 2022) [18]. Fish meal is used as a protein source in feed because it is easily digestible, has an excellent amino acid composition, is highly palatable, contains long chain omega 3 fatty acids - eicosapentanoic acid (EPA) and docosahexanoic acid (DHA), aids in nutrient uptake, and improves nutrient digestion and absorption (Karthick *et al*., 2019 and Olsen *et al*.,2017) [26, 37]. It was once an inexpensive commodity that was utilized in feeds of terrestrial meat-producing animals, accounting for 80% of total world fish meal production in 1988, whilst only 10% was used in aquaculture feed; however, as time progressed, the proportion used in aqua feed increased to 56%, compared to 32% in terrestrial animals in 2010 (Huntington, & Hasan 2009) [19].
Overfishing devastated the world's fisheries from long time, leading in a continuous decline in wild fish capture, while the requirement for fish meal (FM) in aquaculture and cattle feeds grew rapidly (Mousavi *et al*., 2020) [35], putting an immense burden on the wild fishery. These changes resulted in a scarcity of FM raw materials, which culminated in a significant increase in their cost, coupled with a drop in supply, prompting researchers to seek alternatives to protein sources over long periods of time, which has now become an international research priority and is the primary objective of today's fish nutrition research

(Swamy *et al*., 1994, Hodar *et al*., 2022, Salem *et al*.2008) [19].
According to FAO 2020 [11], around 18 million tons of fishmeal and fish oil have been produced in 2018 from global fishing production. Lack of FM supply and growing costs have finally increased the price of feed formulation, and thus the cost of production (Salem *et al*. 2008). As a result, it is vital to increase production rates along with reducing feed costs, which might be accomplished by incorporating zero/minimum amounts of FM into aqua feed (Hodar *et al*. 2022) [18].
Effective outcomes have been obtained with plant protein sources such as soyabean meal, corn gluten, rape seed meal, lupine meals, etc (Salem *et al* 2008), but the major drawback is the presence of antinutritional factors (ANFs) such as protease inhibitors, glucosinolates, saponins, and lectins (Gopan *et al* 2020) [15], as well as their lower palatability and unbalanced amino acid composition (M. Henry 2023) [34]. Scientists explored animal and insect meals with plant feed sources in order to replace FM and overcome the disadvantage of ANFs in plant-based feed stuffs. The latest, though not novel, strategy is to use insects as a source of protein in fish diets (Tacon, 1993 and Adeparusi and Ajayi 2000) [50]. Insect meal or byproducts such as silkworm pupae (*Bombyx mori*), black soldier fly (*Hermetia illucens*), housefly (*Musca domestica*), yellow meal worm (*Tenebrio molitor*), and so on were widely employed in the aqua feed industry (Salem *et al*., 2008).
Edible IMs have received a lot of interest in recent years (karnjanapratum *et al*., 2022) [25], due to their high energy conversion, ability to help with fish and shellfish growth and well-being, and presence of bioactive substances with antibacterial, antioxidant, and immunomodulatory properties (Mousavi *et al*., 2020) [35]. Among the several IMs, silk worm pupal meal, a byproduct of the silk reeling business after reeling silk from the silk moth, is regarded as one of the most effective FM replacers due to its multiple biological elements ((Javali *et al*., 2015) [23]. It is regarded an edible insect (Yhouing-Aree *et al*., 1997) and is commonly used as food in many parts of the world, particularly in Asian nations such as Thailand, China, Vietnam, Indonesia, Korea, and Japan (Wu *et al*., 2021 and karnjanapratum *et al*., 2022) [25]. This is used in Chinese remedies to treat hypertension and fatty liver disease (Zhang and Zhang 2001) [55]. The current review describes about the silkworm pupal meal (SPM) as an FM replacement in the aquatic animal nutrition along with its nutritional profile.

