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Review on Silk Worm Pupal Meal: A Protein Source in Aquatic Animal Nutrition as a Replacement of Fish Meal

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Authors' contributions

This work was carried out in collaboration among all authors. Author SSV helped in literature, wrote the protocol, and wrote the first draft of the manuscript. Author PAP managed the literature searches and collecting the recent data. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Amongst the insect meals, silkworm pupal meal is the most efficient fish meal replacement. It can be utilized in aquatic animal feeds as pupal meal, deoiled silkworm pupal meal and fermented pupal meal, to increase growth performance. It also has a significant impact on animal body composition and digestive enzyme activity. India is the world's second-largest producer of silk, and a vast

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amount of silkworm pupae waste is discharged into the environment, which can be used as protein in feed. It has a strong nutritional profile that is near or equal to fish meal, consists of 50-80% of crude protein on dry matter, rich in important amino acid profile, (methionine 3.5, lysine 7.0, aspartic acid 10.4, threonine 5.2, serine 5.0, glutamic acid 13.9, proline 5.2, glycine 4.8, alanine 5.8, cystine 1.0, valine 5.5, isoleucine 5.1, leucine 7.5, tyrosine 5.9, phenylalanine 5.1, histidine 2.6, and arginine 5.6) and lipid content ranges from 20-40% in freshly spent pupa and less than 10% in defatted pupa. The oil derived from pupa is high in alpha-linolenic acid, oleic acid, palmitic acid and the gross energy values range from 5.09 to 6.28 MJ/kg. It also contains interesting minerals and vitamins, which piqued the interest of researchers in its use in aqua feed. Aside from the nutritional profile, nutrient digestibility, and the effect of diet on organoleptic quality revealed that SWP meal is equivalent to fish meal in all respects. So, the current review focuses on the effects of silkworm pupal meal on aquatic animals when supplied through diets.

Keywords: Feed; fish meal; silkworm pupal meal; aquatic animal.

1. INTRODUCTION

Over the past few decades, aquaculture has expanded in pace with global fish consumption (FAO, 2018), and it is expected to supply 52% of the fish nutritional needs of humans (FAO, 2020). Accordingly, cultural practices have expanded and become significantly more diverse in terms of species and systems (FAO, 2024), with an average growth rate of 8.61% every year.pupal meal when given to aquatic animals through their meals.

Feeding, the most challenging aspect because of the increasing costs of aquafeeds, including meat meal, FM and soybean meals, which account for 60–70% of total aquaculture production cost (Alfiko et al., 2022), owing to the inclusion of fish meal and fish oil (Hodar, 2022). 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 (Olsen and Hasan, 2012; Karthick, 2019). Earlier it was an inexpensive commodity that was utilized in feeds of terrestrial meat-producing animals, accounting for 80% of total world fish meal production, 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 (Huntington and Hasan, 2009).

Exploitation of natural fisheries from oceans 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). Such need of FM in both land and aquatic animals kept an immense burden on the wild fishery. Changes in the fish dynamics in natural waters along with environmental switch towards drastic impact on fisheries in oceans 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 the primary objective of today's fish nutrition research (Swamy and Devara 1994j; Salem et al. 2008).

According to FAO 2020, 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, 2022).

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 anti-nutritional factors (ANFs) such as protease inhibitors, glucosinolates, saponins, and lectins (Gopan, 2020), as well as their lower palatability and unbalanced amino acid composition (Finke, 2002). Researchers 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 (Rashmi et al., 2018, 2022). The latest, though not novel, strategy is to use insects as a source of protein in fish diets (Salem et al. 2008). Insect meal or byproducts such as silkworm pupae (*Bombyx mori*), black soldier fly (*Hermetiaillucens*), 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 , 2022) 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). Among the several IMs, silk worm pupal meal, a by-product 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). It is regarded an edible insect (Yhoung-Aree , 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; Karnjanapratum , 2022). This is used in Chinese remedies to treat hypertension and fatty liver disease (Zhang et al., 2001). The current review describes about the silkworm pupal meal (SPM) as an FM replacement in the aquatic animal nutrition along with its nutritional profile (Blair, 2008).

