Indian J. Anim. Nutr. 2024. 41 (1): 1-14
doi:10.5958/2231-6744.2024.00002.1

Indian Journal of Animal Nutrition

Silkworm Pupae Meal: A Potential Unconventional Protein Source for Animal Feeding: A Review

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ABSTRACT

Silkworm pupae are thrown away as a waste by-product of silk industry after reeling silk from the cocoons. The huge amount of the pupae produced/disposed (about 5500 pupae per kg of raw silk), pose a severe pollution threat to environment, soil and water. This demands technological interventions for efficient disposal or utilization of these pupae in a productive enterprise. Considering the fact that the pupae represent an active growth stage of an insect, they offer a potential nutrient-rich alternative for livestock feeding. Off-late, the silkworm pupae meal (SWPM) has been acknowledged as top-class protein source of animal origin that finds way in utilization as a low-cost unconventional feeding resource for livestock and poultry. Ithas a high nutritive valueand acts as a decent source of protein,carbohydrates,fat,fiber, ash,methionine,lysine, calcium and phosphorus, and could offer a cheap animal food for the growing livestock sector which is generally regarded as resource-hungry in terms of insufficient availability of quality feed and fodder. The increasing dependence of expanding mankind on animal proteins, in decreasing availability of plant-based proteins, further necessitates the development of strategies and policies for harnessing the industrial by-products as alternate animal-foods and SWP finds its best use as an alternate, economical and efficient animal food.

KEYWORDS: Livestock, Poultry,Protein source,Silkworm pupae meal, Unconventional feed ingredient.

Article received: 08 October 2022; Article accepted: 31 October 2023

INTRODUCTION

Human sustenance has proven to be dependent onanimals for their services and products offered since antiquity, and still the most-modern society's remain dependent on animals critically for food, and economic and nutritional safety. In todays' world, where one among eight people living in utmost poverty, 815 million are malnourished, one out of nine people is hungry and 202 million are unemployed, is facing tremendous challenges. Under this scenario, livestock is presumed to play a vital task in directly or indirectly referring to many of these challenges by being catalytic in enhancing human, social, natural, physical, financial as well as reservoir assets by providing access to quality food, constant good health, employment, alternate energy and resilience against external shocks. In particular, foods of animal-source provide almost all essential nutrients and readily digestible protein, and thereby making critical contributions towards improving food safety and nutrition and ending hunger. According to the conservative estimates, livestock products provide 17% of calorie and 33% of protein available to global human diet, in addition to huge micro/macro-nutrient supply. By the year 2030, the projected increase to world's population will be around 8.6 billion and will keep increasing to 9.8 billion by 2050 (UN World Population prospects, 2017). This increase in human population bears a positive correlation with livestock population and products, with presumed increase in global milk and meat production by 33% and 19%, respectively by 2030 (FAO Aglink-Cosimo, 2018). Rearing huge livestock use large amounts of land, water and nutrients, and also significantly contribute to Green-house gas emissions. Livestock would indeed provide food, economic and livelihood security to the increasing human population but at the same time they would fiercely compete for available land, food, water and climate with the humans-putting the mankind at crossroads and confusion as to whether livestock is the final saviour or competitor for existence. The mankind has to advance technological interventions that shall on one hand boost livestock productivity and performance and on the other hand reduce competition for the common food and land. Among the various technological interventions that could be advanced, provisions for alternate livestock food are the most pertinent, especially the food that could be derived from the products/by-products of an economically profitable main venture. The current review shall discuss the feasibility and advantages of silkworm pupae (SWP) meal, the by-product of silk reeling industry, as potential livestock food and its pertinent advantages in conversion of waste to wealth for cheap and quality animal food on one hand and the positive impact on reducing the pollution and degradable waste load on the soil and water on the other hand.