Silk worm pupae

Silk worm pupae are the byproduct of the sericulture industry, following the extraction of silk from silk moths (Javali *et al*., 2015) [23]. Silk worms are raised in silk industries by feeding on mulberry plants, and they go through many life phases such as moth, caterpillar, pupa, and adult. At the caterpillar stage, it spins a cocoon of the silk thread over itself, which is then unwound for silk production in industries by boiling the pupa inside the cocoon, and such pupa is referred to as spent pupa, which is considered waste and discarded (Hodar *et al*., 2022) [18]. It involves the use of around 5500 silkworms to produce 1 kg of raw silk (Tuigong *et al*., 2015), or approximately 8.014 Kg wet and 2 Kg dry pupa to produce 1kg of raw silk (Patil *et al*., 2013) [39]. In India, the yearly pupae output of mulberry silkworm (*Bombyx mori*) is projected to be over 1.5 lakh MT. Such newly spent pupae are simply disposed away in the environment and are frequently used as fertilizer. This is extremely degradable and contains a high concentration of proteins and lipids. Disposing of a large quantity of pupae can cause major environmental difficulties such as environmental pollution and an unpleasant odor in the surrounding areas.
The spent pupa has a high nutritional content; according to Panda, 1970 SWP is 130% better than casein and 90% more digestible than pepsin. Spent pupae include a variety of biological components that are valuable as feed/food for humans and animals, as well as other essential applications such as medicinal and crop manure (Javali *et al*., 2015) [23]. Additionally, the utilization of spent pupa will reduce environmental stress.
Silk worm pupae include 50-80 percent proteins (Rashmi *et al*., 2018; Ichim *et al*., 2008) [20], 8-10 percent lipids, vitamins E, B1, and B2, nicotinic acid, pantothenic acid, copper, iron, and selenium (Ichim *et al*., 2008) [20]. Silkworm pupae have greater protein content than fish meal (Mathur *et al*., 1988; Mishra and Das, 1992) [33, 23] or cow protein. It contains high levels of limiting amino acids including methionine and lysine (Longvah *et al*., 2011; Rao, 1994; Chandrasekaraiah *et al*., 2003b; Sampath *et al*., 2003) [30, 7, 8]. The essential amino acid concentration of pupal protein is comparable to that of whole egg protein, with the exception of tryptophan (0.9g per 16 g of nitrogen) (Rao, 1994). The protein quality of spent silk worm pupae meal was much lower than casein (milk protein) as measured by the protein efficiency ratio (PER) and net protein utilization (Ioselevich *et al*., 2004) [22]. Silkworm pupae meal fat includes 20.7% saturated and 70.1% unsaturated fatty acids. It contains a high proportion of polyunsaturated fatty acids, especially linolenic acid (Makkar 2014) [32]. Silkworm pupae include a variety of biological substances with numerous applications, including animal feed / food, pharmaceuticals, and crop waste. This comprises persons, medications, and agricultural manure.

Status of silk production in world and India:

Silk is a natural fibre secreted in the fluid state as single filament by a caterpillar, popularly known as 'silkworm'. The major silk producing countries in the world are; China, India, Uzbekistan, Vietnam, Thailand, North Korea, Brazil etc., (International sericulture commission 2023).

In world

Silk makes up a small percentage of the global textile market, accounting for less than 0.2%. However, the production base has now reached over 60 countries worldwide. Major producers are in Asia (90% of mulberry production and almost 100% of non-mulberry silk). At present, China and India are the top two silk producers globally. China and India account for 80% and 15% of the total silk produced in the world (International sericulture commission 2023).

Table 1: Top 5 silk producing countries in world

S. No	Country	Production (metric tonnes in the year 2023)
1.	China	50,000
2.	India	38913
3.	Uzbekistan	2,037
4.	Vietnam	1,448
5.	North Korea	370

Source: International sericulture commission 2023.