2. SILK WORM PUPAE

Silk worm pupae are the by-product of the sericulture industry, following the extraction of silk from silk moths (Javali et al., 2015). 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 (Tuigong et al., 2015) and such pupa is referred to as spent pupa, which is considered waste and discarded (Hodar et al., 2022). It involves the use of around 5500 silkworms to produce 1kg 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). In India, the yearly pupae output of mulberry silkworm (*Bombyx mori*) is projected to be over 1.5 lakh metric tons (Roychoudhury and Mishra., 2020). Such newly spent pupae are simply disposed away in the environment and are frequently used as fertilizer (Wei et al., 2009). 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 (Sheikh et al., 2018).

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, 2015) additionally; the utilization of spent pupa will reduce environmental stress.

Silk worm pupae include 50-80 percent proteins (Ichim, 2008; Ioselevich et al., 2004), 8-10 percent lipids, vitamins E, B1, and B2, nicotinic acid, pantothenic acid, copper, iron, and selenium (Ichim, 2008). The calorigenic components such as protein, fat, and carbs contained by silkworms provide up to 230 kcal per 100 g. Furthermore, silkworms provide 43.6 calories with 35 g of protein. The SP contains about 55 g of protein, while the requirement for males is about 53 g/day and for females 45 g/day (Hăbeanu, 2023). According to Roychoudhury and Mishra, 100 g of dried eri silkworms supply 100% of the daily requirements for many vitamins (pyridoxine, riboflavin, thiamine, ascorbic, and folic acids), minerals (calcium, iron, and phosphorus), and 75% of the average individuals' daily protein needs. It also has greater protein content than fish meal (Mathur and Mukhopadhyaya, 1988; Mousavi et al., 2020) or cow protein. It contains high levels of limiting amino acids including methionine and lysine (Rani et al., 2024; Chandrasekharaiah; Sampath et al. Longvah et al., 2011). 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). 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 et al., 2014). It includes a variety of biological substances with numerous applications, including animal feed, pharmaceuticals, and crop waste.This comprises persons, medications, and agricultural manure.

Investigations on keeping quality of the feed (Jayaram, 1980), influence of diet on body composition (Jayaram), digestibility of nutrients in the feed (Jayaram) and the influence of the diet on the organoleptic quality (Sathishkumar et al., 2023) showed that SWP meal was equivalent to fish meal in all respects. SWP has known to improve the digestibility of nutrients like proteins, lipids and carbohydrates in animal when given through diet with respective to concentrations asministered as well as the enzymes activity in *L. fimbriatus* and *C. carpio* (Finke, 2002) and the energy obtained will be 5.09-6.28 MJ/kg (Lamberti et al., 2019).

2.1 Status of Silk Production in World and India

Silk is a natural fibresecreted as single filament by caterpillar, known as 'silkworm'. The major silk producing countries in the world are; China, India, Uzbekistan, Vietnam, Thailand, North Korea, Brazil etc, (Ichim, 2008).

2.2 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 (Ichim, 2008).

2.3 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 metric tons 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 constitues nearly 70% of the total silk production (Roy, 2023). 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 metric tons.

3. 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 amino acids found in appreciable percentage in the silkworm's pupa protein (Chandrasekharaiah; Chandrasekharaiah). 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 (Tuigong et al., 2015; Wei et al., 2009), which enhance acceptance and hence growth (Nandeesha et al., 2020). 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 (Wei et al., 2009). Because of its nutritional profile, it grabbeb the interest of many researchers towards it and found that it can be used in feeds of animals, especially in monogastric species (poultry, pigs and fish) and ruminants (Trivedy et al., 2007; Makkar et al., 2014; Rashmi et al., 2023) and evidences showed that polysaccharides such as silkrose or dipterose, extracted from silkworm possess immunostimulatory effects that could improve the health status of mammals and aquatic species (Motte et al., 2019).

3.1 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 (Jintasataporn, 2011). The amino acid profile of silkworm pupae meal (non-defatted and defatted) has presented in Table 4.

Though there is not much variation in protein% in defatted and non-defatted pupal meal of silkworm, the defatted SWPM will be commonly used in diets of animal feeds, because of its reduced lipid content.

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

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: Arora et al. (2024). Top-10 Silk Producing States in India 2024

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.

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 & Sahib et al., 2024

3.2 Fatty Acid Profile of silkworm Pupae

Freshly spent pupa (nondefatted) 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, rich in alpha-linolenic acid (C18:3n-3), palmitic acid (C16:1n-7) and oleic acid (C18:1n-9) (Hăbeanu, 2023) with testified values stretching from 11-45% of total fatty acids (Ioselevich et al., 2004). Deffated SWPM can be utilized in feed frequently, as the non deffatted meal contains more lipid content which leads to rancidity of the feed. Various fatty acids present in silkworm pupae are presented in Table 5.

