Review Article

SILKWORM PUPAE MEAL:
A BREAKTHROUGH FOR CONVENTIONAL POULTRY FEED

ABSTRACT

The growing demand for cost-effective and sustainable poultry feed has spurred interest in alternative protein sources. This review explores the potential of silkworm pupae meal (SWPM) as a viable substitute for conventional protein sources such as soybean and fish meal in poultry diets. Silkworm pupae, a by-product of the silk industry, are rich in crude protein (up to 80% in defatted meal) and essential amino acids, particularly lysine and methionine. These nutritional attributes, along with a high content of fatty acids, make SWPM an attractive ingredient for poultry feed. The paper discusses the environmental benefits of using silkworm pupae, which include reducing waste and mitigating the ecological impact of traditional feed ingredients. Additionally, the incorporation of SWPM in poultry diets has been shown to improve nutrient digestibility, feeding preferences, and gut health in chickens. This review highlights the promise of silkworm pupae meal as a sustainable and economical alternative in the poultry feed industry, offering a potential solution to the challenges of rising feed costs and environmental sustainability. Replacing the traditional protein sources such as soyabean meal & fish meal with silkworm pupae meal may break a chain of increasing feed costs and make a sustainable change towards a cost-effective feed. In this arena, silkworm pupae meal is a high-nutritional-value proteinrich animal feed component, exceeding up to 50% crude protein content to over 80% at times. It contains methionine, lysine,chitin, and insoluble protein, possibly indicating fibre. The protein content ranges from 6-12%, and the fat content is 20-40%. Researchers have investigated in many ways how the use of full-fat and defatted silkworm pupae meal in chicken feed affects nutrient digestibility, feeding preferences and gut bacteria, with the aim of potentially substituting it for traditional protein sources in poultry diets.

Keywords: Poultry, Silkworm Pupae Meal, Protein, Amino Acid, Soyabean Meal, Fish Meal

INTRODUCTION

Poultry refers to the household or commercial raising of birds such as chickens, ducks, turkeys, geese, etc. for their eggs and meat. Poultry meat along with eggs, both offer highquality animal protein contentprofile for human consumption in adequate amount withoptimum amino acid profile.Thus encourages a major role in the growth & development of the health of human beings (He *et al.*, 2021). India's poultry industry is primarily focused on chicken production, accounting for nearly 95% of egg output. Globally, India ranks third in egg production and fifth in chicken meat production. The industry contributes significantly to the national economy, contributing approximately 1% to GDP and providing employment to around 5 million people. Poultry production is concentrated in specific regions, with Andhra Pradesh leading the way, followed by West Bengal, Maharashtra, Tamil Nadu, and Punjab. (Panda and Samal, 2016)

In India, the poultry market has undergone tremendous transformation over the decades, and the region has emerged as one of the country's important economic sectors. Poultry meats which accounts for around majority of total animal protein consumption, contributes to the broiler business's rise in demand for the consumption of animal protein. The demand for chickens by humans has caused broiler farmers to have trouble because of the scarcity and high cost of feed supplies.(Chatterjee and Rajkumar, 2015)

Rising disposable incomes and changing consumer dietary choices are driving the Indian poultry market. The change from the diet in India which traditionally relies on meat, pulses, dairy products and such to meet basic human body requirements for protein is considerably assisting the tremendous development of the poultry industry. Moreover, increasing awareness of proper physical health & nutritional lifestyle fuels the necessity for a diet rich in protein. Additional reasons driving the industry forward include increased disposable incomes, improved living standards and lifestyle patterns, rapid urbanization, and the expansion of distribution channels. (Panda and Mohapatra, 1993; Vetrivel and Chandrakumarmangalam, 2013; Rao, 2015)

The chicken industry's goal is to reduce production costs while increasing productivity through nutrition, managerial methods, diet changes, and other means.(Mohamad *et al.*, 2020) When it comes to nutrition, the rising cost of feed ingredients is leading the poultry sector to place a great deal of significance on improving feed consumption efficiency without negatively impacting poultry animal growth performance (Krishnan *et al.*, 2011). In the poultry industry, feed cost takes up a significant portion of production expenses, ranging from 60-80% and rising steadily. As we speak, animal protein, the most expensive component of poultry feed accounts for 15% of such feed cost (Dutta *et al.*, 2012).

The dire need to fulfil the needs and feeds of poultry as well as livestock has led to the spontaneous improvement and alterations of diet with more effective ingredients giving economic benefits. The global dilemma of supplying for increasing protein consumption and reducing agricultural acreage is most visible in the increased demand for poultry products. Poultry production is considered environmentally friendly because poultry birds emit less CO_2 than other animals. However, as chicken production intensifies, more protein is required, resulting in a reliance on traditional sources such as soya beans and fish meal. The latter is constrained by overfishing and growing expenses. Given chickens' natural proclivity to devour insects, there is considerable interest in utilizing insect protein in poultry diets serves as a remedy. Ideal insect candidates for protein synthesis should have a short reproduction cycle to ensure sustainability (Józefiak and Engberg, 2015).

Exploring new opportunities: Insects as a potential protein alternative in poultry diets

"Feed-food competition" refers to the conflicts and trade-offs that arise between two possible uses for edible crops: feeding animals and direct human consumption. The utilization of production resources, such as water, land, labour, wild fish followed by ecosystem services, is included in the term "feed-food competition." The ultimate use of the resource, which is usually the most profitable, determines how these resources are distributed among all other possible consumers(Breewood and Garnett, 2020). Because of their rich nutritional content, insects constitute a sustainable feed component alternative to commercial feedstuffs and simultaneously reduce feed-food competition(Zsedely *et al.*, 2022).

