Uttar Pradesh Journal of Zoology

Volume 45, Issue 13, Page 282-293, 2024; Article no.UPJOZ.3516
ISSN: 0256-971X (P)

A Review on Feasibility of Silkworm Pupal Meal in Livestock and Poultry

Dukare Pradip G. [a*], Thrilekha Durgam. [a], Harish Reddy C. [a], Kenchappa N. M. [a] and Amarnatha N [b]

[a] *Department of Sericulture, College of Agriculture, UAS, GKVK, Bengaluru - 560 065, India.*
[b] *Department of Sericulture, College of Sericulture, UAS(B), Chintamani - 563 125, India.*

Authors' contributions

This work was carried out in collaboration between all authors. Author DPG designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors TD, HRC and KNM managed the literature searches. Author AN managed the analyses of the study. All authors read and approved the final manuscript.

Article Information

DOI: https://doi.org/10.56557/upjoz/2024/v45i134155

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://prh.mbimph.com/review-history/3516

Review Article

Received: 14/03/2024
Accepted: 17/05/2024
Published: 15/06/2024

ABSTRACT

The rising cost of soy meal and other ingredients for animal and poultry feed has sparked a hunt for protein alternatives. Pupae of silkworms are a good source of protein and are included in the natural feed diet. Over the last decade, studies on the replacement of feedstuff with silkworm pupal have emerged with promising results. The silkworm pupae, which are a byproduct of the silk reeling industry, possess a high nutritional value which makes them a great choice for poultry feed. Dry pupae contain 50–70% crude protein and 24–33% crude lipid and is a high-quality insect protein source with a rich, balanced content of essential amino acids. Recommended inclusion levels of silkworm pupae meal have been developed as a result of several studies conducted on livestock species. This meal is guaranteed to provide better growth performance than commercial meal (soyabean meal).

**Corresponding author: Email: pradipgdukare555@gmail.com;*

Cite as: G. , D. P., Durgam., T., C. , H. R., N. M. , K., & N, A. (2024). A Review on Feasibility of Silkworm Pupal Meal in Livestock and Poultry. UTTAR PRADESH JOURNAL OF ZOOLOGY, 45(13), 282–293. https://doi.org/10.56557/upjoz/2024/v45i134155

Keywords: Sericulture; silkworm pupae; livestock; poultry.

1. INTRODUCTION

World population is expected to grow from the current 6.9 billion to more than 9 billion in 2050. About 90% of this growth will be in Asia and Africa [52] and the demand for animal-based foods will increases by 70% [40, 66]. "In recent years, the shortage of feed ingredients, particularly, the protein ingredients have become a global concern" [37]. "The complete and rational utilization of the available protein resources and exploring new protein resources has gradually become an immediate challenge for the feed industry" [6]. "Future world food balance will not only depend on increase in overall production, reduction of waste and losses but also the sustainable consumption pattern. According to the Food and Agricultural Organization (FAO), in 2050 the production of food from animal origin should be increased 60-70% to fulfil the need of the worldwide population" [30]. "Moreover, at the current rate of livestock production and existing feed resources, it is not feasible to keep pace with the growing demand for animal protein. Feed expenses make up the majority (70%) of total livestock production costs, with protein accounting for around 15% of the feed cost in livestock and poultry farming [18,19]. Hence, in the prevailing price volatility of conventional feed resources, it is necessary to identify and explore an alternative feed resource for sustainable livestock production throughout the world, along with judicious utilisation of existing feed resources" [20].

"Pupae are the major by-product of the silk industry, often discarded after reeling which leads to the wastage of potential nutrients and adds up to further environmental concerns or used for fertilizers" [82]. Globally at least 3 million tons of pupae are available every year [2] and it is estimated that 40,000 metric tonnes of dry spent silkworm pupae are produced annually [39] Therefore, silkworm pupae can be a rich source of carbohydrates, proteins and lipids**.** Unless used as feed, components in the pupae can be extracted for specific applications [89,91,92].

"Significant oil and chitin from these pupae can be extracted and used to make industrial goods like paints, varnishes, medicines, cosmetics and biofuels". [2,76,78]. "The contents of essential amino acids in SWP protein were on par with the FAO/WHO/UNU suggested nutritional requirements for fish" [29]. Therefore, a better way to mitigate the negative environmental impact of the silk industry is to use these precious resources for feeding poultry and farm animals. Due to their high nutritional content, silk pupae have been used as a possible feed source for livestock and poultry [60,62,90]. This paper examines how silkworm pupae are used as a substitute protein source for cattle and poultry feed, to improve productivity and reduce environmental pollution.

In developing countries – there is an increasing global demand for meat (Fig. 1). The predicted demand for meat and egg in 2050 is 70% and 58% respectively. There is need to increase protein sources in feed rations.