In India

In India, sericulture is one of the driving forces behind silk production, utilizing various climatic conditions to produce various silk varieties such as mulberry, tasar, eri, and muga. Sericulture and the Silk Industry have been an avocation in India since at least the second century BC. According to historians, raw silk was exported during Kanishka's reign in 58 B.C., and the Indian silk industry has grown significantly since independence, from 1437 MT of raw silk output during the First Plan era (1969-74) to 23679 MT by the end of March 2013. Today, India is the second largest silk producer after China, with 36,582 metric tons in 2022-2023, and has the unique distinction of being the only country producing all five types of silks in the world, among them Mulberry silk is being produced predominantly which constitutes nearly 70% of the total silk production (Roy, 2022). Karnataka known as the home to Mysore silk is the largest producer of silk in India followed by Andhra Pradesh with a production rate of 8722mt and 86903 mt.

Nutritional composition of silkworm pupae:

Silkworm pupae meal contains a high concentration of protein, ranging from 50% to more than 80%. This protein has a good amount of crucial amino acids. The limiting amino acids in cattle, such as methionine and lysine, are found in appreciable percentage in the silkworm's pupa protein (Chandrasekaraiah *et al*., 2002, 2003b) [7]. Because of the presence of chitin, truly digested protein contributes for only 73% of total crude protein composition. Silkworm pupa contains several attractants and appetite stimulants, which enhance acceptance and hence growth (Nandeesha *et al*., 1988) [36]. It is regarded as a high-quality protein with a good nutritional source due to presence of essential amino acid profile along with fatty acid profile particularly polyunsaturated fatty acid especially α linolenic acid around 27.99% and has more than 68% total unsaturated fatty acids. Because of its nutritional profile it grabbed the interest of many researchers towards it (SWP) and found that it can be used in feeds of animals, especially in monogastric species (poultry, pigs and fish) and ruminants (Makkar *et al*., 2014) [32] and evidences showed that polysaccharides such as silk rose or dipterose, extracted from silkworm possess immunostimulatory effects that could improve the health status of mammals and aquatic species (Motte *et al*., 2019) [34].

Table 2: Top 5 silk producing states in India

S. No	State	Production (Metric tonnes in the year 2023)
1.	Karnataka	8722
2.	Andhra Pradesh	6903
3.	Assam	5004
4.	Tamil Nadu	1886
5.	West Bengal	1325

Source: Statistica

Table 3: Nutritional composition of fresh silkworm pupa, fatted silkworm pupae and defatted silkworm pupae:

Component	Fresh silkworm pupae	Dried, fatted silkworm pupae	Dried, de fatted silkworm pupae
Dry matter (% as feed)	26.2	91.4	93.8
Crude protein (% DM)	58.8	60.7	75.6
Crude fibre (% DM)	5.8	3.9	6.6
Ether extract (% DM)	28.5	25.7	4.7
Ash (%DM)	4.9	5.8	6.8
Calcium (g/kg DM)	1.5	3.8	4.0
Phosphorus (g/kg DM)	9.0	6.0	7.0
GE (MJ/kg DM)	26.5	25.8	22.0

Source: Sahid *et al*., 2024.

Essential Amino acid of SWP

In Silkworm amino acids like methionine, lysine, threonine and tyrosine are more against to the milk protein (Rao, 1994), while the deoiled silkworm [upae powder contains 5.36% of lysine and 2.39% of methionine on percent dry matter (Joshi *et al*., 1980). The amino acid profile of silkworm pupae meal (non-defatted and defatted) has presented in Table 4.

Table 4: Amino acid profile of SWP:

Amino acids Non-defatted (g/ 16g Nitrogen) Defatted (g/ 16g Nitrogen)
Alanine 5.8 (5.5, 6.1) 4.4±0.2
Arginine 5.6 (4.4, 6.8) 5.1±0.3
Aspartic acid 10.4(9.9, 10.9) 7.8±0.7
Cystine 1.0(0.5, 1.4) 0.8±0.5
Glutamic acid 13.9(12.9, 14.9) 8.3±0.7
Glycine 4.8(4.6, 4.9) 3.7±0.3
Histidine 2.6(2.5, 2.7) 2.6±0.1
Isoleucine 5.1(4.4, 5.7) 3.9±0.2
Leucine 7.5(6.6, 8.3) 5.8±0.2
Lysine 7.0(6.5, 7.5) 6.1±0.4
Methionine 3.5(2.3, 4.6) 3.0±0.4
Phenylalanine 5.1(5.1, 5.2) 4.4±0.3
Proline 5.2(4.0, 6.5) 5.20±0.1
Serine 5.0(4.7, 5.3) 4.5±0.2
Threonine 5.2(4.8, 5.4) 4.8±0.3
Tryptophan 0.9 1.4±0.2
Tyrosine 5.9(5.4, 6.4) 5.5±0.2
Valine 5.5(5.4, 5.6) 4.9±0.2