Hollowing and digging through the ground for food shown to be a natural behaviour of poultry birds. This natural inclination is sparked by the abundance of 'desired delicacies' found on and under the ground, such as worms and insects. Most likely because of their flavour and nutritional value, chickens prefer eating insects or insect-based meals. This behaviour serves insects to have the potential to furnish an alternate protein source for chicken production. This ensures the potential to reduce feed-food competition and provide income for industrial as well as smallholder farmers(on Nutrition *et al.*, 2021).

Poultry and livestock require a specific energy level which can be achieved when fed high-protein diets creating effective pre-starter and starter feeds for chickens(Gous *et al.*, 2018). Recently, using insects as an alternative source of protein in poultry diets has grown in favour(on Nutrition *et al.*, 2021). It has the ability to convert waste biomass into significant feed resources. According to a new study, it has been discovered that large-scale insect multiplication provides a practical substitute for adding protein-rich components to poultry rations (Zhou *et al.*, 2009). Over billions of people consume insects globally; 349 species are thought to be consumed in and around Asia, 524 in case of Africa, 152 to be considered in Australia, 679 around America, and roughly 41 in Europe(Jongema, 2015). The majority of edible-insect species are found in Mexico, with Thailand, Congo, India, Australia, China, and Zambia following(Ramos-Elorduy, 2006)(Jongema, 2015),

Insects account for around three-fourths of all life on Earth (Sindhura *et al.*). Due to their similar fat content of 30-40% dry matter basis and protein content of 40-60% dry matter basis compared to traditional Soyabean Meal and Fish Meal, insects are gaining traction as a potential alternative protein source in poultry feed(Makkar *et al.*, 2014). This diversion could result in higher efficiency in the use of natural resources with reduced greenhouse gas emission and less eutrophication of water habitats through nutrient loss(Van Zanten *et al.*, 2014). For these reasons, the use of insect protein in poultry diets has promising implications. Essentially, this is demonstrated by the fact that chickens with outside access gather and consume insects at every stage of growth, suggesting that they have evolved to use insects as food. Insect-derived products contain a large proportion of digestible crude protein with amino acids, making them a powerful solution for improving self-sufficiency of protein in poultry feed in the progressing future. Insects suit the adequate nutritional needs concerned towards poultry birds and contribute towards building of such highly formulated nutritional feed since they are abundant in necessary amino acids(Slimen *et al.*, 2023). Therefore, insect-derived meals in poultry diets have been found to improve chicken palatability, and chickens fed with such meals are highly preferred by humans for consumption. This shift could lead to more efficient utilization of resources. (Van Zanten *et al.*, 2014)

A study examined the potential of black soldier fly larvae and silkworm pupae as protein sources for broiler chickens. These insect meals were added to chicken feed at a 10% level to assess their impact on chicken growth, meat quality, and overall health. The results indicate that both insect meals could effectively replace soybean meal in chicken diets as they promoted better growth performance. (Lalev *et al.*, 2022)

Another study compared the nutritional value of black soldier fly larvae meal to traditional feed ingredients like soybean meal and fishmeal for broiler chickens. The results showed that black soldier fly larvae meal has a similar or even superior nutritional profile to fishmeal and soybean meal. This suggests that it could replace fishmeal in chicken feed and enhance the nutritional quality of soybean meal without negatively affecting the chickens' growth or overall health. (Oluokun, 2000)

Given the growing global population and the need for alternative protein sources, the black soldier fly (*Hermetiaillucens*) has emerged as a promising candidate. This study aimed to increase the protein content of black soldier fly prepupae (BSFP) by exploring the impact of various feeding strategies. This study demonstrated that feeding black soldier fly prepupae (BSFP) with dried bacterial cells effectively increased their protein content. (Mohamad *et al.*, 2020)

Maurer *et al.* (2016) conducted a study to evaluate the suitability of Black Soldier Fly (BSF) larvae meal as a replacement for traditional protein sources like fishmeal and soybean meal in poultry diets. Their findings indicated that BSF larvae meal can be effectively incorporated into both broiler and laying hen diets without negatively impacting bird performance.

Agunbiade *et al.* (2006) investigated replacing fishmeal with house fly larvae meal in the diets of laying hens fed a cassava-based feed. The researchers found no significant differences in how much the hens ate or how efficiently they converted feed into eggs. These results suggest that house fly larvae meal could be a suitable replacement for fishmeal in both chickens raised for meat and those raised for egg production.

For mealworms, a study investigated the use of mealworms as a feed additive for broilers found promising results. Adding mealworms to diets primarily composed of soybean meal did not negatively impact the chickens' growth, feed consumption, or feed efficiency. This suggests that mealworms could be a valuable addition to poultry feed without compromising performance. Ramos-Elorduy *et al.* (2002)

A turn-over of Insect as Feed: Silkworm Pupae Meal

Silkworms and their life cycle prompts to serve a great purpose of being utilized for the conversion of waste to wealth (Krishnan *et al.*, 2011). This tradition of domesticating the silk moth *Bombyx mori* L. started about 5200 years ago among the Chinese people(Makkar *et al.*, 2014). Silkworm is a sericigenous insect that develops from the eggs laid by the silk moth. Initially, eggs are black which then hatch and produce young larvae or worms that grow by feeding on mulberry leaves. The larva grows from Instar I to Instar V in which they attain full size of about 7.5-10cm(Chapman, 1998). Silkworm larva later spins cocoon inside which the pupa develops. Cocoon is the protective cover made of raw silk spun by the fifth-instar silkworms. In the end, a certain enzyme that is released by the pupa creates a hole in the walls of the cocoon from which the moth emerges(Ullah; Khan; Hafeez*; et al.*, 2017).