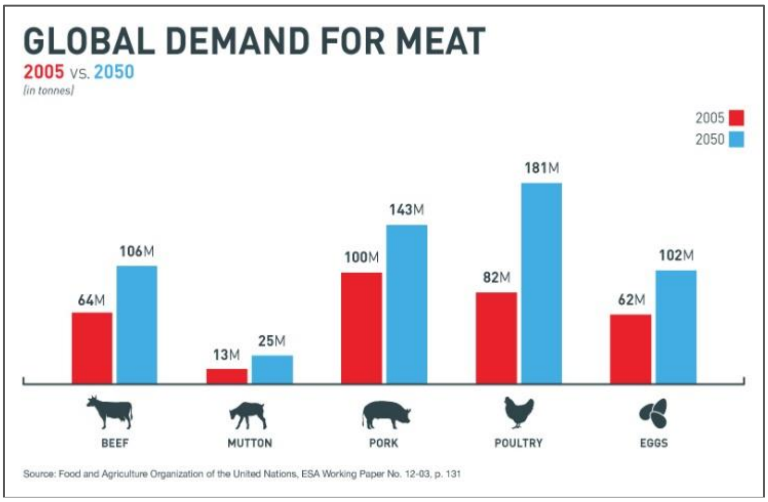

Fig. 1. Global demand for meat
Source: FAO,2009

2. WHY THERE IS NEED FOR ALTERNATIVE PROTEIN

The soyabean meal and fish meal are main conventional protein source. But, due to the Marine over-exploitation and limited availability of land for soyabean cultivation, the cost of soyabean meal and fish meal doubled during the last twenty years (Fig. 2). it is up to 60-70 % of the production cost. So, alternative protein sources for livestock are urgently needed. [48]. Soyabean requires 4000 m^2 area and 2500 m^3 water for the production of a thousand kg crude protein (Table 1). But silkworm pupae are the by-product which not required area and water for crude protein production as it has been used as waste. Utilizing the spent pupae by replacing soyabean meal could reduce the cost of cultivation and soyabean protein can be used for further purposes.

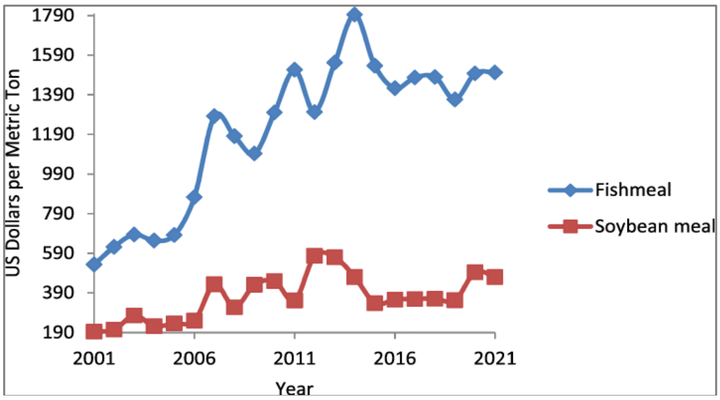

Fig. 2. Cost of soyabean meal and fish meal
[48]

Table 1. Resource needed for 1000 kg protein [26]

	Plant protein (Soyabean mean)	Insects (Silkworm pupae)
Area needed	4000 m^2	0 m^2
Water needed	2500 m^3	0 m^3

3. NUTRITIONAL COMPOSITION OF SILKWORM PUPAE

According to Ni and Liang [51] silkworm pupae contain 49-50 per cent of protein, 29-30 per cent of fat, 8-10 per cent of moisture, 4-5 per cent ash and 2.5-3 per cent chitin.

Table 2. Chemical composition of pupal meal, fishmeal and soyameal [41,46]

Constituents (% in DM)	Silkworm pupae meal	Silkworm pupal meal (defatted)	Fish meal	Soyameal
Crude protein	60.7	75.6	70.6	51.8
Lipid	25.7	4.70	9.90	2.00
Calcium	0.38	0.40	4.34	0.39
Phosphorus	0.60	0.87	2.79	0.69
Ca:P ratio	0.63	0.46	1.56	0.57

On a dry matter (DM) basis, its crude protein content varies from 50% to over 80% (in defatted meal) [29,41,46, 64]. It is abundant in essential amino acids such as methionine (2-4%) and lysine (6–7%) [8,29,38,68,74) and it contains approximately 30% crude fat (CF) (28, 64), with a high content of polyunsaturated fatty acids like linolenic acid (26.8% of fatty acids) [13,28,41,77,82]. Dry pupae also contain 2.9% minerals (Cu, Fe, Se) and 1.9% vitamins (E, B1, B2) [12]. "SWPM contains high amounts of vitamins such as pyridoxine, riboflavin, thiamine, ascorbic acid, folic acid and minerals such as calcium, phosphorous and iron", as reported by Koundinya and Thangavelu [33].

Table 3. Proximate composition of silkworm pupal

Specification	Fresh weight basis (%)	Dry weight basis (%)	References
Dry matter (DM)	23.2-25.9		[36]
		94.45	[58]
		87.50	[56]
Protein	-	48-60	[23]
	21.5	49-54	[84]
	13.81-16.83	59.52–94.98	[36]
	-	60.7	[74]
	-	62.75	[57]
		57.22	[3]
Lipid	-	30	[23]
	13	-	[84]
	-	23.3	[58]
	-	25.7	[74]
			[41]
		23.3	[58]
Fiber	-	2.39	[3]
	-	3.9	[74]
			[41]
Ash	-	5.8	[74]
	1.16-1.33	-	[36]
	-	4	[3]
Chitin	-	3-4	[23]
Gross Energy - (MJ/kg)	5.09-6.82	-	[36]

Table 4. Amino acid profile of silkworm pupal meal and soybean meal

Composition	Silkworm pupal meal	Soybean meal
Amino acids	Mean ± SE (%)	Mean ± SE (%)
Alanine	5.22 ± 0.255	4.24 ± 0.231
Arginine	6.31 ± 0.388	2.90 ± 0.212
Aspartic acid	9.59 ± 0.740	11.45 ± 0.614
Cystine	0.97 ± 0.388	0.74 ± 0.361
Glutamic acid	10.19 ± 1.007	17.91 ± 1.02
Glycine	4.61 ± 0.376	4.17 ± 0.218
Histidine	3.28 ± 0.425	1.02 ± 0.054
Leucine	7.04 ± 0.303	7.72 ± 0.213
Lysine	7.52 ± 0.376	2.62 ± 0.201
Methionine	3.88 ± 0.327	0.52 ± 0.017
Proline	6.31± 0.510	5.43 ± 0.209
Phenylalanine	5.58 ± 0.316	2.12 ± 0.072
Serine	5.22 ± 0.243	4.56 ± 0.213
Threonine	5.58 ± 0.121	1.66 ± 0.023
Tryptophan	1.70 ± 0.413	0.65 ± 0.011

** % in dry matter*
[79]

“The proximate composition of SWPM, is summarised in Table 3. SWPM is approximately composed of 57.21% protein, 31.29% fat, 2.39% fibres, 4.01% ash and 94.45% dry matter. Differences in harvesting location, season, environmental conditions and meal processing technique may be the cause of the variations in the proximate composition of SWPM between studies”. (54, 55, 88]. “The information regarding mineral content reveals that SWPM has high K content with a low Na/K ratio and low heavy metal content” [88]. SWPM contains a considerable amount of essential fatty acids (α-linolenic acid+linoleic acid) (49.0%) and contains non-essential fatty acids (8.6%), eicosapentaenoic acid (0.3%) and riboflavin, as reported by Kwon et al. [35].