SILK PRODUCTION

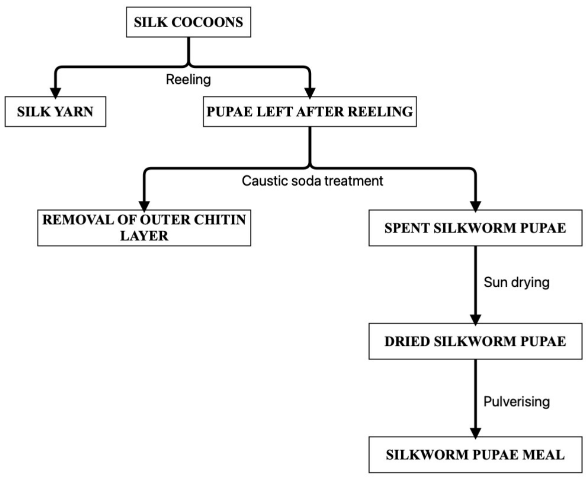
Silk, as an aesthetic and sought-after fabric is produced across the globe with China, India, Uzbekistan, Brazil, Japan, Republic of Korea, Thailand, Vietnam, DPR Korea, Iran, etc., being the leading producers. The global silk industry produced about 91,765 Metric tons of raw silk in 2020 (International Sericulture Commission, 2020).The various silkworm species that exist are *Bombyx mori L.* (Bombycidae), *Samia cynthia ricini* (Saturniidae),*Antheraea mylitta*, *Antheraea paphia*, *Antheraeaproyeli*, *Antheraeaassamensis*, etc. Among various silkworm species the most important is mulberry silk (*Bombyx mori L.*) which contributes almost 90% of world production(Valerie et al., 2015). In India, sericulture is an age old tradition and all the four varieties of silk namely Tasar, Muga, Eri and Mulberry are produced, making the country second-largest producer of raw-silk in the world, with an annual production of 33,770 Metric tons in 2020-2021. Around 70% of silk produced in India is of Mulberry type which generates a massive amount of pupal waste as the main by-product (Chatterjee, 2022).

GENERATION OF SILKWORM PUPAE

The production of a silk fiber involves two main processes, *viz*., cultivation of mulberry trees and production of cocoons by rearing silkworm on their leaves. A cocoon is made by mature larva and is oval in shape. A small amount of usable silk is produced inside the cocoon during larval development into pupa (Takeda, 2009). To harvest the silk produced in the process, the cocoons are collected and the pupa inside is killed by boiling or in ovens. The silk yarn is then wound-off from the cocoon by a subtle process known as reeling (Tuigong, et al., 2015). The process, though sounding simple, is highly cumbersome as about 5500 silkworms are to be required for production of 1 kg of raw silk (Tuigong, et al., 2015).

Thesilkworm pupa (SWP) is the leftover after wounding-off the silk-thread from cocoon. The silkworm pupae are commonly known by various other names like silkworm pupae meal, silkworm meal, spent silkworm pupae,deoiled silkworm pupae meal, defatted silkworm pupae meal, non-deoiled silkworm pupae meal, non-defatted silkworm pupae meal, Eri silkworm pupae meal and Muga silkworm pupae meal at different places (Valerie et al., 2015). SWP constitutes about 60% of dry cocoon weight, which is mostly used as fertilizer or discarded as industrial waste (Hu et al., 2017). In India, it is estimated that annual pupae production of mulberry silkworm (*Bombyx mori*) comes around 1.5 lakh MT, which is considered as waste material (Roychoudhuryand Mishra, 2020). The process of making silkworm pupae meal is presented in figure 1.

Figure 1. Process of making silkworm pupae meal (Takeda, 2009; Tuigong, et al., 2015)