Fresh spent silkworm pupae debris are discarded in nearby areas after being reeled from cocoons.The silk industry generates a massive amount of waste in the form of silkworm pupae, with global estimates reaching a staggering three million tons annually(Battampara *et al.*, 2020). These fresh silkworm pupae are highly degradable that create pollution and odour in the surrounding locations. The category of spent silkworm pupa is a natural, biodegradable product. However, large concentrations of these pupae being dumped in the environment can cause major environmental hazards in silk-producing areas(Wang *et al.*, 2010). Silkworm pupae, often discarded after silk production, are packed with nutrients and could offer significant health benefits. These underutilized resources could be transformed into valuable dietary supplements(Sadat; Biswas; Cardoso; Mondal; ... 2022). Hence, for waste-to-wealth purposes, using these resources for feed formulation as well as the production of useful biological compounds to help lessen the negative impact of silk production on the environment.

Scientific studies have indicated that silkworm pupae are rich in compounds beneficial to human health.Both laboratory and animal research have shown that these pupae possess antioxidant, antibacterial, anti-cancer, and liver-protective properties(Deori *et al.*, 2014). Silkworm pupa inside the cocoon accounts for a high content of fatty acids, lipids, and protein which makes them ideal for inclusion in poultry and other animal feed. Fresh pupae with high moisture content are dried in order to prevent them from rotting (Jintasataporn, 2012);(Wei *et al.,* 2009). These silkworm pupae produce a certain pungent smell that is caused due to the degradation of the pupae relating to the existence of chemicals in mulberry leaves that the silkworms may feed on such as essential oils, flavonoids and terpenoids. This foul odour is related to palatability (Rao, 1994; Finke, 2002).

Pupal powder extracted from the silkworm pupae also known as silkworm pupae meal has been afairly researched aspect for poultry as well as livestock feed. Silkworm pupae (SWP), silkworm meal, wasted silkworm pupa, deoiled silkworm pupa meal, non-deoiled silkworm pupa meal, etc. are some of the other frequent names(Makkar *et al.*, 2014). The nutritional component present in silkworm pupae meal has the ability to replace the protein sources in conventional animal feed. This area of research has been widely opened through experiments conducted by scientists all over the world. It was found that defatted pupal meal had a higher content of protein compared to un-defatted pupal meal ((Nixey, 2010).

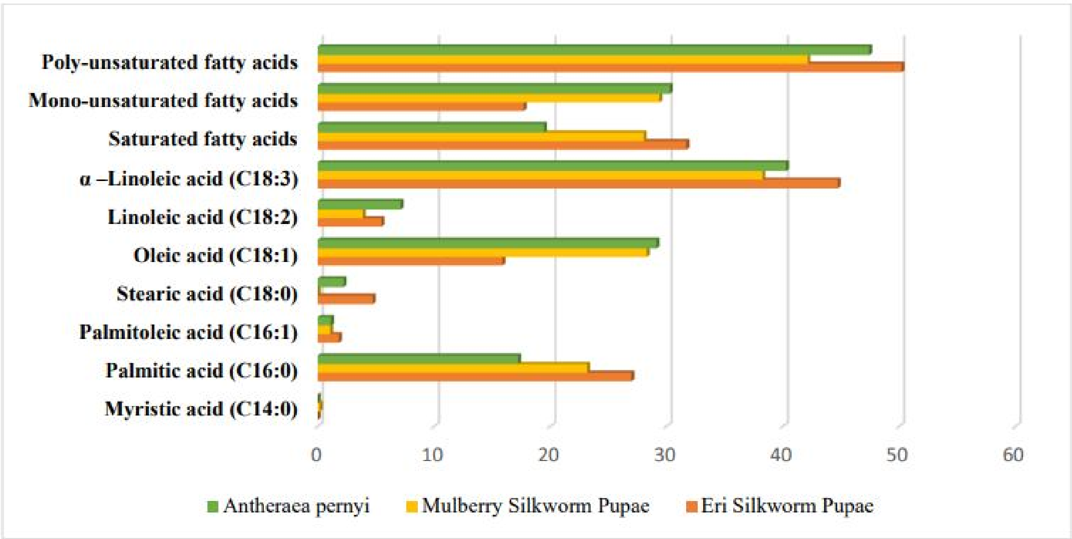
Composition of Silkworm Pupae Meal

Bombyx mori is found to be the most prevalent dry matter in silkworm pupa and possess a high protein content of about 55.6% dry weight(Tomotake *et al.*, 2010). Pharmacological actions of silkworm pupa can be carried out by hydrolysing these pupae proteins to create a range of physiologically active peptides. All species of silkworm pupae have about the same amino acid content, with 18 amino acids making up each protein. Of these, the WHO/FAO/UNU criteria are met by eight essential amino acids(Zhou and Han, 2006; Karthick Raja *et al.,* 2019; Reddy *et al.,* 2024). Consequently, silkworm pupae is therefore regarded as an essential nutrient and a premium source of protein (Altomare *et al.*, 2020).