SWPM protein is rich in essential amino acids such as phenylalanine, methionine, and valine. Comparable to soyabean meal, SWPM protein has similar amounts of essential amino acids. The amino acid profile shows that, in contrast to soybean meal, SWPM contains almost all of the essential amino acids. (Table 4). The amino acid profile of SWPM (Defatted) was described by Ullah et al. [79].

4. SAFETY AND LIMITATIONS

"The degradation of silkworm pupae results in bad odour which associate with palatability issues" (19,62). "Therefore after washing the pupae they are pressed to remove excess of moisture and dried in sun or in mechanical driers and ground" [27,80,83]
These dried pupae are susceptible to rancidity because of their high fat content. Consequently, solvent extraction is done on the dried pupae to remove oil and to ensure longer storage. Because of their low-fat content, the extracted pupae can be stored for longer. The defatted silkworm pupae meal that is ultimately obtained has a longer shelf life and a higher protein content than the undefatted meal [4]. The shelf life of silkworm pupae meal can also be extended by ensiling, which produces high-quality silage when combined with molasses, propionic acid, and curd [61, 85].

"The high oil content of pupae limits its use as ruminant feed. When silkworm pupae meal is fed in large quantities, one of the main requirements is the fat extraction process" [25]. "The increased level of chitin in SWPM is responsible for poor nutrient utilisation in young chicks" [17,32,54,55]. "A higher level of chitin in feed may influence the nutrition digestion and further interference the animal immune system which induce physiological stress at the same time, as observed *i.e*., in fish and hens" [5,86]

5. EFFECT OF PUPAL MEAL ON LIVESTOCK

Ruminants: Silkworm pupal meal (SWPM) is a rich source of highly undegradable protein with a favourable amino acid profile, making it a suitable addition to cattle diets. According to Narang and Lal [50], pupae meal may safely take the place of 33% of groundnut cake (GNC) in Jersey calves' diets without having an adverse effect on their ability to grow. It was also reported that the SWPM diet had a higher crude protein digestibility than the groundnut cake diet. In an in vitro experiment, 100% DSWP supplementation on an finger millets (FMS) based diet had no effect on the rumen fermentation or digestibility of the cattle [64]. Rashmi et al., [65] reported that defatted silkworm pupae meal (DSWP) did not show any ill effects on health (Rumen fermentation, purine derivatives) and performance (Nutrient intake, digestibility) by safely substitute with Soyabean meal (SBM) up to 30 % in concentrate mixture. They also found that the blood ingredients (glucose, cholesterol, total protein, albumin and globulin) were unaltered by feeding SWPM in diet.

Therefore, in terms of nutrients and cost, DSWP can be a great substitute for traditional protein sources for ruminants. The meal made from silkworm pupae has a relatively low effective in situ nitrogen degradability. Effective degradability values (5%/h outflow rate) for defatted meal [7]. were only 20%, compared to 29% and 25% for undefatted silkworm pupae, as reported in previous studies [9, 25]. This indicates that a good proportion of undegradable protein was present, particularly in the defatted meal. According to Sampath et al. [68], the bypass protein fractions of silkworm pupae meal are good sources of lysine and methionine for ruminant diets because they have a low in situ disappearance of 26% (24 hours of incubation, 5%/h outflow rate), which is the major limiting amino acid for milk production. Similar increases in nitrogen and energy retention were observed when Ioselevich et al. [25] fed lambs a basal diet consisting of barley and hay (75:25) when they substituted undefatted silkworm meal for an iso-nitrogenous potato protein supplement. The costly Fish meal could replace up to 50% level by SWPM without affecting feed intake, growth and nutrient uptake of crossbred cattle calves [67].

Pig: Limited information is available regarding the use of silkworm pupae in pig diets. A small number of studies demonstrated the effectiveness of using silkworm pupae meal in place of traditional protein sources. Un-defatted silkworm meal was used up to 100% in place of soybean meal in the diets of growing pigs, with no apparent effect on the carcass features and growth performance of pig. When the substitution rate exceeded 50%, there was a detrimental impact on intake, which was linked to either a lower palatability or a higher energy density in the diet. The silkworm-based diet's higher lysine content may have contributed to the improved feed conversion rate that make up the lower intake [11]. Without significantly affecting the quality of the carcass and meat or the blood parameters, silkworm meal has the potential to completely (up to 100%) replace fish meal in the diet of growing and finishing pigs [42,43,44]. A study by Choudhury et al. [10] found that feeding 2% and 4% of Muga SWP to large White Yorkshire grower pigs improved overall production efficiency while reducing production costs.