CHEMICAL COMPOSITION OF SILKWORM PUPAE VIS-A-VIS OTHER FOODS

On comparing fish meal with silkworm pupae, the latter is a low-cost ingredient and is plentiful in both protein and lipid (Bhuiyan et al., 1989), and is considered as one of the top-class unconventional protein sources (65-75%). The refined protein from silkworm pupae has proven its superiority over fish meal and shows similarity with beef. Fatted silkworm pupae meal has higher crude protein and ether extract compared to soybean meal,while the defatted silkworm pupae meal has higher crude protein compared to fatted silkworm pupae meal, and soybean meal (Rashmi et al., 2018). Various amino acids like methionine,lysine, threonine and tyrosine in silkworm pupae are higher than in whole milk protein (Rao, 1994). Deoiled silkworm pupae powder contains 5.36% lysine and 2.39% methionine on a per cent dry matter basis (Joshi et al., 1980). The proximate composition and amino-acid profile of silkworm pupae meal (non-defatted and defatted) is shown in Table 1 and Table 2, respectively.On comparing the SWPM (non-defatted and defatted) with other conventional protein sources (Table 5 and Table 6), 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).

Table 1. Proximate composition of silkworm pupae

Moisture (%)	Dry matter (%)	Fat (%)	Protein (%)	Fibre (%)	NFE (%)	Ash (%)	Reference
10	-	25-27	55	3	-	-	Panda, 1970
-	-	2.50	68.7	4	-	-	Panda, 1970*
-	-	-	76	-	-	-	Chopra et al., 1971
-	-	-	73.4	-	-	-	Joshi et al., 1980
-	90.9	27	47.9	3.40	-	5.60	Fagoone, 1983
-	-	6	81.6	-	-	2.10	Lin et al., 1983
-	-	34.2	48.1	1.84	11.4	4.44	Majaonkar & Biamber, 1987
5.89	-	0.47	72.8	-	-	-	Bose and Majumder, 1990
-	-	31.1	51.6	-	-	-	Koreleskiet al., 1993
-	91.3	18.6	70.5	-	4.61	6.19	Hossain et al., 1997
-	94.4	2.80	84.3	-	6.27	7.61	Hossain et al., 1997*
5.14	-	27.8	50.2	4.93	-	10.6	Nandeesha et al., 2000
-	94.2	22.6	49.1	5.60	11.1	5.80	Majumdar, 2002
61.30	-	-	25.5	-	9.7	1.60	Rangacharyuluet al., 2003
12.82	-	25.4	43.1	-	-	12.3	Sheikh et al., 2005
-	-	27.8	52.3	-	-	-	Ji et al., 2010
-	-	5.60	72.3	-	-	6.30	Lee et al., 2012
-	91.7	4.71	51.2	3.67	-	11.7	Olayani and Babasanmi, 2013
-	-	4.70	75.6	6.60	-	6.80	Makkaret al., 2014
7.18	-	32.5	48.4	-	-	4.59	Nisha et al., 2014
-	87.5	11.7	69.5	5.01	-	7.88	Osa and Iwalaye, 2014
6.65	-	31.2	57.2	2.39	-	4.01	Bhagat and Barat, 2016
-	92.1	23.3	57.6	5.55	-	11.2	Rafiullah, 2016
-	79.3	19.2	51.5	3.85	9.13	16.2	Sahib et al., 2023

*Defatted silkworm pupae meal.

Table 2. Amino acid profile of silkworm pupae (non-defatted and defatted)

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

Source: Makkar et al., 2014.

Non-deoiled silkworm pupae meal is high in fat ranging between 20-40% on dry matter basis and the deoiled meal contains not more than 10% of fat on dry matter basis. The oil from silkworm contains an excessive fraction of polyunsaturated fatty acids, especially linolenic acid (18:3) with testified values stretching from 11-45% of the total fatty acids (Ioselevich et al., 2004). Various fatty acids present in silkworm pupae are presented in Table 3.

Table 3. Fatty acid profile of silkworm pupae

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.

The calcium and phosphorus contents of silkworm pupae (Assam muga) were 0.26 and 0.80% respectively (Bora and Sharma, 1965). Vitamins such as riboflavin, thiamine, pyridoxal,folic acid and ascorbic acidare present in silkworm pupae making them more nutritive (Koundinya and Thangavelu, 2005). The mineral and vitamin composition of silkworm pupae is mentioned in Table 4 and Table 5, respectively.

Table 4. Mineral content of silkworm pupae

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.

