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A Review on Medicinal Value of Silkworm Product and By-Products

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Sericulture is an agro based industry that includes production of raw silk by breeding, rearing of silkworm and cultivation of their host plants. The manufacture of various types of silk was the only emphasis of the traditional sericulture industry, and leftovers were typically disposed away as trash. Byproducts and products from sericulture can be used medicinally in addition to generating silk. The silkworm is a valuable tool in laboratory research and has been utilised as a model organism in life sciences, environmental monitoring, antimicrobial drug screening, and other applications. Protein extract from silkworm eggs is used to improve memory and assist control weight. The silkworm's larvae are also beneficial medicinally; they include blood glucose-lowering agents and silkworm gut fibre, among other things. Similarly, silkworm pupae, a significant by-product of the silk reeling business, have great nutritional content and potential medical applications including hepatoprotection, anticancer, and anti-aging. They can be utilised as an alternative to conventional dietary supplements. As a result, functional sericulture under a new paradigm has replaced sericulture to produce solely silk fabric, greatly increasing farmer revenue while also relieving patient suffering.

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1. INTRODUCTION

Sericulture agro industry is worth for generating foreign currency and uplifting socioeconomic status of farmers in India [1]. Sericulture mainly involves the silkworms are reared mainly for the production of the different kind of silk from different type of silkworms. There are four commercially exploited silkworms namely: Mulberry (*Bombyx mori*), Muga *(Antheraea assamensis*), Eri (*Samia ricini*) and Tasar (*Antheraea Mylitta* and *Antheraea proylei*). A Chinese oak silk moth (*Antheraea pernyi*) is another temperate silk moth, which is commercially exploited and their silk is produced in large numbers after mulberry silk.

The silkworm is a lepidopteran insect that belongs to the family Bombycidae and Saturniidae. Silkworm is holometabolic insect that undergoes four developmental stages i.e. egg, larva, pupa and adult; where pupa and adult are non-feeding stage. The life cycle duration of a silkworm is about 45 to 80 days approximately and female moth lays about 150 to 500 eggs approximately. The egg hatches in 7-21 days after oviposition. The larval period is the longest among the four stages of silkworm and also silkworm larva rearing is the main base for the production of good quality of silk. The pupa is non active stage, which is covered with a protective layer called cocoon. The moth emerges within 7-12 days after spinning [2-4].

In traditional sericulture, the primary goal of production is to produce silk. The term "by-product" refers to a product that is produced incidentally to the production of another product [5,6]. During the rearing of silkworms, numerous by-products are produced, such as cocoons, pupas, excreta, silk waste, etc. Despite the worldwide increase in byproduct value aimed at surpassing the cost-benefit ratio, India has lagged behind other countries in the sericulture sector [7-10]. By-products, which are typically seen as trash, can be more effectively utilised to create valuable products, propelling the sector to a more lucrative and sustainable position. To put sericulture on solid ground, these waste products must be used effectively for value addition. These raw materials have been used to create new commercial products that have the potential to be valuable for a variety of uses, including zootechnic (fodder for pigs, sheep, rabbits, and goats), food (oil, juice, marmalade, wine, fruit distillate, vinegar, dried fruit powder, natural coloring), cosmetic (skin and hair products), and ecological (landscape, phytoremediation).

1.1 Composition of Product and by-Product of Silkworm

In recent times, silkworm silk has garnered significant interest owing to its exceptional mechanical characteristics, biocompatibility, and potential uses in the biomedical field. The silk protein is synthesized by silk gland cells which is stored in the lumen of the silk glands. The major protein component of this silk is fibroin and sericin [11]. Sericin is insoluble in cold water, but it can be easily hydrolyzed or dissolved in hot water. According to Rui's analysis of the silk fibre's composition in Bombyx mori, the outer layer has a higher sericin content whereas the inner layer has a higher fibroin concentration [12] (Table 1). Sericin and fibroin has bio medicinal properties which are now being used in cosmetic industries (Fig. 1).

Table 1. Composition of silk in Bombyx mori (Gulrajani, 1988)

Component	Percentage (%)
Fibroin	70-80
Sericin	20-30
Wax matter	0.4-0.8
Carbohydrates	1.2-1.6
Inorganic matter	0.7
Pigment	0.2
Total	100

On other hand, Pupae of silkworms are useful to human health because, apart from their high nutritional content, they can serve a number of therapeutic purposes when eaten. Silkworm pupae have a high nutrient content. Pupae of silkworms are nutrient-rich. The most prevalent materials are sugar, fat, and protein, together with a variety of additional nutrients such vitamins, minerals, and polyphenolic chemicals. With the exception of Eri silkworm pupae, all species of silkworm pupae have almost the same amino acid content, with 18 amino acids making up the proteins has been compared with the egg of hen (Table 2) [13].