Coming to the pupal meal sector, Silkworm Pupae Meal (SWPM) is a high-nutritional-value, protein-rich animal feed component. Crude protein (CP) content of this meal exceeds 50%, rising up to 80% (for defatted pupal meal) on a dry matter (DM) basis. The amino acid profile stands out with particularly high levels of lysine of about 6-7% of total protein and methionine of about 2-3%.Furthermore, the chitin and some insoluble proteins that are present in it may explain the presence of fibre. Also, the acid detergent fibre (ADF) concentrations have been recorded to range from 6-12% DM basis(Finke, 2002). The pupae meal is high in concentration of fat ranging from 20 to 40%DM. Defatted silkworm pupa meal contains less than 10% oil, but remarkably boasts a high proportion of polyunsaturated fatty acids, particularly linoleic acid (18:3), which comprise 11% to 45% of its total fatty acid content(Zsedely *et al.*, 2022). The proximate components of silkworm pupa (SWP) on a fresh basis include crude protein (12-16%), moisture (65-70%), ash (0.79-1.41%), carbohydrate (1.18-1.79%) and Ether extract (EE) (11-20%). In SWP, energy content ranges from 706 to 988 kJ(Mishra *et al.*, 2003). However, in dried SWP powder the contents are 20.1% EE, 71.9% CP and 3.9% ash on a dry matter basis (Zhou and Han, 2006). Another study found that the concentration of about 55.6% CP and 32.2%, EE on a dry matter basis (Tomotake *et al.*, 2010). In addition to that the potential role of 1-DNJ (1-

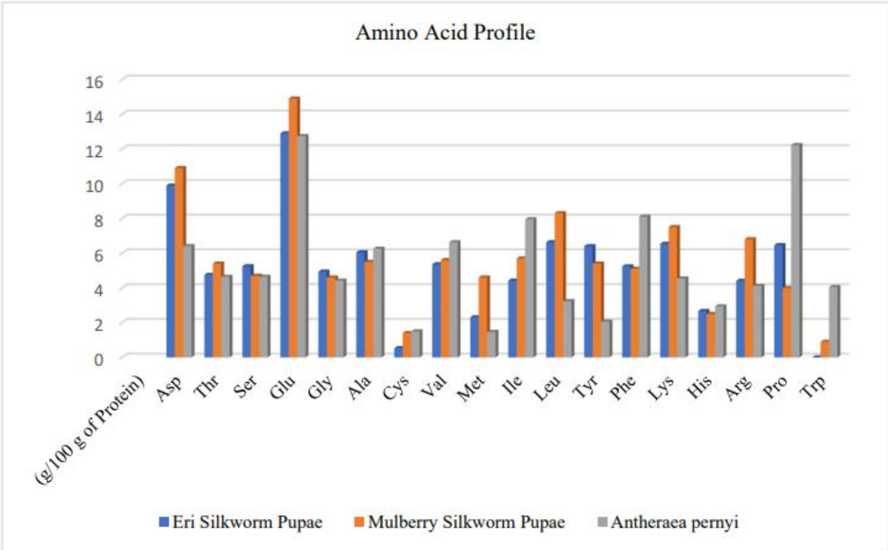
Deoxynojirimycin), a certain silkworm bio-compound is studied, that tends to affect the absorption of glucose in poultry feeding. As a result, certain research studies examined the influence of diet incorporation of full-fat and/or defatted silkworm pupae meal on nutrient digestibility, feed preferenceas well as faecal microbiota in chicken (Dalle Zotte *et al.*, 2021). It is also rich in essential fatty acids, such as alpha-linolenic and linoleic acid along with riboflavin(KWON *et al.*, 2012).

Figure 1: Fatty acid composition of different silkworm pupae



Source: (Tomotake *et al.*, 2010); (Longvah *et al.*, 2012); (Sadat; Biswas; Cardoso; Mondal; Ghosh*; et al.*, 2022); (Venkatesh Kumar *et al.*, 2020); (Hu *et al.*, 2017); (Wang *et al.*, 2020)

Figure 2: Amino acid profile of different silkworm pupae



Source: (Tomotake *et al.*, 2010);(Longvah *et al.*, 2011);(Rao, 1994);(Zhou and Han, 2006)

In the end, among alternative protein sources, silkworm pupae meal being low-cost would alsomitigate the environmental concerns associated with the disposal of this by-product and contribute to a more sustainable livestock feed industry. The meal can also contribute to cost savings, as it has the potential to replace more expensive protein sources in animal diets without negatively impacting the performance and health of the animals, including poultry, fish, rabbits, and ruminants(Rashmi *et al.*, 2023).

Current Scenario: Attempts in replacing conventional feed with SWPM

Throughout a study of diet incorporation of defatted silkworm pupa meal for feeding broilers in Hungary, the health of the chickens was reported to be ideal across all experimental groups, illustrating that the incorporation of silkworm pupae meal at the tested amount is well-tolerated by the chickens. Since carcass yield and other key metrics remained consistent across all dietary groups, the inclusion of the meal appeared to have no negative impact on carcass quality. This suggests that the meal's suitability as a protein alternative is promising, further supported by the minimal to no effects observed on specific aspects of meat quality and the absence of any detrimental impact on growth performance. Overall, the study concludes that defatted silkworm pupae meal presents a promising and sustainable alternative protein source for broiler diets(Zsedely *et al.*, 2022).