Rabbits: Kowalaska et al. [34] reported that “the dried silkworm pupae meal can be used as feed material in rabbit diets at 4% inclusion level without any adverse effect on growth performance, as well as quality and dietetic value of rabbit meat. They also found that, in the tissues of rabbits fed the silkworm meal diet, PUFA-3 concentration increased and cholesterol level decreased”. In contract, Gugolek et al. [21] reported that, “the both partial and complete replacement of SBM with SWPM in the contributed to decrease in the final body weights of rabbits (2416.50 and 2390.78 vs. 2616.78 g), average daily gains (30.23 and 30.52 vs 33.12 g) and feed intake (5.61 and 5.15 vs 6.51 kg), but it improved the feed conversion ratio (3.28 and 3.05 vs. 3.41 kg/kg). rabbits fed diets supplemented with SWPM were characterised by lower values of selected carcass parameters such as carcass weight and dressing percentage”. Gugolek et al. [22] suggested that rabbit diets can be supplemented with SPM at up to 5%.

6. EFFECT OF PUPAL MEAL ON POULTRY

Broilers: According to Banday et al. [1], substituting 75% of the fishmeal with SWPM did not negatively impact the carcass quality. Ecdysteroid, a hormone involved in the pupae's metamorphosis, is responsible for the growth-promoting effect observed in developing chicks [16]. Similar to this, the amino acid present in silkworm pupae may be the cause of the enhanced growth performance in birds fed SWPM [32,59]. According to reports by Banday et al. [1] and Qadri [57], broiler chickens fed diets supplemented with 0, 25 and 50% SWPM in the diet instead of fish meal did not exhibit any significant effects on various blood biochemicals.

“A reduction in dressing percentage was observed in the group of birds fed SWPM containing ration” [49]. A slightly higher edible carcase yield and dressing percentage were recorded by Sengupta et al. [70] in broiler chicken fed Muga silkworm pupae containing feed. “There was no effect on carcase characteristics of broiler chicken fed Muga SWPM replacing fishmeal in the diet” [69,73]. Feeding silkworm pupal meal by substituting soyabean meal not affects the dressing yield of chickens as reported by Rafiullah [58]. However, with increasing SWPM in the diets broiler diet, the dressed weight of broilers was increased [31]. The body weight gain, feed conversion ratio increased without any adverse effect on carcass quality when fed with 25% and 50% silkworm pupae in broilers diet [47]. Chickens showed better feed conversion ratio after feeding with fermented silkworm pupae, also found reduced fishy smell in meat quality [63]. Similarly, higher feed conversion ratio noticed in broilers fed with 10% silkworm pupae without any negative impact on growth performance, muscle characteristics and on its sensory evaluation [27]. Sheikh and Sapcota [72] reports for marked retention in nitrogen, calcium and phosphorus in broilers fed on complete silkworm pupae diet, which has been attributed to better utilization of dietary protein. Meat from chickens fed diets containing full-fat silkworm meal (SWM) showed improved protein and fatty acid composition. It had higher levels of beneficial omega-3 fatty acids and lower levels of omega-6 fatty acids, resulting in a healthier omega-6/omega-3 ratio. Substituting soybean meal/oil with SWM in chicken diets maintains performance and carcass quality while enhancing the nutritional value of the meat [45]. Broilers were fed with the fermented silkworm pupae (FSWP) not shown any negative effect on growth performance (average daily weight gain (ADG), average daily feed intake (ADFI) and feed conversion ratio (feed/gain, F/G). Moreover, the broiler meat quality increased with FSWP group compared with the fishmeal. Also concluded that fermented silkworm pupae improve thymic index of broilers and lowers the drip loss in meat quality [87]. Increment of SWP pupae in partial or total replacement of fish meal at percentages of 50 to 100% in kuroiler chicks shows a positive significant effect on growth performance traits like feed intake, weight and daily feed intake. Also, it will not affect negatively carcass characteristics and its sensory traits [53]. Furthermore, administering SWM during the grower-finisher phase demonstrated beneficial effects on meat healthiness, ultimately enhancing

Table 5. Economic feasibility defatted silkworm pupae meal versus other concentrate ingredients

Ingredient	Maize	Soybean meal	Rice bran	Wheat bran	Defatted silkworm pupae meal*
Price (INR/kg)	20	70	12	20	50
CP (%)	9.18	47.1	7.53	14.3	68.7
Cost (INR)/ kg CP	218	149	159	140	72.7
ME (MJ/kg)	13.6	13.4	9.70	11.0	8.87
Cost (INR/ MJ ME)	1.47	5.22	1.23	1.81	5.60

** Including cost of silkworm pupae, extraction of pupal oil and drying process [Heuze* et al. [24] *Rashmi* et al. *[65].*

n-3 fatty acids content and reducing the n-6/n-3 ratio [14].

Layers: Replacing 100% of protein cone by SWPM showed the greatest and most cost-effective results on egg quality, egg size & shell thickness [81]. Egg weight was not significantly different in the silkworm pupae-based diet fed to layer birds than the control [58]. Ullah et al. [79] discovered that when soybean meal was substituted with silkworm meal at 0, 25, 50, and 100% of the layer chickens' diet, there was no discernible change in the body weight, feed intake, hen day production (%), egg weight, feed conversion ratio, blood profile and egg quality parameters. The researchers came to the conclusion that silkworm meal could likely be used as a substitute protein source for soybean meal without significantly harming the layers. Sheikh, et al*.* [73] concluded that the addition of SWPM in the broiler ration had no significant impact on serum protein, cholesterol and SGOT among the various experimental groups. However, the serum phosphorous and serum glutamic pyruvic transaminase differed significantly when the diet's silkworm meal was included at a 5% level.

7. ECONOMIC FEASIBILITY OF SILKWORM PUPAL MEAL

Khatun et al. [32] observed that the addition of fish meal and SWPM at varying concentrations enhanced growth rate, considerably reduced the overall production cost per kg live broiler and dramatically raised profit per broiler as the SWP level increased. Furthermore, Sheikh and Sapcota [71] found that the best outcomes in terms of production economics were obtained when muga silkworm meal was substituted 100% for fish meal. According to Sinha et al. [75], Rao et al. [63] and Dutta *and* Dutta [15], silkworm meal replaced 50% of fish meal and showed an elevated profit margin because it was significantly less expensive than fishmeal. This finding confirms that when the amount of SWPM added to poultry feed increases linearly, there will be an increase in profit margin.