Table 5. Vitamin content of silkworm pupae

Vitamin	Amount
Vitamin A(µg/100 g)	273.99
Vitamin B_1(mg/100 g)	1.91
Vitamin B_2(mg/100 g)	5.43
Vitamin B_3(mg/100 g)	15.20
Vitamin B_5(mg/100 g)	12.49
Vitamin B_7(µg/100 g)	144.51
Vitamin B_9(mg/100 g)	0.41
Vitamin B_{12}(mg/100 g)	500.00
Vitamin C (mg/100 g)	5.70
Vitamin E (IU/kg)	51.45

Source: Sadat et al., 2022.

USES OF SILKWORM PUPAE

After the reeling process, the freshly spent silkworm pupae are generally discarded in nearby areas without disposing properly. This improper disposal causes environmental pollution as the fresh silkworm pupae are highly degradable, which in turn leads to off smell in the near vicinity areas. Discarding huge quantity of silkworm pupae can trigger severe environmental nuisances around silk-producing areas (Yhoung-Aree et al., 1997). Use of silkworm pupae as food by humans is an age old practice in many Asian countries like China (Luo Zhi-Yi, 1997),India (Longvah et al., 2011), Japan (Mitsuhashi, 1997), Thailand (Yhoung-Aree et al., 1997), and elsewhere. Some pharmacological studies have shown that consumption of silkworm pupae increases immunity, and provide protection against certain cancers.The consumption of silkworm pupae could also prevent the severe effects of Vitamin-B_2 deficiency as it contains some decent amount of Vitamin-B_2(Priyadarshini et al., 2017).

Chitin and a long-chain polymer of N-acetylglucosamine are also produced from the exoskeleton of an extracted meal (Suresh et al., 2012), the latter being for treating osteoarthritis (Priyadarshini et al., 2017).The oil extracted from silkworm pupae can be of industrial importance such as for the production of soaps, candles,paints, pharmaceuticals, varnishes and bio-fuels (Trivedy et al., 2008). The oil yield of silkworm pupae is about 20% of the dry weight of pupae. The oilfrom silkworm pupaeholds not less than 70% unsaturated fatty acids, chiefly the oleic and á-linolenic acid (Rao, 1994).Silkworm pupae can be used as manure/ fertilizer as it contains high amount of protein and fat (Wei et al., 2009).

SILKWORM PUPAE MEAL AS POTENTIAL LIVESTOCK FEED

Silkworm pupae has been found suitable for livestock feeding because of its high protein content and nutritive value. It can also be used in the feeding of poultry, rabbits and fishes. It is offered to the animal in the form of meal, and not as whole pupae. In the present article main emphasis is given on use of spent silkworm pupae meal as a source of dietary protein for feeding ruminants, poultry, pigs, rabbits and fishes and some of the relevant and recent studies related to use of silkworm pupae as unconventional protein source are incorporated.

A) Silkworm pupae meal as a source of dietary protein in ruminant ration

In livestock feed, use of silkworm pupae meal has found its waydue to its high protein content (Trivedy et al., 2008). The fraction of bypass protein in silkworm pupae meal contains a good amount of methionine and lysine for ruminants (Sampath et al., 2003). It has been found that the defatted silkworm pupae meal can be safely included upto 100% level replacing conventional protein without any adverse effect on nutrient digestibility and rumen fermentation (Rashmi et al., 2018).The inclusion of defatted SWP into the ration of cattle upto 30% by replacing SBM did not showed any significant effect on rumen fermentation pattern and nutrient utilisation(Rashmi et al., 2022).The diet based on silkworm meal has better protein digestibility when compared with groundnut cake diet. The non-defatted silkworm meal resulting in a cheaper dietcould replace 33% of groundnut cake (weight basis) safely without affecting performance in fattening diets for Jersey calves (Narang and Lal, 1985). In case of defatted Tussore silkworm pupae,the crude protein digestibility has been found around 70%when fed to sheep with wheat straw and molasses (Khan and Zubairy, 1971).