3.3 Vitamin and Mineral Content of Silkworm Pupae

The vitamin profile *viz.,* ribofalvin, thiamine, pyridoxine, folic acid and ascorbic acid and minerals such as, calcium., phosphorus, potassium, iron etc are present at a great ranges in silkworm pupa which makes it more nutritive (Koundinya, 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.

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, Sahib et al., 2024

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, Sahib et al., 2024

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, Sahib et al., 2024

Table 8. Nutritional profile of silk worm pupal meal vs other insect meals, fish meal, 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

Source: Chandrasekaraiah et al., 2003a, Miles et al., 2006, Makkar et al., 2014, Tran et al., 2015

Table 9. Amino acid Profile of Silkworm pupa vs other insect meals, fish meal, soya bean meal and Hen's egg albumen

Amino acids	Black soldier fly Larvae	Housefly maggot meal	Meal worm	Locust meal	Silkworm pupal meal	Silkworm pupal meal (defatted)	Fish meal	Soy meal	Egg Albumen
Methionine	2.1	2.2	1.5	2.3	3.5	3.0	2.7	1.32	4.73
Cystine	0.1	0.7	0.8	1.1	1.0	0.8	0.8	1.38	3.84
Valine	8.2	4.0	6.0	4.0	5.5	4.9	4.9	4.50	6.85
Isoleucine	5.1	3.2	4.6	4.0	5.1	3.9	4.2	4.16	5.42
Leucine	7.9	5.4	8.6	5.8	7.5	5.8	7.2	7.58	8.65
Phenylalanine	5.2	4.6	4.0	3.4	5.2	4.4	3.9	5.16	5.93
Tyrosine	6.9	4.7	7.4	3.3	5.9	5.5	3.1	3.35	3.74
Histidine	3.0	2.4	3.4	3.0	2.6	2.6	2.4	3.06	2.28
Lysine	6.6	6.1	5.4	4.7	7.0	6.1	6.1	6.18	6.98
Threonine	3.0	3.5	4.0	3.5	5.1	4.8	4.8	3.78	4.63
Tryptophan	0.5	1.5	0.6	0.8	0.9	1.4	1.4	1.36	4.88

Source: Makkar et al., 2014; Tran et al., 2015, Dajnowska et., al 2023

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 (Mathur and Mukhopadhyaya, 1988), 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.

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 ralatively 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 (Sheikh et al., 2018). 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; Makkar et al., 2014).

All the above cited insect meals are compared against with egg albumin, it is found that SWPM is better after egg albumin and more or less equal to fish meal and soya meal and can be used in aquatic animal feed as a protein source.

4. 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 relatedin addition to rancidity (Rao, 1994 and Finke, 2002).Hence the pupa is washed and pressed to remove the moisture first and dried either under sun or in driers followed by the grinding (Rashmi et al., 2023). 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 (Arora , 2024). The other method is ensiling, to enhanceits shelf life as well as reduces the microbial development. Ensiling with molassess, propionic acid and curd will give better results in preparing the good quality silage (Yashoda et al.; Rangacharyulu et al., 2003).

List 1. In finfish

Species	Form of SWP	Result	Reference
Catla (*Catlacatla*)	Fermented Silkworm puapae	Incorporating fermented silkworm pupae (SWP) silage improved body weight increase, feed conversion ratio (FCR), and specific growth rate (SGR) and showed superior to untreated fresh SWP pastes and fishmeal in carp species diets (IMC).	Rangacharyulu *et al*., 2003.
Catla-Rohu (*Labeorohita*) Hybrid	SWP meal	Dietary supplementation of 15% SWP and 10% FM accelerated growth, causing 37.19% increase in final weight over the control; the overall average specific growth rate for both weight (3.64%) and length (1.17%) was similar greater; however, feed conversion efficiency decreased marginally.	Nandeesha *et al*., 1998
Catla	SWP meal	When SWP was incorporated from 0-40%, fat and nitrogen free extract (NFE) digestibility were higher at 20 and 30% of pupa inclusion, whereas the protein digestibility of SWP meals revealed no significant difference.	Gangadhar *et al*., 2018
Catla fingerling	SWP meal	Conducted a study to examine if SWP can entirely or partially replace fishmeal, and had The diets were prepared with 25%, 50%, 75%, and 100% of the total dietary protein from silk worm pupae meal	Hasan 1991