Souce: Sadat *et al*., 2022 [42]

Fatty acid profile of silkworm pupae

Freshly spent pupa (Non-defatted) will have a good range of lipid content varies from 20-40%, whereas the defatted pupa contains less than 10% on dry matter basis. Oil extraxt of silkworm pupa will contain a good fraction of polyunsaturated fatty acids, mainly linolenic acid (18:3) with testified values stretching from 11-45% of total fatty acids (Ioselevich *et al*., 2004) [22]. Various fatty acids present in silkworm pupae are presented in Table 5.

Table 5: Fatty acids of silkworm pupa

Fatty acids Amount (%/100 g)
Unsaturated 70.1
Saturated 20.7
Linoleic acid 24.6
Palmitic acid 14.0
Oleic acid 9.10
Linolenic acid 14.0
Others 8.40

Source: Sadat *et al*., 2022 [42]

Vitamin and Mineral content of silkworm pupae

The vitamin profile *viz.*, riboflavin, thiamine, pyridoxal, folic acid and ascorbic acid and minerals such as, calcium., phosphorus, potassium, iron etc. are present at a great range in silkworm pupa which makes it more nutritive (Koundinya and Thangavelu, 2005). According to Bora and Sharma, 1965 calcium and phosphorus contents of silkworm pupae (Assam muga) were 0.26 and 0.80%. the mineral and vitamin composition of SWP was presented in table 6 and table 7.

The crude protein (CP) value of different meals used in aqua diet ranges from 42 to 70%, where the maximum CP accounted by defatted silkworm pupal meal with 75%. At their immature stages insects do accumulate the lipid in body, later used for development (Manzano-Agugliaro *et al*., 2012), which on defatting enhances the protein percent. Lipids value ranges from 8.5 (Locust meal) to 36% (Meal worm), where defatted SWP contains 4.7% of lipid content. Black soldier fly meal and fish meal are rich in Calcium and phosphorus, where silkworm shows less percent of it, but shows a considerable range of Ca:P ratio.

Table 6: Mineral content of silkworm pupa

Mineral Amount
Calcium (mg/100 g) 102.31
Phosphorus (mg/100 g) 1369.94
Magnesium (mg/100 g) 287.96
Potassium (mg/100 g) 1826.59
Iron (mg/100 g) 9.54
Sodium (mg/100 g) 274.57
Zinc (mg/100 g) 17.75
Manganese (mg/100 g) 1.04
Copper (mg/100 g) 1.04
Selenium (µg/100 g) 80.00

Source: Sadat *et al*., 2022 [42]

Table 7: Vitamin content of silkworm pupae

Vitamin Amount
Vitamin A(µg/100 g) 273.99
Vitamin B1(mg/100 g) 1.91
Vitamin B2(mg/100 g) 5.43
Vitamin B3(mg/100 g) 15.20
Vitamin B5(mg/100 g) 12.49
Vitamin B7(µg/100 g) 144.51
Vitamin B9(mg/100 g) 0.41
Vitamin B12(mg/100 g) 500.00
Vitamin C (mg/100 g) 5.70
Vitamin E (IU/kg) 51.45

Source: Sadat *et al*., 2022 [42]

Table 8: Nutritional profile of silk worm pupal meal vs other insect meals, fish meal and soya bean meal:

Constituents	Black soldier fly Larvae	Housefly maggot meal	Meal worm	Locust meal	Silkworm pupal meal	Silkworm pupal meal (defatted)	Fish meal	Soy meal
Crude protein	42.1 (56.9)	50.4 (62.1)	52.9 (82.6)	57.3 (62.6)	60.7 (81.7)	75.6	70.6	51.8
Lipids	26.0	18.9	36.1	8.5	25.7	4.7	9.9	2.0
Calcium	7.56	0.47	0.27	0.13	0.38	0.40	4.34	0.39
Phosphorus	0.90	1.60	0.78	0.11	0.60	0.87	2.79	0.69
Ca:P ratio	8.4	0.29	0.35	1.18	0.63	0.46	1.56	0.57

*Values in parentheses are calculated values of the defatted

Source: Makkar *et al*., 2014 [32] & Tran *et al*., 2014 [32].

Table 9: Amino acid Profile of Silkworm pupa vs other insect meals, fish meal and soy meal:

Amino acids	Black soldier fly Larvae	Housefly maggot meal	Meal worm	Locust meal	Silkworm pupal meal	Silkworm pupal meal (defatted)	Fish meal	Soy meal
Methionine	2.1	2.2	1.5	2.3	3.5	3.0	2.7	1.32
Cystine	0.1	0.7	0.8	1.1	1.0	0.8	0.8	1.38
Valine	8.2	4.0	6.0	4.0	5.5	4.9	4.9	4.50
Isoleucine	5.1	3.2	4.6	4.0	5.1	3.9	4.2	4.16
Leucine	7.9	5.4	8.6	5.8	7.5	5.8	7.2	7.58
Phenylalanine	5.2	4.6	4.0	3.4	5.2	4.4	3.9	5.16
Tyrosine	6.9	4.7	7.4	3.3	5.9	5.5	3.1	3.35
Histidine	3.0	2.4	3.4	3.0	2.6	2.6	2.4	3.06
Lysine	6.6	6.1	5.4	4.7	7.0	6.1	6.1	6.18
Threonine	3.0	3.5	4.0	3.5	5.1	4.8	4.8	3.78
Tryptophan	0.5	1.5	0.6	0.8	0.9	1.4	1.4	1.36

Source: Makkar *et al*., 2014 [32]

The amino acid profile of silkworm, compared against with the Fish meal (FM), soy meal, along with other insect meals. It was observed that silkworms are relatively rich in lysine and phenylalanine. Sulfur amino acids (in percent CP) tend to be less in insects than in fish meal, except for silkworms. Tryptophan levels are high in silkworm pupa and in black soldier fly, where threonine ranges almost equally in all the meals but relatively higher in silkworm. (Tran *et al*., 2014) [32]. On comparing the SWPM (non-defatted and defatted) with other conventional protein sources, it is noted that the defatted SWPM has superior protein content and essential amino-acid profile than the conventional protein sources (Chandrasekharaiah *et al*., 2004; Makkar *et al*., 2014) [8, 32].

Processing Silkworm pupae as feed

Spent silkworm pupae immediately after reeling, are highly perishable and more prone to detoriation/degradation, as it is rich in moisture and lipids which associates with the palatability related in addition to rancidity (Finke, 2002) [14]. Hence the pupa is washed and pressed to remove the moisture first and dried either under sun or in driers followed by the grinding. Before drying, pupa is subjected to solvent extraction, to withstand longer storage by less fat content. Finally obtained defatted silkworm pupae meal has a higher protein content and longer shelf life than undefatted meal and studies had revealed that the defatted silkworm pupae have better protein content than the non defatted pupal meal, also can be used as a suitable dietary protein source in fish diet (Blair, 2008) [4]. The other method is ensiling, to enhance its shelf life as well as reduces the microbial development. Ensiling with molasses, propionic acid, curd will give better results in preparing the good quality silage.