A study conducted on crossbred calves in pre-ruminant stage showed that the fish meal can be successfully replaced upto 50% level by silkworm pupae meal without any contrary effect on feed intake, nutrient utilization, growth and health status of the crossbred calves (Sahib et al., 2023).

B) Silkworm pupae meal assource of dietary protein for poultry

In poultry diets, use of insect meal is a budding solution to mend the sustainability of poultry feeds (Elahi et al., 2022). A broad variety of insects are available for use and can be used as fresh (live), paste or dried form in poultry feeds (Elahi et al., 2020). In poultry diet, dried form is considered to be suitable as they have less moisture as compared to that of fresh insects, so decreasing the chances of degradation and Maillard reaction (Kröncke et al., 2019). On comparison with the conventional feed stuff, the insect meal contains higher amount of essential amino acids (Al-Qazzaz and Ismail, 2016). Among various insect meals, silkworm pupae meal is most commonly used in poultry diets. The silkworm pupae meal is found to be cheaper but valuable unconventional protein source substitute that can be utilized for feeding poultry, replacing costly fishmeal and soybean (Sheikh et al., 2018).

The replacement of 50% of the conventional protein source *i.e*., fish meal by SWP meal has been suggested as harmless, though there may be requirement of mineral supplementation (Valerie et al., 2015). A study on broiler finisher ration showed that replacing soybean meal with silkworm meal did not have any negative effect on carcass quality and blood profile, but in terms of feed intake and live body weight most beneficial results may be achieved when 75% of soybean meal were replaced by silkworm meal in the ration of commercial broiler finisher (Ullah et al., 2017). On replacing 100% fishmeal by muga silkworm meal showed no antagonistic effect on carcass parameters (Sheikh et al., 2005), while the production economics showed best results (Sheikh and Sapcota, 2007). Feeding of 70% acetone treated silkworm pupae meal to broilers have been reported to improve the performance (Yhoung-Aree et al., 1997).

An experiment performed to assess the effect of feeding silkworm pupae meal in young RIR pure line layers revealed that growth, egg production performance and profitability was significantly higher for the group containing diet with 6% silkworm pupae meal when compared to groups fed on diets containing 0% and 8% pupae meal (Khatun et al., 2005). Khan et al. (2020) conducted a trial on white leghorns to evaluate the effect of replacing soybean meal with graded levels of silkworm pupae meal on egg production performance,serum biochemistry and intestinal histological features. The study showed no negative effect on growth,egg production, intestinal health and serum biochemistry.

A study on growing chicks revealed the growth-stimulating effect of silkworm pupae is correlated with the activity of hormone ecdysteroid which is responsible for metamorphosis of pupae (Fagoonee, 1983). On feeding geese with silkworm pupae, high amino acid digestibilities (95% for methionine and 94% for lysine) were determined (Penkov et al., 2002).

C) Silkworm pupae meal as source of dietary protein in pig feed

Scarce literature is available on utilization of silkworm pupae meal as replacement of conventional protein sources in porcine species. The 100% replacement of soymeal with non-defatted silkworm meal in diets of growing and finishing pigs showed no adverse effect on growth performance and carcass characteristics. However, when the replacement rate was more than 50%, there was a negative effect on intake, which may be because of lower palatability or greater energy bulk of the diet. The better feed conversion rate was observed at lower levels, which may be due to higher lysine level of silkworm-based diet (Coll et al., 1992). Likewise, in growing and finishing pigdiet, silkworm pupae meal could fully replace fishmeal without changing meat quality, carcass and haematological parameters (Medhi et al., 2009a,b; Medhi, 2011). Recommended inclusion rate of silkworm excreta is about 7% and should not exceed 10% in pig ration (Virk et al., 1980).