Species	Form of SWP	Result	Reference
		and fish meal, and the results showed that all SWP-supplemented diets performed significantly (P>0.05) better than the control diet. A similar pattern was observed for protein usage. In terms of feed cost and economic return, diets with 100% inclusion and SWP were determined to be the most cost-effective.	
Rohu fingerling	SWP meal	Fish meal replaced with 50% SWP considerably increased the growth performance of Labeorohita fingerlings, and carcass composition demonstrated that the diet supplemented with 50% SWP and 50% FM also contained the highest crude protein composition.	Begum *et al*., 1993
Rohu	SWP meal	SWP inclusion at 30% in rohu dirt improved specific growth rate (SGR), final body weight (FBW), percent weight gain (WG), protein efficiency ratio (PER), and feed conversion ratio (FCR) compared to other treatments (where housefly maggot meal (HMM) and earthworm meal (EWM) were included at 30% each and the control had 30% soya meal). The total saturated fatty acid content was higher in the SM and SPM diets, while the EWM diet resulted in the largest body crude protein deposition, followed by the SPM diet.	Rani *et al* 2024
Grass Carp *Ctenopharyngodonidellus*	Nuclear polyhedrosis virus infected silworm pupa (*B.mori*) (BmNPV) larve powder	Dietary supplementation of *B.mori* nuclear polyhedrosis viruses (BmNPV) carrying the grass carp (*Ctenopharyngodonidellus*) growth hormone (GH) cDNA. Silkworm powder prepared from larvae infected with the recombinant virus was used as food supplement for fish, which was made into pellet and fed to Grass carp, thereby evaluated the Relative somatic growth rate (RSGR) and relative linear growth rate (RLGR). The results found that fish fed with p6 infected silkworm powder had a 28% and 8.7% higher RSGR and RLGR, respectively.	Ho *et al*., 1998
Nile Tilapia (*Oreochromis niloticus*)	SWP meal	This study determined the impact of SWP meal on Nile tilapia fingerlings and demonstrated that the diet containing 66.66% SWPM (from fish meal) was economically superior and reduced about 18.79% of feeding cost per unit of fish compared with other diets, but there is no significant (P>0.05) differences in the final body weight, weight gain, daily gain, specific growth rate, feed conversion ratio, protein efficiency ratio, and protein productive value between fish fed.	Salem *et al*., 2008
Tilapia	Fermented SWP meal	This study demonstrated that the fermented SWP meal can able to influence the fatty acid profile (Poly unsaturated fatty acid), especially the n3fatty acids and n3/n6 ratio (1.25) benificially, which is good for the quality of the fish produced with respect to the benefits of consumers' health and also notably enhanced the grwth parameters, FCR, PER, Hepatosomatic index (HIS), and Gonado somatic index (GSI) with a significant difference in comparison with the control (Market	Bag *et al*., 2013