One of the studies implemented on Ross 308 broiler chicks revealed that up to 75% of soybean meal in broiler finisher meals can be successfully replaced with silkworm meal without affecting performance, carcass quality, or bird health. As a result, silkworm meal appears to be a feasible alternative protein source with the capability to reduce feed costs and improve profitability in broiler production(Ullah; Khan; Hafeez*; et al.*, 2017)

Poultry diets of Rhode Island Red pure line chickens in a study in Bangladesh showed that increasing the amount of SWP in the diet by up to 6% increased growth performance, egg production performance, and profitability. The data show that, despite contradictory findings from prior studies, incorporating SWP into the meals did not increase mortality, implying that SWP is not acutely harmful to birds. Furthermore, as the dietary levels of SWP grew, the feed cost per kilogram decreased. As a result, the authors argue that SWP is a realistic alternative for layer diet formulation in Bangladesh, which could lead to higher profitability for poultry producers, especially given the existing scarcity and high costs(Khatun *et al.*, 2005).

A study investigates the effect of adding full-fat silkworm chrysalis meal to the diet of Rhode Island Red and Fayoumi crossbred chickens, specifically focusing on their growth and meat quality outcomes. They ensured that a 25% SWM inclusion level appeared to be the most favorable, with better overall results than the control and 50% inclusion levels(Miah *et al.*, 2020).

A study of RIR strain chicks established a concrete result on the growth performance along with proximate analysis of varying percentages of silkworm pupae that were used to prepare the feed. Tasar silkworm pupae meal that was used from Central Tasar Research and Training Institute (CSR&TI), Jharkhand demonstrated that the least expensive and most viable alternative to the pricey and tainted fish meal utilized as a source of protein in the poultry sector is silkworm pupal meal. Feed cost per kilogram at 8 weeks of age decreased steadily as the amount of SWP in the diet increased. Numerous writers concluded that dietary protein intake has a direct impact on the average amount of weight gain. Therefore, this inexpensive by-product of the tasar silk business can be utilized to replace expensive traditional feed such as fish meal as a protein source in poultry feed(Dutta *et al.*, 2012).

A study investigated the potential of silkworm pupae meal as a replacement for fishmeal in broiler chicken feed. Results indicated that substituting up to 50% of the fishmeal with processed silkworm pupae meal led to enhanced broiler performance metrics(Banday; Bhat; Shenaz; Bhakat, 2009).

A certain researcher explored the potential of replacing soyabean meal with silkworm pupae meal in the diets of White Leghorn hens. The study examined how this substitution affects various aspects, including growth performance, blood profile. Nutrient digestibility and egg quality. The findings suggest that SWPM can be sustainable protein alternative to soyabean meal, offering comparable protein content without compromising the health or productivity of the hens.(Ullah; Khan; Khan*; et al.*, 2017).

For a study with Arber Acres broiler chicks with feed alteration with SWMP showed that with an increase in silkworm pupae meal level their growth performance, liveability, meat yield, feed conversion and market profitability rose nearly linear(Khatun *et al.*, 2003).

In a study for incorporating eri SWP in broiler chickens fed 10% eri silkworm pupae meal grew better, had healthier growth and produced higher quality carcasses compared to those without it. This level of supplementation is beneficial and safe. (Kongsup *et al.*, 2022)

Table 1: Key findings of various research conducted

Experiments conducted	**Place**	**Result & Inference**	**Source**
Incorporating defatted Silkworm Pupae Meal for Broiler chicken diets	Hungary	Suitable source of protein for broiler diets because it had no detrimental effect on growth rate or quality of carcass	(Zsedely *et al.*, 2022)
Replacement of soyabean meal with SWPM in Ross 308 Broiler chicks	Pakistan	75 % of soybean meal in broiler finisher meals can be successfully replaced with silkworm meal without affecting performance,	(Ullah; Khan; Hafeez*; et al.*, 2017)

		carcass quality, or bird health	
Inclusion of SWP in Rhode Island Red pure line chickens	Bangladesh	Increasing the amount of SWP in the diet by up to 6% increased growth performance, egg production performance, and profitability	(Khatun *et al.*, 2005)
Addition full-fat silkworm chrysalis meal to the diets of Rhode IslandRed and Fayoumi crossbred chickens	Bangladesh	25% SWM inclusion level yielded the most positive results across the board	(Miah *et al.*, 2020)
Inclusion of varying percentages of SWP in diets of RIR Strain chicks	India	Feed cost substantially decreased as the amount of SWP in the diet increased	(Dutta *et al.*, 2012)
Replacement of soyabean meal for SWPM on white leghorn layer	Pakistan	Soyabean meal can be replaced with SWPM with no negative impact on the layers	(Ullah; Khan; Khan*; et al.*, 2017)
Feed alteration of Arber Acres broiler chicks with SWMP	India	A positive, near-linear trend in growth rate, meat yield, feed conversion and market profitability observed as the level of SWPM in the diet increased	(Khatun *et al.*, 2003)
Effect of SWPM with enzyme supplementation on growth of broilers	India	Incorporating silkworm pupae meal and an enzyme supplement improved growth	(Konwar *et al.*, 2008)

		performance and reduced feed intake.	
Effect of SWPM inclusion in broiler using *Eri Silkworm*	Thailand	Adding 10% eri pupae resulted in CP content similar to Soyabean meal with higher final weight, lower FCR(Feed Conversion Ratio) and higher CCW(Cold carcass weight)	(Kongsup *et al.*, 2022)
Replacing Fishmeal with SWPM In broiler chicken feed	India	25% and 50% Replacement helped improve broiler growth	(Banday; Bhat; Shenaz; ... 2009)