Role of Silkworm pupa in Aquaculture

As the silkworm's nutritional profile is almost similar to fishmeal, an extensive research work on the utilization of silkworm pupal meal has been carried out in diets of finfish and shellfish as protein source for replacement of fishmeal. It is considered as an essential ingredient in fish feed, especially in Indo-Pacific region (Hansan 1991). Literatures have proved that silkworm pupae (SWP) can be used as target Insect meals (IM's) in various aquatic organisms (Tran *et al*., 2014) [32]. It can be utilized as silkworm pupal meal (SWPM) either de-oiled, dried or as fermented forms in the diets of aqua feed.

In Finfish

Table 10: In Ornamental Fishes

SWP meal	Substitution of silkworm pupae for fish meal in broodstock diets for snakeskin gourami has revealed that SWP can be used to replace fish meal upto 50% in broodstock diets without any adverse effect on egg quality in terms of fry number fingerling number and survival rate during the first month of nursery rearing.	Jintasataporn *et al*., 2011 [24]
SWP meal	SWP meal could be effectively utilized in rearing of Red zebra fingerlings (Maylandia estherae) diets up to 60% without any adverse effects on growth performance and feed utilization. The supplementation of SWP meal not only enhanced the growth of Red zebra fingerlings (M. estherae) but also reduced the cost of feed formulation [68] .	Karthick *et al*., 2019 (review) [26]

Table 11: In Shellfish

Pacific white shrimp	SWP meal	SPM inclusion Apparent digestibility coefficients of dry matter, gross energy and phosphorous Serum antioxidant parameters including total antioxidant capacity and malondialdehyde concentration were beneficially influenced were significantly improved chitin deacetylase activity was enhanced. the entire replacement of FM with SPM did not influence shrimp growth, and its beneficial impacts were found on diet digestibility, antioxidant capacity and molting time. However, the substitution level is recommended to be restricted to 75% as total replacement led to shrinkage of hepatopancreatic cells.	Rahimnejad *et al*., 2019
abalone	SWP meal	dietary effect of substitution of animal and/or plant protein sources for fishmeal on the growth and body composition of juvenile abalone and suggested that a combination of soymeal (29%, DM basis) and SWP meal (16.9%, DM basis) could totally replace fishmeal and also result in better survival and growth performance in Abalone juveniles (Haliotis discus).	Cho *et al*., 2010
Juvenile whiteleg shrimp	SWP meal	Observed enhanced growth rates and ignificant higher crude protein in carcasswhen FM replaced by 50% SBM + SPM and concluded that fishmeal protein in juvenile vannamei diets was possible to replace 50% with soyabean meal and silkworm pupal meal without compromising on growth performance, feed utilization and body composition of th shrimp.	Hodar *et al*., 2022 [18]
Pacific white shrimp	SWP meal	60% incorporation level of SWP meal can replace FM. At this concentration digestive enzymatic activity was (amylase, trypsin and lipase) high along with growth as well as amino acid profile.	Sathishkumar *et al*., 2023
Giant freshwater prawn	SWP meal	When silkworm pupal meal was incorporated in giant freshwater prawn @ 0%, 8.6%, 17.2%, 25.8% and 34.7% by weight to replace fishmeal, concluded that no considerable difference arised at any concentration of SWP introduction in growth performance anf feed utilization. Therefore, silkworm pupae can be replaced for fishmeal in giant freshwater prawn without any adverse effects on productive performance.	Jintasataporn *et al*., 2011 [24]

Conclusion

This review on silkworm pupa has revealed nutritional status along with the influence of it on different finfish and shellfish. The amino acid and fatty acid profile makes the silkworm pupa as an efficient protein source through dietary supplementation to be used in aqua feed, also can be as a fish meal replacer to reduce the cost of feed, as it can be available easily and inexpensive than fish meal. Its vitamin and mineral profile makes it more nutritive. Based on the various studies on silkworm pupal meal in diets of fish/shell fish, it can be effectively benefit the animal's growth, digestive enzyme activities and the immune response too and can be concluded that about 30 to 50% of silkworm pupal meal can replace the fish meal without showing any negative impact on growth performance in farmed aquatic species.

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