Species	**Form of SWP**	**Result**	**Reference**
		avaliable diet).	
GIFT Tilapia	Oxidized silkworm pupae	Utilization of highly oxidised and lightly oxidised silkworm pupa meal (HOSP and LOSP) in comparison to fresh silkworm pupa (FSP). Both HOSP and LOSP have had a significant impact on growth performance, villu height, and histological structure of the foregut, liver, and muscles. The activities of intestinal Na+-K+-ATPase, protease, lipase, and pepsin were adversely affected, and the crude protein and crude ash content in muscle of the HOSP group was significantly lower than that of the FSP and LOSP groups. HOSP's muscle ∑n-3PUFA content decreased by 37.28% compared to FSP, indicating that dietary oxidized silkworm pupae inhibited growth, reduced gastrointestinal digestive and absorptive capacity, and hepatic antioxidant capacity. The negative effects increased with the oxidative degree of the silkworm pupae.	Qi-feng Feng *et al*., 2021
Chum Salmon	SWP meal	Fed with SWP (@ 5%), exhibited better feed efficiency ratio, however there was no significant difference in growth performance.	Akiyama, *et al*., 1984
Flounder	SWP meal	Dietary inclusion of 10% silkworm pupae meal meal and 10% silkworm pupae meal+promate meal resulted in improved growth rates, feed efficiency ratio, crude protein percent of body, and serum chemistry of juvenile olive flounder.	Lee *et al*., 2012
African catfish	SWP meal	Growth rate and feed utilization parameters was higher in fingerlings fed the diets with mixed fishmeal and SPP (the highest was 50:50) and lower in those fed 100 % of SPP or fishmeal.	Kurbanov *et al*., 2015
African catfish	SWP meal	*Bombyx mori* meal (BMM) dietary supplementation can fruitfully @ 25%, effect the growth, feed utilization efficiency, whereas carcass and mineral compositions of the fish differed marginally, while 100%, 75% and 50% gave better result than the control.	Oso *et al*., 2014
Rainbow trout	SWP meal	10% and 15% of silkworm pupa can efficiently replace the fish meal and improves the feed conversion ratio (FCR), specific growth rate (SGR), weight gain percent (WG), protein content, lipid content, or nutrition protein utilization (NPU).	Shakoori *et al* 2015
Mirror carp	Enzymatic Hydrolysates of defatted silkworm pupa (EHDSP)	Improved serum alanine aminotransferase and total cholesterol, spleen index, Intestinal trypsin activity with 25% and 50% of EHDSP. But gthe growth parameters did not differ greatly among all the diets.	Xu *et al*., 2018
Mirror carp	Fermented meal mixture (silkworm pupa, rapeseed, wheat)	In conclusion, 40 g kg1 FMM can be included into diets of juvenile mirror carp with respect to growth, apparent digestibility coefficient (ADC), enzymes like trypase and lipase; viscera index, haepatosomatic index, general relative intestine length.	Zhou *et al*., 2017
Mirror carp	SWP meal	SWP incorporated @20, and 30 % to replace of fish meal protein is higher growth performance,	Rahman *et al*., 1996

Species	Form of SWP	Result	Reference
		Apparent net protein utilization (ANPU%) and improves the crude protein percent of mirror carp.	
Trout	SWP meal	Revealed that inclusion of SPM in the diet of Rainbow trout as a replacer of shrimp meal (SM) and full-fat soybean meal (FFS) can positively affect the growth performance and concluded 35.7% of SPM can replace SM and FFS in rainbow trout diets without affecting growth and feed utilization.	Mahato *et al*., 2023
Large mouth bass	Fermented silkworm pupae meal (FSPM)	30% of FSPM can beneficially influence the growth rates. By polynomial regression analysis indicated that the optimal ratio of replacement fishmeal by FSPM was 27%.	Qihan Zhang *et al*., 2022
Silver pompano	Deoiled silkworm pupae meal (DWSP)	Dietary supplementation of DWSP to silver pompano @ 25% enhanced growth rates, apparent digestibility co-efficient of crude protein and fat and protease activity; whereas lipase and amylase activity was more @ 75 &100%. Fat accumulation was less @75% and concluded DSWP can able to replace the 30.5% of Fishmeal with beneficial outcomes.	Mithunkumar *et al*., 2023

List 2. In ornamental fishes

Snakeskin gourami	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
Red zebra fingerlings	SWP meal	SWP meal could be effectively utilized in rearing of Red zebra fingerlings (*Maylandiaestherae*) 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.	Karthick *et al.,* 2019 (review)

List 3. 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	Cho *et al*.,

		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).	2010
Juvenile white leg shrimp	SWP meal	Observed enhanced growth rates and ignificant higher crude protein in carcasswhenFM 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 the shrimp.	Hodar *et al., 2022*
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 raised at any concentration of SWP introduction in growth performance and 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

5. 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 (Huntington and Hasan, 2009). Literatures have proved that silkworm pupae (SWP) can be used as target Insect meals (IM's) in various aquatic organisms (Tran et al., 2015). It can be utilized as silkworm pupal meal (SWPM), de-oiled, dried or as fermented forms in the diets of aqua feed

6. CONCLUSION

The nutritional status of silkworm pupa and its effects on different finfish and shellfish were shown by the current review. The silkworm pupa's amino acid and fatty acid composition makes it a good source of protein for aqua feed nutritional supplements. Because it is more affordable and more widely available than fish meal, it can also be used as a substitute to reduce feed expenses. It is more nutrient-dense because to its vitamin and mineral content. Numerous studies on the use of silkworm pupal meal in fish and shellfish diets have shown that it effectively enhances the animals' growth, immune response, and digestive enzyme activities. It is also possible that between 30 and 50 percent of silkworm pupal meal could be used in place of fish meal without having an adverse impact on the growth performance of farmed aquatic organisms.

DISCLAIMER (ARTIFICIAL INTELLIGENCE):

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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