According to Ullah et al. [79], there is a greater economic benefit when the amount of SWPM included in the diet increases. Additionally, it was found that broiler performance and carcass quality were unaffected by replacing soybean meal with silkworm meal. Because silkworm meal is regarded as a valuable, inexpensive and safe source of protein [93-97]. Sheikh et al. [74] found that feeding it to livestock and poultry instead of traditional soybean meal or fish meal may improve farm economics. The DSWP, a protein with a high concentration of essential amino acids, has been demonstrated to provide a substantial amount of ME (MJ/kg) and one unit of crude protein for half the cost of SBM, according to Rashmi et al. [65] (Table 5).

8. CONCLUSION

Silkworm pupae meal (SWPM) presents significant potential as an alternative protein source for livestock due to its abundance and higher protein and amino acid content compared to conventional sources like soybean meal and groundnut cake. This can help bridge the gap between feed supply and demand while reducing environmental pollution. SWPM offers good quality natural protein with high digestibility, making it suitable for poultry diets. Its efficient utilization can lower feed costs without compromising growth performance. Research is needed to explore its long-term effects on meat quality and sensory properties. Reviews suggest that SWPM can economically replace soybean meal or fish meal in livestock and poultry diets without adverse effects on production performance.

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 writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Banday MT, Bhat GA, Shahnazand S, Bhakat M. Influence of feeding processed silkworm pupae meal on the performance of broiler chicken. Indian Journal of Animal Nutrition. 2009;26(3):292–295.
2. Battampara P, Sathish TN, Reddy R, Guna V, Nagananda GS, Reddy N, Ramesha BS, Maharaddi VH, Rao AP, Ravikumar HN, Biradar A. Properties of chitin and chitosan extracted from silkworm pupae and egg shells. Int. J. Biol. Macromol. 2020;161:1296-1304.
3. Bhagat RP, Barat S. Effect of Artificial Feed on Survival and Growth of Rainbow Trout, *Oncorhynchusmykiss* (Walbaum) During Exogenous Feeding in the Raceways of Kathmandu, Nepal. Int. J. of Fisheries and Aquatic Studies. 2017;5(1):149–156.
4. Blair R. Nutrition and feeding of organic poultry. Cabi Series, CABI, Wallingford, UK; c2008.
5. Cardinaletti G, Randazzo B, Messina M, Zarantoniello M, Giorgini E, Zimbelli A, Bruni L, Parisi G, Olivotto I, Tulli F. Effects of graded dietary inclusion level of full-fat Hermetia illucens prepupae meal in practical diets for rainbow trout (*Oncorhynchus mykiss*). Animals. 2019;9:251.
Available:https://doi.org/10.3390/ani9050251
6. Carlberg H, Lundh T, Cheng K, Pickova J, Langton M, Vázquez GJL, Kiessling A, Brännäs E. In search for protein sources: Evaluating an alternative to the traditional fish feed for Arctic charr (*Salvelinus alpinus* L.). Aquaculture. 2018;486:253-260.
7. Chandrasekharaiah M, Sampath KT, Praveen US Umalatha. Chemical composition and in vitro digestibility of certain commonly used feedstuffs in ruminant rations. Indian Journal of Dairy Science. 2004;57:114-117.
8. Chandrasekharaiah M, Sampath KT, Thulasi A. Essential amino acid content of commonly used feedstuffs. Indian J Anim Sci. 2003;73(3):305-307.
9. Chandrasekharaiah M, Sampath KT, Thulasi A. Rumen protein degradability of certain feedstuffs in cattle determined by nylon bag technique. Indian J. Dairy Bioscience. 2002;13:18-21.
10. Choudhury M, Barman K, Banik S, Das PJ. Effect of dietary inclusion of muga silkworm pupa meal on the growth performance of large white Yorkshire grower pigs. Int. J. Creat. Res. Thoughts. 2021;9:493-498.
11. Coll JFC, Crespi MPAL, Itagiba MGOR, Souza JCD, Gomes AVC, Donatti FC. Utilization of silkworm pupae meal (*Bombyx mori* L.) as a source of protein in the diet of growing finishing pigs. Rev. Soc. Bras. Zootec. 1992;21:378-383.
12. Cui Z, Ahn MY, Lee YB, Ryu KS. Materia medica from insects. Shinilbooks, Seoul. 2002;137-145.
13. Dalle Zotte A, Singh Y, Squartini A, Stevanato P, Cappellozza S, Kovitvadhi A, Subaneg S, Bertelli D, Cullere M. Effect of a dietary inclusion of full-fat or defatted silkworm pupa meal on the nutrient digestibility and faecal microbiome of fattening quails. Animal. 2021;15:100112.
14. Dalle Zotte A, Singh Y, Zsedely E, Contiero B, Palumbo B, Cullere M. Dietary inclusion of defatted silkworm (*Bombyx mori* L.) pupa meal in broiler chickens: Phase feeding effects on nutritional and sensory meat quality. Poultry Science. 2024;103812.
15. Dutta AS, Dutta KS. Growth of poultry chicks fed on formulated feed containing silkworm pupae meal as protein supplement and commercial diet. Journal of Animal Feed Research. 2012;3:303–307.
16. Fagoonee I. Possible Growth Factors for Chickens in Silkworm Pupae Meal. British Poultry Science. 1983;24:295–300.
17. Fanimo AO, Moduna E, Umukoro TO, Oduguwa OO. Substitution of shrimp waste meal (SWM) for fishmeal in broiler ration. Tropical Agriculture. 1996;73:201–205.
18. FAO. How to feed the world in 2050. Food and agriculture organization. Accessed on Feb. 1, 2022; 2009.
Available:www.fao.org/3/a-ak542e/ak542e13.pdf

