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Behind the Silk: The Untold Story of Silkworm Pupae

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Insects known as silkworm pupae are good for human health because of their high nutritional content and more significantly the range of pharmacological actions they can have when ingested. The pharmacological uses of silkworm pupae are currently of great interest. Domestic silkworm pupae's biological roles have been gradually discovered and validated in recent years, particularly their positive impact on human health. According to studies, silkworm pupae have beneficial effects on blood pressure reduction, blood glucose and lipid regulation, liver protection, immunological boosting, antiapoptosis, antitumor, and antibacterial properties. Pupae from spent silkworms are a waste product that is frequently dumped outdoors or used into fertilizer. It can be extracted to produce valuable oil that is utilized in industrial products including paints, varnishes, soaps, candles, plastic, medicines, and biofuels. The long-chain polymer of N-acetylglucosamine, chitin, the primary building block of the exoskeleton, is occasionally made from the extracted meal. In Asian nations that produce silk, people have long consumed silkworm pupae, which are regarded as a delicacy in parts of China, Japan, Thailand, and other countries. Silkworm pupae meal's high protein content has made it appropriate for use as animal feed, particularly for monogastric animals (fish, pigs, and poultry), but also for ruminants.

Introduction

About 18,500 metric tons of raw silk are produced each year in India, the second-largest producer in the world (Mishra *et al.*, 2003). The cultivated mulberry silkworm, *Bombyx mori*, is the primary source of silk, making up around 90% of the world's production. The Eri silkworm (*Philosamia ricini*), the Assam silkworm (*Antheraea assamensis*), and tussar moths like *Antheraea mylitta* and *Antheraea paphia* are other noteworthy silk-producing moths. Cocoons are harvested during the pupa stage in order to produce silk. The pupa must be killed before it releases enzymes that break the cocoon in order to produce continuous silk strands. As a result, a significant amount of spent silkworm pupae (SWP) is produced. For a silk outfit, up to 2,000 cocoons are needed (Mishra *et al.*, 2003). Approximately 8 kg of wet pupae or 2 kg of dry pupae are thrown away for every 1 kg of raw silk produced. Approximately 60–70% of the approximately 1.2–1.5 lakh metric tons of fresh pupae produced annually in India are deemed trash if they are not used efficiently. In regions where silk is produced, this means that more than 65% of fresh pupae end up as garbage, raising significant disposal and environmental issues. Because they are nutrient-rich and highly biodegradable, spent pupae are not just waste but also a potential resource. They are composed of excellent oils that are high in unsaturated fatty acids, bioactive substances including α -linolenic acid and chitin, and roughly 55–60% protein (Dewi *et al.*, 2020). In rural sericulture zones, this enormous volume can lead to health risks and environmental degradation if it is not handled or recycled. Several approaches to waste utilization and value addition have been investigated to help alleviate this issue. Turning wasted pupae into animal feed is one of the most promising (Mishra *et al.*, 2003). By doing this, dependency on

pricey protein sources like fishmeal and soybean meal may be lessened. Furthermore, it is possible to extract and use silkworm pupae oil, which is high in omega-3 fatty acids, in pharmaceuticals, cosmetics, and food supplements. Additionally, chitin and its derivative chitosan, which are used in water purification, biodegradable packaging, medicine, and agriculture, can be obtained industrially from pupal shells. In some parts of Asia, silkworm pupae are even eaten by humans because of their high nutritional content. This important by-product can be turned into a significant financial asset by promoting the establishment of small-scale pupae processing facilities and increasing public knowledge of their possible uses. Making good use of the 60–70% waste produced by fresh pupae can improve circular economy principles, promote sustainable rural development in India, and lessen the environmental effect of the silk business. This article aims to highlight the often-overlooked potential of silkworm pupae discarded after silk extraction. By repurposing them for livestock and poultry feed, edible oil extraction, BT media, and pharmacological applications such as antioxidant and anticancer agents, we can enhance sustainability and economic value in multiple sectors.

Uses of Silkworm Pupa

1. Extraction of oil from silkworm pupae and their use

Edible oils are getting increasingly expensive on the global market due to the recent surge in demand. For the first time Ferdousi and his co-workers during 2023 used a simple acid fermentation procedure to create edible oil from desilked silkworm pupae (*Bombyx mori*) at a reasonable price (Figure 1.). Palmitic acid and oleic acid were among the several fatty acids that were present in the oil, which had low peroxide and acid values of 4.82 meq/kg and 1.35 mg KOH/g oil, respectively. Furthermore, the extracted oil contained the health-promoting acids linoleic, α -linolenic, and dihomo-gamma-linolenic (Ferdousi *et al.*, 2023). The extracted oil had a good nutritional value since it was rich in minerals including iron, sodium, potassium, calcium, magnesium, zinc, and phosphorus and had very little of the hazardous elements manganese, cobalt, nickel, copper, lead, cadmium, chromium, arsenic, and silver (Susirirut *et al.*, 2023). Furthermore, it has a high concentration of healthy lipids, with omega-3 accounting for 35–40% of its total fatty acids (FAs) as mentioned in Table-1 and Table-2.