D) Silkworm pupae meal as rabbit feed

In China,the silkworm pupae meal is used as a traditional ingredient in the feed of rabbits. For balanced diets of growing rabbits, dried form of silkworm pupae meal could successfully replace soymeal without any antagonistic effects. Gugolek et al. (2021) studied that on replacing 5% of soybean meal with silkworm pupae meal did not disrupt gastrointestinal physiology, and a similar result was observed when silkworm pupae meal was incorporated at 10% level in rabbit diets. On increasing inclusion levels of silkworm pupae meal leads to slight decrease in nutrient digestibility and a significant decrease in Nitrogen retention. On addition of 10% silkworm pupae meal to rabbit diets resulted in increased mass of small intestinal, caecal and colonic digesta, reduced bacterial enzyme activity and short chain fatty acid concentrations in the cecum, and increased caecal pH.Thus, it was concluded that in rabbit diets silkworm pupae meal up to 5% level can be supplemented.

E) Silkworm pupae meal as feed ingredient for fishes

In the Indo-Pacific region,silkworm pupae have been found as important fish feed ingredient (Hasan, 1991). The high inclusion of raw pupa leads to off-odour and unpleasant taste (Sawhney, 2014). The dead moths of silkworm could also be used as fish feed. Various studies have revealed that defatted silkworm pupae meal has better protein content than the non-defatted silkworm pupae meal and is suitable protein source for fish (Blair, 2018).In Japan and China,silkworm pupae constitute an important component in carp diet (Karthick Raja et al., 2019). The silkworm pupae after processing offers an outstanding protein source in fish feed. The similar growth of fish attained with de-oiled silkworm pupae might be due to the protein quality and presence of appetite stimulants (Umalatha et al., 2018).A study revealed that the inclusion of silkworm pupaein the diet of rohu (*Labeo rohita*) upto the level of 43.50% resulted in betterfeed utilization, growth and survival rate on comparing with diets containing other oil cakes. The results confirmed that the silkworm pupae can be successfully used to formulate a low-cost feed for rohu fingerlings (Olaniyi and Babasanmi, 2013).

Silkworm pupae meal is an important protein source in the diets of Asian catfish (*Clarias batrachus*) fingerlings. A study revealed that the diet with 100% silkworm pupae meal resulted in better utilization of protein, feed conversion and growth rate in catfish (*Clarias batrachus*) fingerlings (Habib et al., 1994). Moreover, in protein digestibility of catfish (*Clarias batrachus*) non-significant difference was observed when fed with non-defatted silkworm pupae meal (Borthakur and Sarma, 1998).

ECONOMIC IMPORTANCE OF FEEDING SILKWORM PUPAE MEAL

The inclusion of silkworm pupae meal in layer ration has resulted in gradual decrease in cost of feeding/ kg. The birds receiving silkworm pupae meal in their ration have shown improved efficiency as compared to the control group. Therefore, the use of silkworm pupae meal in the ration of layer birds could be more beneficial as it has shown to increase profitability (Khatun et al., 2005) with more economical output from lesser inputs than traditional feeding system. Sheikh and Sapcota (2007) also revealed that in case of broiler chicken the production economics showed better results on replacing 100% of fish meal with Muga silkworm meal. Being produced from an industrial waste, the inclusion of

SWP in the ration of other livestock species would surely bring down the cost of feeding and might improve the performance and growth rate of the animals, considering the fact that silk worm pupae is a rich source of essential amino-acids, vitamins, protein, fats and minerals.

ADVERSE CONSTITUENTS IN SILKWORM PUPAE MEAL

Silkworm pupae meal does not seem to hold any toxic component. The mortality among poultry birds fed on silkworm meal based diets is almost alike to that of animals fed more conventional protein sources (Dutta et al., 2012). The area of concern with insect eating is their possibility of evoking allergic reactions. The important sources of allergen in silkworms include dander, excrement and silk. These allergens are enough to evoke severe allergic reactions, like respiratory, cardiovascular and cutaneous symptoms, and sometimes anaphylactic shock (Gautreau et al., 2017). The list of various allergens associated with silkworm are presented in Table 6.