2. MEDICINAL VALUE OF SILKWORM EGG

Silkworm eggs are the base of sericulture. After hatching, silkworm egg shells are mostly discarded. Silkworm egg shells is also known for major source of chitin with as high as 74% in chicken eggs. Silkworm eggs are found to contain chorionins and cysteine proteinase [14]. The eggs are also widely employed in transgenic experiments [15].

Chitin is one of the most widely used polymers next only to cellulose. Rather than chitin, its deacetylated form chitosan is more widely used for commercial applications. Silkworm egg shell chitosan has antibacterial and anti-fungal activity similar or better than commercially available chitosan. With large availability and limited applications, egg shells can be used as renewable and sustainable sources for chitosan [16]. The protein extract of egg shell is sold as the Humanofort B product in Romania (Fig. 3). Albumin, lipids, carbohydrates, glycoproteins, vitamins B1 and B2, and other substances are present in the eggs. The eggs are turned into a protein extract, which is then utilised in the food and pharmaceutical industries to make medications with hepatoprotein-stimulating, hypolipidic, and hypoglycemic effects as well as for male sexual stimulation [17]. There is a belief in Bulgaria that if silkworm eggs eaten by alcohol drinkers, give up drinking completely because, they start feeling disgust. But the fact has not been proved scientifically.

3. MEDICINAL VALUE OF SILKWORM LARVA

Numerous chemical components have been identified from the larvae, including b-N-acetylglucosaminidase, DOPA, quinone amine conversion factor, adipokinetic hormone (AKH), insulin-like growth factor-II (IGF II), and the sex pheromone bombykol {(10E, 12Z)-10,12-hexadecadien-1-ol} [18].

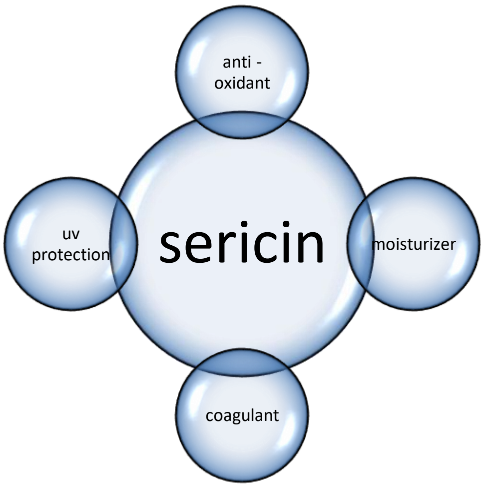

Fig. 1. Diagrammatic representation of attributes of sericin

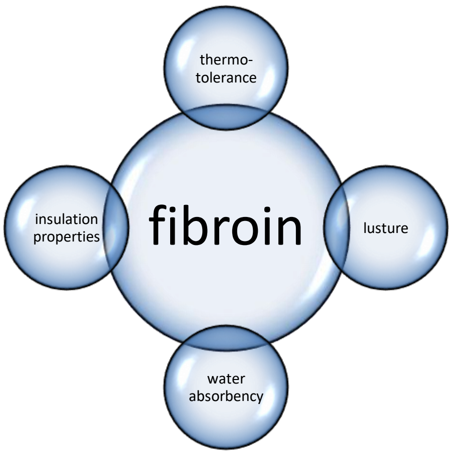

Fig. 2. Diagrammatic representation of attributes of fibroin

Table 2. Amino acid composition of different varieties of silkworm pupae proteins [13]

Amino acid (g/100g of protein)	*Bombyx mori* (mulberry)	*Samia ricini* (Eri)	*Antheraea pernyi* (oak silkworm)	Hen egg
Asp	9.1	9.89	6.41	8.92
Thr	3.9	4.75	4.64	4.47
Ser	3.7	5.25	4.64	6.72
Glu	9.5	12.9	12.74	12.13
Gly	3.6	4.94	4.42	3.02
Ala	3.9	6.05	6.26	5.03
Cys	1.4	0.53	1.5	1.90
Val	4.7	5.36	6.63	5.42
Met	3.4	2.31	1.47	2.81
Ile	3.4	4.42	7.95	4.88
Leu	6.2	6.63	3.24	8.11
Tyr	5.6	6.4	2.06	3.81
Phe	4.6	5.24	8.10	4.82
Lys	6.1	6.54	4.54	6.59
His	2.7	2.67	2.94	2.09
Arg	4.7	4.41	4.12	5.70
Pro	7.0	6.46	12.22	3.38
Trp	1.5	NA	4.05	1.72