CONCLUSION

Silkworm pupae meal (SWPM) presents a promising and sustainable alternative to traditional poultry feed ingredients such as soybean meal and fish meal. Its high protein and fat content make it a nutritious option for poultry, while its production aligns with a circular economy approach.The incorporation of SWPM into poultry diets offers several advantages, including improved palatability, potential enhancement of market preference for chicken meat, and reduced environmental impact. By utilizing a waste product from silk production, SWPM contributes to more efficient resource use and reduces feed-food competition.

FUTURE PORSPECTS

To fully realize the potential of SWPM as a poultry feed ingredient, further research is needed. Key areas of focus include:

- **Processing optimization:** Refining processing methods to enhance digestibility, palatability, and shelf life of SWPM.
- **Performance evaluation:** Conducting comprehensive studies to assess the impact of SWPM on animal performance, gut health, and meat quality across various poultry species and rearing conditions.
- **Regulatory considerations:** Addressing any regulatory hurdles and developing guidelines for the safe and effective use of SWPM in poultry feed.

- **Consumer acceptance:** Understanding consumer perceptions and preferences regarding insect-based feed ingredients and addressing any potential concerns.

By addressing these areas, researchers and industry stakeholders can contribute to the wider adoption of SWPM as a sustainable and economically viable option for poultry nutrition.

Disclaimer (Artificial intelligence)

Option 1:

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.

Option 2:

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc have been used during writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology

Details of the AI usage are given below:

1.

2.

3.

REFERENCES

Agunbiade, J., Olajide Adeyemi, O. Ashiru, H. Awojobi, A. A. Taiwo, D. B. Oke, and A. A. Adekunmisi. 2006. "Replacement of fishmeal with maggot meal in cassava-meal based layer diet." *Japanese J. Poult. Sci* 44:278-282.

Altomare, Alessandra Anna, Giovanna Baron, Giancarlo Aldini, Marina Carini, and Alfonsina D'Amato. 2020. "Silkworm pupae as source of high-value edible proteins and of bioactive peptides." *Food Science & Nutrition* 8 (6):2652-2661.

Banday, Mohd Tufail, Gulam Ahamad Bhat, Sayed Shenaz, and Mukesh Bhakat. 2009. "Influence of feeding processed silkworm pupae meal on the performance of broiler chicken." *Indian Journal of Animal Nutrition* 26 (3):292-295.

Banday, MT, GA Bhat, S Shenaz, and ... 2009. "Influence of feeding processed silkworm pupae meal on the performance of broiler chicken." *Indian Journal of Animal ...*.

Battampara, P, TN Sathish, R Reddy, V Guna, and ... 2020. "Properties of chitin and chitosan extracted from silkworm pupae and egg shells." *International Journal of ...*.

Breewood, H, and T Garnett. 2020. "What is feed-food competition." *Foodsource: building blocks). Food Climate Research Network, University of Oxford*.

Chapman, Reginald Frederick. 1998. *The insects: structure and function*: Cambridge university press.

Chatterjee, RN, and U Rajkumar. 2015. "An overview of poultry production in India." *Indian Journal of Animal Health* 54 (2):89-108.

Dalle Zotte, A, Y Singh, A Squartini, P Stevanato, S Cappellozza, A Kovitvadhi, S Subaneg, Davide Bertelli, and M Cullere. 2021. "Effect of a dietary inclusion of full-fat or defatted silkworm pupa meal on the nutrient digestibility and faecal microbiome of fattening quails." *Animal* 15 (2):100112.

Deori, M, D Devi, and R Devi. 2014. *Nutrient composition and antioxidant activities of muga and eri silkworm pupae*, *Int. J. Sci. Nat*.

Dutta, A, S Dutta, and S Kumari. 2012. "Growth of poultry chicks fed on formulated feed containing silk worm pupae meal as protein supplement and commercial diet." *Online J. Anim. Feed Res* 2 (3):303-307.

Finke, Mark D. 2002. "Complete nutrient composition of commercially raised invertebrates used as food for insectivores." *Zoo biology: published in affiliation with the American zoo and aquarium association* 21 (3):269-285.

Gous, R. M., A. S. Faulkner, and H. K. Swatson. 2018. "The effect of dietary energy:protein ratio, protein quality and food allocation on the efficiency of utilisation of protein by broiler chickens." *British poultry science* 59 (1):100-109. doi: 10.1080/00071668.2017.1390211.

He, Wenliang, Peng Li, and Guoyao Wu. 2021. "Amino acid nutrition and metabolism in chickens." *Amino Acids in Nutrition and Health: Amino Acids in the Nutrition of Companion, Zoo and Farm Animals*:109-131.

Hu, Bin, Cheng Li, Zhiqing Zhang, Qing Zhao, Yadong Zhu, Zhao Su, and Yizi Chen. 2017. "Microwave-assisted extraction of silkworm pupal oil and evaluation of its fatty acid composition, physicochemical properties and antioxidant activities." *Food Chemistry* 231:348-355.

Jintasataporn, Oratai. 2012. "Production performance of broiler chickens fed with silkworm pupa (Bombyx mori)." *Journal of Agricultural Science and Technology. A* 2 (4A):505.