Table 1: Extraction Process and Basic Oil Properties

SL.No	Parameter	Value/Details
1	Acids Used in Extraction	Acetic acid (3%), Citric acid (3%)
2	Extraction Yield	3.52 $\pm$ 0.23% from fresh silkworm pupae
3	Moisture Content of Extracted Oil	0.06% (lower than standard edible oil limit of 0.2%)
4	Peroxide Value	4.82 meq/kg
5	Acid Value	1.35 mg KOH/g oil
6	Protein Content (Dry Basis)	45–80%

Table 2: Composition of Fatty Acid and Nutritional in oil of silkworm pupa

SL. No	Component	Details
1	Major Fatty Acids	Myristic (C14:0), Palmitic (C16:0), Stearic (C18:0), Oleic (C18:1), Linoleic (C18:2), α -Linolenic (C18:3)
2	Omega-3 Content	35–40% of total fatty acids
3	Unsaturated Fatty Acid Content	60–70% (mainly oleic and α -linolenic acids)
4	Minerals Present	Iron, Sodium, Potassium, Calcium, Magnesium, Zinc, Phosphorus
5	Low Toxic Elements Detected	Manganese, Cobalt, Nickel, Copper, Lead, Cadmium, Chromium, Arsenic, Silver
6	Comparison with Vegetable Oils	Nutritionally comparable to sunflower oil

2. Silkworm Pupa Extract's Impact on Vasodilation Activation

Hypertension is a notable health challenge worldwide with the angiotensin-I converting enzyme (ACE) playing a central role in its development and progression. The silkworm (*Bombyx mori*) stands out due to its production of bioactive peptides that exhibit potent ACE inhibitory properties, making it a promising candidate for functional food development & evaluation of the safety & antihypertensive potential of crude mature silkworm hydrolysate powder (MSHP) derived from Thai silkworms (Anuduang et al., 2024). MSHP derived from Thai mature silkworms is a sustainable, safe and effective alternative to conventional synthetic drugs, coping with the growing demand for natural health products worldwide.

3. Silkworm pupae for mass production of *Bacillus thuringiensis*

The mass production of *Bacillus thuringiensis* (Bt), a crucial microbial pesticide, can be effectively achieved using silkworm pupae, a readily available and nutrient-rich waste product from the sericulture industry. The pupae powder is used to prepare a nutrient medium by combining it with carbohydrate sources such as glucose or jaggery and mineral salts like magnesium sulfate and potassium phosphate. The medium is sterilized and inoculated with a pure culture of *Bacillus thuringiensis* and the fermentation is carried out at 28–32°C for 48–72 hours (Li et al., 2021) with constant aeration to facilitate bacterial growth and the production of insecticidal Cry proteins.

4. Use of Silkworm pupa in cosmetics industry

The cosmetics industry makes extensive use of substances obtained from silkworms. Because of their advantageous qualities, proteins taken from chitin and pupal skin are frequently used in cosmetic goods (Mishra et al., 2003). New hybrid films made of silk are used to heal wounds and scars because of their absorbency and durability. Additionally, the silk biopolymer is used in the manufacturing of contact lenses and in medical applications including tissue regeneration, namely for wound dressings and burn therapy. Because of its anti-aging, relaxing, moisturising, and UV-blocking qualities, sericin, another silk protein, is ideal for hair care products, moisturisers, and sun protection. Additionally, silkworm pupae oil is used to make lotions, face powders, body deodorants, and hair oils.

5. Use of Silkworm pupa in Chemical industries

A by-product of the silk industry, silkworm pupae are used extensively in the food and chemical processing industries because of their high fat and oil content. The oil that is produced from silkworm pupae is abundant in unsaturated fatty acids and is widely used in the oleochemical sector, especially in the manufacturing of cosmetics, glycerin, and soaps. N-triacontanol is another useful substance that is isolated commercially for use in agriculture from silkworm pupae. It is a natural plant growth stimulator. Pupal skin and excreta, which are frequently thrown away as trash in drainage and reeling units, can be recycled to make organic fertilizers, supporting environmentally friendly farming methods. A nutrient-dense addition to animal feed for pigs, ruminants, and poultry, silkworm pupae are a significant source of protein.