Table 6. Allergens present in silkworm pupae

Allergen	Family	Reference
Juvenile hormone epoxy hydrolase	Abhydrolase 1 superfamily	Jeong et al., 2016
Cell differentiation protein	Cell differentiation family	Jeong et al., 2016
Chitinase precursor	Chitinase A N	Zhao et al., 2015
27-kDa glycoprotein	DUF1397	Jeong et al., 2016
Cuticular protein RR−2 motif 63 precursors	Insect cuticle protein	Liang et al., 2016
Putative cuticle protein	Insect cuticle protein	Jeong et al., 2016
Chemosensory protein 5 precursor	Insect pheromone-bindingfamily	Ma et al., 2016
Cellular retinoic acid binding protein	Lipocalin/cytosolic fatty acid binding protein	Liang et al., 2016
30-kDa protein precursor	Lipoprotein 11	Zuo et al., 2015
30-kDa lipoprotein precursor	Lipoprotein 11	Cao et al., 2017
Mature 30-kDa lipoprotein	Lipoprotein 11	Zuo et al., 2015
LOC114242470 low molecular mass 30-kDa lipoprotein 21G1	Lipoprotein 11	Zuo et al., 2015
Low molecular mass 30-kDa lipoprotein 19 G1 precursor	Lipoprotein 11	Zuo et al., 2015
Heat shock protein 20.8	Metazoan ACD (Alpha-crystallin domain ofmetazoan)	Zuo et al., 2015
Paramyosin	Myosin tail 1	Zhao et al., 2015)
Thiol peroxiredoxin	Peroxiredoxin(PRX) family	Wang et al., 2016)
AGAP008849-PA	Phosphoglycerate dehydrogenases	Zuo et al., 2015)
Xanthine dehydrogenase	PLN02906 superfamily	Jeong et al., 2016
Profilin	Profilin	Hu et al., 2017
Triosephosphate isomerase	PTZ00333	Zuo et al., 2015
Chymotrypsin inhibitor CI-8A	Serpin	Zuo et al., 2015
Tropomyosin	Tropomyosin	Liu et al., 2009
Uncharacterizedprotein LOC101743840	unknown	Liang et al., 2017
Cuticular protein hypothetical 30	unknown	Hu et al., 2016
Vitellogenin	Vitellogenin N	Zuo et al., 2015

*Source: Wu et al., 2021.

Apart from allergens, silkworm contains a bio-compound namely 1-Deoxynojirimycin (1-DNJ), also known as moranolin or duvoglustat, which gets accumulated in larvae on consuming mulberry leaves. This 1-DNJ acts as potential intestinalá-glucosidase inhibitor as it competitively inhibits specific glycosidase enzymes by imitating the enzyme's normal carbohydrate substrates such as D-mannose and D-glucose (Vichasilp et al., 2016). As a result, 1-DNJ can inhibit the enzymes concerned with glycogenolysis, saccharidehydrolysis and glycoprotein processing. Chitin present in the exoskeleton of insects has been reported to be present in silkworm pupae which can worsen nutrients absorption in chicken (Bovera et al., 2015). So, the potentialuse of silkworm pupae in poultry feed needs to be cautiously assessed and procedures need to be developed for neutralizing these allergens so that the nutritive value of SWP meal is further enhanced.

CONCLUSION

The unconventional silkworm pupae meal could successfully replace the conventional fish meal or soybean meal in the ration of livestock, poultry and rabbits for economic production. The adoption and inclusion of SWP meal in livestock food is a compelling strategy to keep livestock sector profitable and sustainable and reduce the cost of human food that ought to be produced from the livestock. However the recent ethical issues for ruminants in Indian context need to be considered. The development of alternate livestock food would subsequently reduce the competition between humans and animals for common land and food resources and hence lead to sustainability of animal food for human sustenance and mutual co-existence on the planet. The development of alternate livestock food from industrial wastes assumes greater significance in this post-industrial era of pollution due to rough and non-scientific disposal of industrial wastes and by-products. Thus, technological interventions aiming at harnessing the benefits of these industrial wastes and effluents are the need of the hour and the development of strategies for widespread use of SWP meal in animal ration demands an immediate attention and action-plan which may require policy legislations, especially in countries like India where huge quantities of silk worm pupae are produced.

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