Jongema, Y. 2015. "World list of edible insects." *Wageningen University* 75.

Józefiak, Damian, and Ricarda Margarete Engberg. 2015. "Insects as poultry feed." 20th European Symposium on poultry nutrition.

Karthick Raja, P, S Aanand, J Stephen Sampathkumar, and P Padmavathy. 2019. "Silkworm pupae meal as alternative source of protein in fish feed." *Journal of Entomology and Zoology Studies* 7 (4):78-85.

Khatun, R, SA Azmal, MSK Sarker, MA Rashid, MA Hussain, and MY Miah. 2005. "Effect of silkworm pupae on the growth and egg production performance of Rhode Island Red (RIR) pure line." *Int. J. Poult. Sci* 4 (9):718-720.

Khatun, R, MAR Howlider, MM Rahman, M Hasanuzzaman, and MZ Rahman. 2003. "Replacement of fish meal by silkworm pupae in broiler diets." *Pakistan Journal of Biological Sciences* 6 (11):955-958.

Kongsup, Penpicha, Somporn Lertjirakul, Banthari Chotimanothum, Pipatpong Chundang, and Attawit Kovitvadhi. 2022. "Effects of eri silkworm (Samia ricini) pupae inclusion in broiler diets on growth performances, health, carcass characteristics and meat quality." *Animal bioscience* 35 (5):711.

Konwar, P, BK Konwar, HF Ahmed, NC Nath, and MK Ghosh. 2008. "Effect of feeding silkworm pupae meal with enzyme supplementation on growth performance of broilers."

Krishnan, R, L Sherin, M Muthuswami, R Balagopal, and C Jayanthi. 2011. "Seri waste as feed substitute for broiler production." *Sericologia* 51 (3):369-383.

KWON, MG, DS KIM, JH LEE, SW PARK, and ... 2012. "Isolation and analysis of natural compounds from silkworm pupae and effect of its extracts on alcohol detoxification." *Entomological ...*. doi: 10.1111/j.1748-5967.2011.00439.x.

Lalev, M, P Hristakieva, N Mincheva, and ... 2022. *Insect meal as alternative protein ingredient in broiler feed*, *Bulgarian Journal of ...*: researchgate.net.

Longvah, T, K Mangthya, and PJFC Ramulu. 2011. "Nutrient composition and protein quality evaluation of eri silkworm (Samia ricinii) prepupae and pupae." *Food Chemistry* 128 (2):400-403.

Longvah, Thingnganing, Korra Manghtya, and Syed SYH Qadri. 2012. "Eri silkworm: A source of edible oil with a high content of α-linolenic acid and of significant nutritional value." *Journal of the Science of Food and Agriculture* 92 (9):1988-1993.

Makkar, Harinder PS, Gilles Tran, Valérie Heuzé, and Philippe Ankers. 2014. "State-of-the-art on use of insects as animal feed." *Animal Feed Science and Technology* 197:1-33.

Maurer, V, M Holinger, Z Amsler, and ... 2016. "Replacement of soybean cake by Hermetia illucens meal in diets for layers." *Journal of Insects ….* doi: 10.3920/jiff2015.0071.

Miah, Mohammad Yousuf, Yazavinder Singh, Marco Cullere, Sandro Tenti, and Antonella Dalle Zotte. 2020. "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* 19 (1):447-456.

Mishra, N, NC Hazarika, K Narain, and J Mahanta. 2003. "Nutritive value of non-mulberry and mulberry silkworm pupae and consumption pattern in Assam, India." *Nutrition Research* 23 (10):1303-1311.

Mohamad, L, F Dina, HA Hasan, and ... 2020. "Effect of feeding strategy on the protein and fatty acid contents of black soldier fly prepupae (Hermetia illucens) for the potential applications as animal feed and …." *IOP Conference ….* doi: 10.1088/1757-899x/716/1/012006.

Nixey, Cliff. 2010. Nutrition and feeding of organic poultry by robert blair. Taylor & Francis.

Oluokun, JA. 2000. "Upgrading the nutritive value of full-fat soyabeans meal for broiler production with either fishmeal or black soldier fly larvae meal (Hermetia illucens)." *Nigerian Journal of Animal Science*.

on Nutrition, EFSA Panel, Novel Foods, Food Allergens NDA, Dominique Turck, Torsten Bohn, Jacqueline Castenmiller, Stefaan De Henauw, Karen Ildico Hirsch-Ernst, Alexandre Maciuk, and Inge Mangelsdorf. 2021. "Safety of frozen and dried formulations from whole yellow mealworm (Tenebrio molitor larva) as a novel food pursuant to Regulation (EU) 2015/2283." *EFSA Journal* 19 (8).

Panda, AK, and Pinaki Samal. 2016. "Poultry production in India: opportunities and challenges ahead." *EMPOWERING FARMWOMEN THROUGH LIVESTOCK AND POULTRY INTERVENTION*:50.

Panda, B, and SC Mohapatra. 1993. "Poultry development strategies in India." *World's Poultry Science Journal* 49 (3):265-273.

Ramos-Elorduy, Julieta. 2006. "Threatened edible insects in Hidalgo, Mexico and some measures to preserve them." *Journal of Ethnobiology and Ethnomedicine* 2:1-10.