6. Pharmacological Functions and Mechanisms of Silkworm Pupae

6.1 Anti-cancer effect

Cancer now-a-days is often treated with radiotherapy and chemotherapy, which can cause various deadly side effects. However, it is found that, proteins and amino acids from

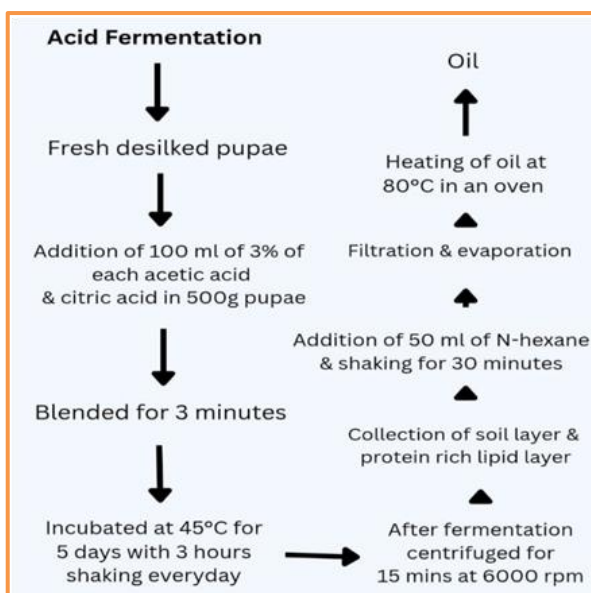


Fig.1: SWP oil extraction process

silkworm pupae can fight cancer by killing human stomach, breast, and liver cancer cells (Hu et al., 2005). Both silkworm pupa protein and oil have anticancer effects. The proteins work by disrupting the cancer cell division cycle and triggering factors that cause cancer cells to self-destruct (apoptosis).

6.2 Antioxidant activity

The natural compounds found in silk worm pupa are good at neutralizing harmful molecules and radicals and reducing reactive oxygen species (ROS) inside cells. The antioxidant power also varies by the pupae's sex and age, with female pupae in early pupation showing stronger effects. The unsaturated fatty acids, peptides, and phenolic compounds present in silkworm pupae could be used to make antioxidant-rich foods or medicines. Natural antioxidants are important for preventing diseases because they work well with the body and are safe.

6.3 Anti bacterial effects

Research on silkworm pupae's antibacterial properties has only lately advanced, despite the fact that they have long been used in medicine. First, the oil from silkworm pupae was discovered to have antimicrobial properties. Chitin and chitosan, which are abundant in silkworm pupae shells and have useful antibacterial qualities, have been applied in a variety of biomedical applications. The silkworm pupae's chitosan exhibited superior antibacterial and antifungal properties compared to commercially available chitosan, with the fastest bacterial suppression occurring within 1-2 h.

6.4 Anti Alzheimer effects

Silkworm pupae have been demonstrated in vivo in animal models of Alzheimer's disease to improve cognitive performance in Wistar rats by boosting cholinergic activity and exhibiting neuroprotective benefits by lowering oxidative stress. Pupae of silkworms may offer a treatment approach for Alzheimer's disease in humans as well as a potential functional diet for Alzheimer's disease prevention. Once more, this illustrates the potential benefit of employing silkworm pupae in vaccine production and serves as a guide for creating new vaccines with silkworm pupae.

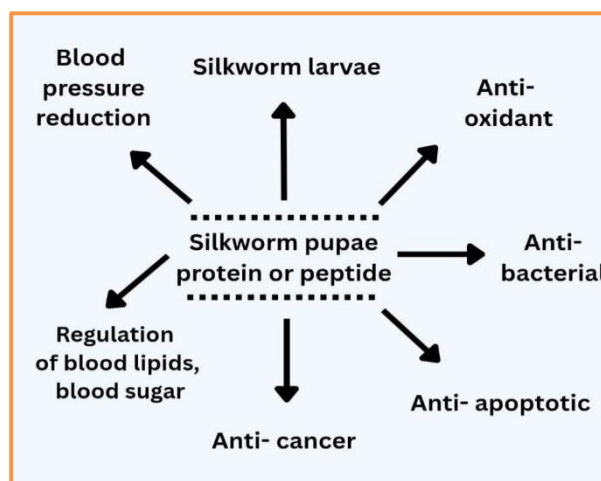


Fig.2: Pharmacological effects of SWP

Conclusion

The pupae of silkworms, which are frequently seen as a waste product of the silk business, have enormous unrealized potential in a variety of industries, including food, medicine, cosmetics, and agriculture industry. These pupae are often thrown away following the silk extraction procedure, however incorrect disposal of them raises environmental issues. For ruminants, poultry and fish, silkworm pupae are a good feed substitute due to their nutritional profile, especially their high protein and fat content. In animal feed formulations, defatted silkworm meal has demonstrated encouraging results, improving growth and feed conversion efficiency and even taking the place of traditional protein sources like fish meal. In aquaculture, pupae meal is a sustainable and efficient substitute that doesn't degrade the quality of the fish. *Bacillus thuringiensis*, a microbial pesticide in sustainable agriculture, is mass-produced using silkworm pupae as a nutrient-rich substrate, providing the twin advantages of waste reduction and pest control. These diverse applications not only add economic value but also support waste minimization and environmental sustainability.

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