19. Finke MD. Complete nutrient composition of commercially raised invertebrates used as food for insectivores. Zoo Biology. 2002;21(3):269–285.
DOI: 10.1002/zoo.10031
20. Groot JCJ, Von Keulen H, Oosting SJ. Exploration and design of alternative feeding systems for livestock in the tropics by integrative system approaches. Advances in Animal Bioscience. 2010;1:441–442.
21. Gugołek A, Strychalski J, Kowalska D. Growth performance and meat composition of rabbits fed diets supplemented with silkworm pupae meal. Span J Agric Res. 2019;17(3):e0607.
Available:https://doi.org/10.5424/sjar/2019 173-14 882
22. Gugołek A, Kowalska D, Strychalski J, Ognik K, Juśkiewicz J. The effect of dietary supplementation with silkworm pupae meal on gastrointestinal function, nitrogen retention and blood biochemical parameters in rabbits. BMC Veterinary Research 2021;17(1):1-14.
23. Herman RA, Yan CH, Wang JZ, Xun XM, Wu CK. Li ZN, Ayepa E, You S, Gong LC, Wang J. Insight into the silkworm pupae: Modification technologies and functionality of the protein and lipids. Trends in Food Science and Technology. 2022;129:408-420.
24. Heuzé V, Tran G, Giger-Reverdin S, Lebas F. Silkworm pupae meal. Feedipedia, a programme by INRAE, CIRAD, AFZ and FAO; 2017.
Available:https://www.feedipedia.org/node/ 199 last updated on september 14, 2017, 10:43.
25. Ioselevich M, Steingaß H, Rajamurodov Z, Drochner W. Nutritive value of silkworm pupae for ruminants. VDLUFA *Rostock*. 2004/09/13-17; 116:108; 2004.
26. Jensen LJ, Franceschini A, Kuhn M, Simonovic M, Roth A, Minguez P, Doerks T, Stark M, Muller J, Bork P, Szklarczyk D. Functional interaction networks of proteins, globally integrated and scored. Nucleic Acids Res. 2010;39(1):61-568.
27. Jintasataporn O. Production performance of broiler chickens Fed with Silkworm Pupa (*Bombyx mori*). Journal of Agricultural Science and Technology. 2012;2(4):505–5010.
28. Karnjanapratum S, Kaewthong P, Indriani S, Petsong K, Takeungwongtrakul S. Characteristics and nutritional value of silkworm (*Bombyx mori*) pupae-fortified chicken bread spread. Scientifc Report. 2022;12:1492.
29. Karthick RP, Aanand S, Stephen SJ, Padmavathy P. Silkworm pupae meal as alternative source of protein in fish feed. Journal of Entomology and Zoology Studies. 2019;7:78–85.
30. Khan S, Khan RU, Sultan A, Khan M, Hayat SU, Shahid MS. Evaluating the suitability of maggot meal as a partial substitute of soya bean on the productive traits, digestibility indices and organoleptic properties of broiler meat. J. Anim. Physiol. Anim. Nutr. 2016;100:649–656.
31. Khatun R, Azmal SA, Sarker MSK, Rashid MA, Hussain MA, Miah MY. Effect of silkworm pupae on the growth and egg production performance of Rhode Island Red (RIR) pure line. Int. J. Poultry Sci. 2005;4(9):718-720.
32. Khatun R, Howlider MAR, Rahman MM, Hasanuzzaman M. Replacement of fish meal by silkworm pupae in broiler diets. Pakistan Journal of Biological Sciences. 2003;6:955–958.
DOI: 10.3923/pjbs.2003.955.958
33. Koundinya PR, Thangavelu K. Silk proteins in biomedical research. Indian Silk. 2005;43(11):5-8.
34. Kowalska D, Gugolek A, Strychalski J. Evaluation of slaughter parameters and meat quality of rabbits fed diets with silkworm pupae and mealworm larvae meals. Annals of Ani. Sci. 2020;20(2):551-564.
35. Kwon MUG, Kim DS, Lee JH, Park SW, Choo YK, Han YS, Kim JS, Hwang KA, Kinarm KO, Kiung K. Isolation and analysis of natural compounds from silkworm pupae and effect of its extracts on alcohol detoxification. ENT Research. 2012;42:55–62.
36. Lamberti C, Gai F, Cirrincione S, Giribaldi M, Purrotti M, Manfredi M, Marengo E, Sicuro B, Saviane A, Cappellozza S, Giuffrida MG, Cavallarin L. Investigation of the protein profile of silkworm (*Bombyx mori*) pupae reared on a well-calibrated artificial diet compared to mulberry leaf diet, Peer J. 2019;7:6723.
37. Li XM, Gao K, Dong SJ, Liu X, Fu KH, Wang PL, Zhang AQ, Su XO, Fu JJ. Length-specific occurrence and profile of perfluoroalkyl acids (PFAAs) in animal protein feeds. J. Hazard. Mater.. 2019;373:224-231.