Ramos-Elorduy, Julieta, Ernesto Avila González, Alma Rocha Hernández, and José Manuel Pino. 2002. "Use of Tenebrio molitor (Coleoptera: Tenebrionidae) to recycle organic wastes and as feed for broiler chickens." *Journal of Economic Entomology* 95 (1):214-220.

Rao, P Udayasekhara. 1994. "Chemical composition and nutritional evaluation of spent silk worm pupae." *Journal of Agricultural and Food Chemistry* 42 (10):2201-2203.

Rao, R Srinivasa. 2015. "Trends and challenges of poultry industry." *International Journal of Engineering Technologies and Management Research* 1 (1):8-13.

Rashmi, KM, M Chandrasekharaiah, NM Soren, KS Prasad, CG David, Y Thirupathaiah, and V Shivaprasad. 2023. "Silkworm pupae meal: An alternative protein source for livestock."

Reddy, Harish, NM Kenchappa, and N Amarnatha. 2024. "A Review on Feasibility of Silkworm Pupal Meal in Livestock and Poultry." *UTTAR PRADESH JOURNAL OF ZOOLOGY* 45 (13):282-293.

Sadat, A, T Biswas, MH Cardoso, R Mondal, and ... 2022. "Silkworm pupae as a future food with nutritional and medicinal benefits." *Current Opinion in Food ….*

Sadat, Abdul, Trishanjan Biswas, Marlon H Cardoso, Rittick Mondal, Ashmita Ghosh, Paulami Dam, Jannatun Nesa, Joydeep Chakraborty, Debjoy Bhattacharjya, and Octávio L Franco. 2022.

"Silkworm pupae as a future food with nutritional and medicinal benefits." *Current Opinion in Food Science* 44:100818.
Sindhura, KA, SB Sawant, and AR Mohapatra. "Markers in Entomology."
Slimen, Imen Belhadj, Houari Yerou, Manel Ben Larbi, Naceur M'Hamdi, and Taha Najar. 2023. "Insects as an alternative protein source for poultry nutrition: a review." *Frontiers in Veterinary Science* 10.
Tomotake, Hiroyuki, Mitsuaki Katagiri, and Masayuki Yamato. 2010. "Silkworm pupae (Bombyx mori) are new sources of high quality protein and lipid." *Journal of nutritional science and vitaminology* 56 (6):446-448.
Ullah, R, S Khan, NA Khan, M Mobashar, A Sultan, N Ahmad, and J Lohakare. 2017. "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* 5 (7):200-207.
Ullah, Rafi, Sarzamin Khan, Abdul Hafeez, Asad Sultan, Nazir Ahmad Khan, Naila Chand, and Ahmad Naseer. 2017. "Silkworm (Bombyx mori) meal as alternate protein ingredient in broiler finisher ration." *Pakistan Journal of Zoology* 49 (4).
Van Zanten, HH, DGAB Oonincx, Herman Mollenhorst, Paul Bikker, Bastiaan G Meerburg, and IJ de Boer. 2014. "Can the environmental impact of livestock feed be reduced by using waste-fed housefly larvae." Proceedings of the 9th International Conference LCA of Food, San Francisco, CA, USA.
Venkatesh Kumar, R, Devika Srivastava, Umesh Kumar, Mukesh Kumar, and Prashant Singh. 2020. "Bioprospecting of omega 3 fatty acid from silkworm pupal oil: From molecular mechanism to biological activities." *Journal of Biologically Active Products from Nature* 10 (6):495-506.
Vetrivel, SC, and S Chandrakumarmangalam. 2013. "The role of poultry industry in Indian economy." *Brazilian Journal of Poultry Science* 15:287-293.
Wang, Jun, F Wu, Yao Liang, and Meng Wang. 2010. "Process optimization for the enrichment of α-linolenic acid from silkworm pupal oil using response surface methodology." *African Journal of Biotechnology* 9 (20).
Wang, Weifei, Long Xu, Yuxiao Zou, Daorui Pang, Wei Shi, Lixia Mu, Erna Li, Dongming Lan, Yonghua Wang, and Sentai Liao. 2020. "Comprehensive identification of principal lipid classes and tocochromanols in silkworm (Antheraea pernyi and Bombyx mori) pupae oils." *European Journal of Lipid Science and Technology* 122 (2):1900280.
Wei, Zhao-Jun, Ai-Mei Liao, Hai-Xiang Zhang, Jian Liu, and Shao-Tong Jiang. 2009. "Optimization of supercritical carbon dioxide extraction of silkworm pupal oil applying the response surface methodology." *Bioresource Technology* 100 (18):4214-4219.
Zhou, Jun, and Dingxian Han. 2006. "Proximate, amino acid and mineral composition of pupae of the silkworm Antheraea pernyi in China." *Journal of Food Composition and Analysis* 19 (8):850-853.
Zhou, Xiaoyun, Mingyun Li, Khalid Abbas, and Weimin Wang. 2009. "Comparison of haematology and serum biochemistry of cultured and wild Dojo loach Misgurnus anguillicaudatus." *Fish Physiology and Biochemistry* 35:435-441.
Zsedely, Eszter, Marco Cullere, Georgina Takacs, Zsolt Herman, Klaudia Szalai, Yazavinder Singh, and Antonella Dalle Zotte. 2022. "Dietary Inclusion of Defatted Silkworm (Bombyx mori L.) Pupa Meal for Broiler Chickens at Different Ages: Growth Performance, Carcass and Meat Quality Traits." *Animals* 13 (1):119.