38. Longvah T, Mangthya K, Ramulu P. Nutrient composition and protein quality evaluation of eri silkworm (*Samia ricinii*) prepupae and pupae. Food Chemistry. 2011;128(2):400-403.
39. Mahesh DS, Vidhathri BS, Narayanaswamy TK, Subbarayappa CT, Muthuraju R, Shruthi P. A review – Bionutritional science of silkworm pupal residue to mine new ways for utilization. Int. J. Adv. Res. Biol. Sci. 2015;2(9):35-140.
40. Makkar HPS. Review: Feed demand landscape and implications of food- not feed strategy for food security and climate change. Animal. 2018;12:1744–1754.
41. Makkar HPS, Tran G, Heuzé V, Ankers P. State-of-the art on use of insects as feed. Animal Feed Science Technology. 2014;197:1–33.
42. Medhi D, Math NC, Sharma DN. Effect of silk worm pupae meal and enzyme supplementation on blood constituents in pigs. Indian Veterinary Journal. 2009a;86:433-434.
43. Medhi D, Nath NC, Gohain AK, and Bhuyan R. Effect of silk worm pupae meal on carcass characteristics and composition of meat in pigs. Indian Veterinary Journal. 2009b;86:816-818.
44. Medhi D. Effects of enzyme supplemented diet on finishing crossbred pigs at different levels of silk worm pupae meal in diet. Indian Journal of Field Veterinarian. 2011;7(1):24-26.
45. Miah MY, Singh Y, Cullere M, Tenti S, Dalle Zotte A. Effect of dietary supplementation with full-fat silkworm (*Bombyx mori* L.) chrysalis meal on growth performance and meat quality of Rhode Island Red× Fayoumi crossbred chickens. Italian Journal of Animal Science 2020;19(1):447-456.
46. Miles RD, Chapman FA. *The benefits of fish meal in aquaculture diets*. Series of the Department of Fisheries and Aquatic Sciences University of Florida. FA. 2006;122:7-8.
47. Mohd, Tufail B, Ahamad BG, Sayed S, Mukesh B. Influence of Feeding Processed Silkworm Pupae Meal on the Performance of Broiler Chicken. Ind J Anim Nutr. 2009;26(3):292-295.
48. Nagappan S, Das P, AbdulQuadir M, Thaher M, Khan S, Mahata C, Al-Jabri H, Vatland AK. Kumar G. Potential of microalgae as a sustainable feed ingredient for aquaculture. Journal of Biotechnology. 2021;341:1-20.
49. Narahari D, Sundarasu V, Thygarajan D, Prabakaran R. Effect of feeding silkworm pupae meal containing diets with or without amino acid supplementation on broiler performance. Indian Journal of Animal Science. 1990;60:1385.
50. Narang MP, Lal R. Evaluation of some agro-industrial wastes in the feed of jersey calves. Agricultural Wastes. 1985;13:15-21.
51. Ni C, Liang HA. Study on the chemical components of silkworm pupae curst and its microstructure. J. Nat. Sci. 1999;21(1):69-72.
52. Nutreco. Feeding the future, Annual Results, 2010. Amsterdam, The Netherlands; 2011.
53. Nyanchoka W, Muriithi AN, Kasina M. Growth performance and carcass characteristics of Kuroiler chicks fed on Silkworm pupae (*Bombyx mori*) diet. African Journal of Agricultural Research. 2024;20(3):284-292.
54. Oduguwa OO, Fanimo AO, Oso MJ. Effect of replacing dietary fish meal or soybean with shrimp waste meal on the performance of laying hens. Nigerian Journal of Animal Production. 2005;32:224–232.
55. Ojewola GS, Okopyo FC, Ukoha OA. Comparative utilisation of three animal protein sources by broiler chickens. International Journal of Poultry Science. 2005;4:462–467.
56. Oso JA, Iwalaye OA. Growth Performance and Nutrient Utilization Efficiency of Clarias Gariepinus Juveniles Fed *Bombyx mori* (Mulberry Silkworm) Meal as a Partial Replacement for Fishmeal. British Journal of Applied Science and Technology. 2014;4(26):3805–3812.
57. Qadri. Studies on the utilisation of silkworm excreta and pupae meal in the diets of broiler chicken. Thesis submitted to Sher-e-Kashmir, University of Agriculture Sciences and Technology of Kashmir; 2015.
58. Rafiullah. Replacement of Soybean Meal with Silkworm Meal *(Bombyx mori) in Poultry Ration.* Thesis in poultry science, Peshawar: The University of Agriculture; 2016.
59. Rahman MA, Rahaze M, Mazed MA, Mahata SC. Replacement of Costly Fish Meal by Silkworm Pupae in Diet of Mirror

Carp (*Cyprinuscarpio*). Pakistan Journal of Scientific and Industrial Research. 1996;39:64–67.

60. Karthick Raja P, Aanand S, Stephen Sampathkumar J, Padmavathy P. Silkworm pupae meal as alternative source of protein in fish feed. Journal of Entomology and Zoology Studies. 2019;7(4):78-85.
61. Rangacharyulu PV, Giri SS, Paul BN, Yashoda KP, Rao RJ and Mahendrakar NS. Utilization of fermented silkworm pupae silage in feed for carps. Bioresource Technol. 2003;86(1):29-32.
62. Rao PU. Chemical composition and nutritional evaluation of spent silk worm pupae. Journal of Agricultural and Food Chemistry. 1994;42:2201–2203.
63. Rao RJ, Yashoda KP, Mahendrakar NS. Utilization of fermented silkworm pupae in feed for broiler chicks. Bulletin of Indian Academy Sericulture. 2011;15(1):1–9.
64. Rashmi KM, Chandrasekharaiah M, Soren NM, Prasad KS, David CG. Effect of dietary incorporation of silkworm pupae meal on *In vitro* rumen fermentation and digestibility. Indian Journal of Animal Sciences. 2018;88:731-735.
65. Rashmi KM, Chandrasekharaiah M, Soren NM, Prasad KS, David CG, Thirupathaiah Y, Shivaprasad V. Defatted silkworm pupae meal as an alternative protein source for cattle. Trop. Ani. Health and Prod. 2022;54(5):327.
66. Robinson TP, Wint GRW, Conchedda G, Van Boeckel T, Mcleod M, Bett B, Grace D, Gilbert M. The global livestock sector: Trends, drivers, and implications for society, health and the environment. Science with Impact annual conference 2015—BSAS/AVTRW/WPSA. University of Chester, Chester, United Kingdom. 2015;6.
67. Sahib QS, Ahmed HA, Ganai AM, Farooq J, Sheikh GG, Islamuddin Sheikh, Beigh YA. Evaluation of silkworm pupae meal based calf starter diet on the performance of crossbred cattle calves. The Indian Journal of Animal Sciences. 2023;93(9):903-906.
68. Sampath KT, Chandrasekharaiah M, Thulasi A. Limiting amino acids in the bypass protein fraction of some commonly used feedstuffs. Indian Journal of Animal Sciences. 2003;73:1155-1158.
69. Sapcota D, Sheikh IU, Dutta KK, Sarma S, Ranjana G. Effect of dietary MUGA silkworm supplementation on the performance of broilers. Indian Veterinary Journal. 2003;80(1):19–22.
70. Sengupta S, Choudhry K, Bhattacharyya IK, Choudhry IK. Effect of Feeding Muga Silkworm Pupae Waste as a Substitute for Fishmeal in Broiler Ration. Indian Journal of Animal Science. 1995;65(7):827–829.
71. Sheikh IU, Sapcota D. Economy of Feeding Muga Silkworm Pupae Meal in the Diet of Broilers. The Indian Veterinary Journal. 2007;84(7):722–724.
72. Sheikh IU, Sapcota D. Effect of feeding silkworm pupae meal on nutrient and mineral retention in broilers. The Indian Veterinary Journal. 2010;87:1047–1050.
73. Sheikh IU, Sapcota D, Sarma S. Effect of Dietary Muga Silkworm Pupae Meal on the Blood Biochemistry in Broilers. Indian Veterinary Journal. 2006;82(7):752–755.
74. Sheikh IU, Banday MT, Baba IA, Adil S, Nissa SS, Zaffer B, Bulbul KH. Utilization of silkworm pupae meal as an alternative source of protein in the diet of livestock and poultry: A review. Journal of Entomology and Zoology Studies. 2018;6(4):1010–1016.
75. Sinha S, Abhijit D, Chattopadhyay S. Effect of replacement of fishmeal by de-oiled Silkworm Pupae of *Antheraea Mylitta* (Drug) on the Performance of Broiler Chickens. Bulletin of Indian Academy Sericulture. 2009;13(2):70–72.
76. Suresh HN, Mahalingam CA, Pallavi. Amount of chitin, chitosan and chitosan based on chitin weight in pure races of multivoltine and bivoltine silkworm pupae *Bombyx mori* L. Int. J. Sci. Nature. 2012;3:214.
77. Thirumalaisamy G, Malik PK, Kolte AP, Trivedi S, Dhali A, Bhatta R. Effect of silkworm (*Bombyx mori*) pupae oil supplementation on enteric methane emission and methanogens diversity in sheep. Animal Biotechnology. 2020;33:128–140.
78. Trivedy K, Kumar SN, Mondal M, Kumar Bhat CA. Protein banding pattern and major amino acid component in de-oiled pupal powder of silkworm, *Bombyx mori* Linn. Journal of Entomology. 2008;5:10–16.
79. Ullah R, Khan S, Khan NA, Mobashar M, Sultan A, Ahmad N, Lohakare J. Replacement of soybean meal with silkworm meal in the diets of white leghorn layers and effects on performance, apparent total tract digestibility, blood

profile and egg quality. Int. J. Vet. Health Sci. Res. 2017;5(7):200-207.
80. Usub T, Lertsatitthanakorn C, Poomsa-ad N, Wiset L, Yang L, Siriamornpun S. Experimental performance of a solar tunnel dryer for drying silkworm pupae. Biosystems Engineering. 2008;101:209-216.
81. Wang J. Process optimization for the enrichment of a-linolenic acid from silkworm pupae oil using response surface Methodology. African Journal of Biotechnology. 2010;9:2956–2964.
82. Wei ZJ, Liao AM, Zhang HX, Liu J, Jiang ST. Optimization of supercritical carbon dioxide extraction of silkworm pupal oil applying the response surface methodology. Bioresour. Technol. 2009;100:4214–4219.
83. Wijayasinghe MS, Rajaguru AS. Use of silkworm (*Bombyx mori* L.) pupae as a protein supplement in poultry rations. J Natn. Sci. Coun. 1977;5(2): 95-104.
84. Wu X, He K, Cirkovic Velickovic TC, Liu Z. Nutritional, functional, and allergenic properties of silkworm pupae. Food Science Nutrition. 2021;9:4655–4665.
85. Yashoda KP, Rao RJ, Rao DN, and Mahendrakar NS. Chemical and microbiological changes in silkworm pupae during fermentation with molasses and curd as lactic culture. Bulletin Ind. Ac. Sericulture. 2008;12(1): 58-66.
86. Zarantoniello M, Bruni L, Randazzo B, Vargas A, Gioacchini G, Truzzi C, Annibaldi A, Riolo P, Parisi G, Cardinaletti G, Tulli F, Olivotto I. Partial dietary inclusion of *Hermetia illucens* (black soldier fly) full-fat prepupae in zebrafish feed: Biometric, histological, biochemical, and molecular implications. Zebrafish. 2018;15:519-532.
87. Zhao X, Kuang Z, Yang J, Bilal M, Yang R. Effect of fermented silkworm (*Bombyx mori*) pupae on growth performance, immune index and meat quality in Lingnan yellow broiler chickens. Pak. J. Zool. 2022;17(2):1-8.
88. Zhou J, Han D. Proximate, amino acid and mineral composition of pupae of the silkworm *Antheraea pernyi* in China. Journal of Food Composition and Analysis. 2006;19(8):850-853.

Peer-review history:
The peer review history for this paper can be accessed here:
https://prh.mbimph.com/review-history/3516