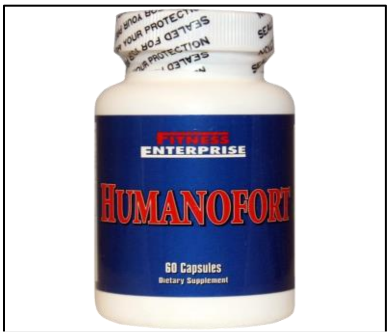

Fig. 3. Humanofort-B

Silkworm larvae are used to feed young animals and reptiles as a dietary supplement, as well as an etheric extract with high bombycisterol (a cholesterol isomer) content. Florence lily is also used as surgical thread. Silkworm larvae at various stages of evolution are employed as a complete protein extract in the pharmaceutical sector (anti-diabetic activity) and in the food industry as supplementary nutraceuticals. Silkworm has traditionally been used as a diabetic treatment in oriental nations such as China, Korea, and Japan, and several studies have lately demonstrated the silkworm's ability to decrease blood glucose levels. Silkworm larva goes into four moult and five instars, with the late instar being used more frequently in the pharmaceutical business. Numerous medical benefits of silkworm include anti-diabetic, anti-cancer and hepatoprotective effects in addition to its use in surgery. It is well known that the freeze-dried silkworm larvae powder has potent anti-diabetic properties. Studies have discovered that the nitrogen molecule 1-deoxynojirimycin, which was isolated from silkworm larvae as well as mulberry leaves, exerting blood glucose lowering effect [19]. Nitrogen compounds, including DNJ (1-deoxynojirimycin), were found to be ineffective in decreasing blood glucose levels. The silkworm has the highest concentration of DNJ per gram compared to mulberry leaves, mulberry fruit, and syncarp. This suggests that DNJ is deposited in the silkworm body. Additionally, fatty liver disease is treated with silkworm powder. An increase in liver serum triglycerides is what causes fatty liver disease. The mature silkworm powder greatly reduced the hepatic buildup of triglycerides caused by ethanol treatment [20]. Traditional Chinese medicine in China employs dried silkworm larvae infected with muscardine to treat a range of underlying conditions, including spasms and flatulence (Fig.4). Silkworm larvae that are sick are frequently tossed in India. *Beauveria bassiana* infection causes white spores to appear in the body of the silkworm, which are then dried and utilized as treatments. The intestine of silkworm larvae is used to produce a unique kind of thread that is utilized in surgery. The intestine of silkworms and their glands are used to prepare the surgical gut. The braided scaffolds revealed higher tensile strength and strain at break values in the case of *Samia cynthia ricini* and *Bombyx mori* materials with a potential application in tissue engineering [21].

4. MEDICINAL VALUE OF SILKWORM PUPA

A significant by-product of the silk reeling business, silkworm pupa has excellent medicinal and nutritional value and can be utilized as a substitute food supplement (Fig. 5). Chitin, a component of pupal skin, is commonly utilized in post-operative therapies such conchotomy, deviatory, and polypectomy due to its ease of administration, reduced hemophase, improved pain management, and faster wound healing. Chitin is an effective anti-microbial agent against Staphylococcus aureus, Klebsiella pneumoniae, Aspergillus niger, and Trichophyton equinum. It also acts as a buffer against acids and can be used as a food additive to reduce carcinogenicity. Chitin can be utilized as an immuno-adjuvant, bacteriostatic, fungistatic, and anti-sordes agent to prevent carcinogenic microorganisms from teeth, as well as a biocompatible barrier to control bleeding during major surgeries. Silkworm pupa are mostly used as animal feed and fertilizer in South East Asia and are also used as food insects. Asian nations either consume it directly as food or in the form of powder or oil. A silkworm pupa's nutritional makeup is composed of 50–60% proteins, 25–35% fats, 8–10% carbohydrates, a small amount of vitamins B1, B2, and E, as well as minerals including calcium, phosphorus, copper, and iron. Serrapeptidase, a protein from silkworms, is utilized in pharmaceuticals for its anti-inflammatory and anti-tumor properties. It is also used in dental surgery for fillings, cleanings, and tooth extraction. Artificial fibers and membranes made from pupal proteins have potential medical applications. It also contains n-3 omega fatty acids, with α-linolenic acid serving as a main component. As a result, silkworm pupae are regarded as a high-quality source of protein and a vital nutrient. The active components in silkworm pupa have a wide range of pharmacological purposes and have a strong therapeutic impact on various disorders. The potent pharmacological effects of silkworm pupae have been demonstrated in both in vivo and in vitro studies. Examples of these actions include anti-tumor, anti-oxidant, antibacterial, anti-apoptotic, hypotensive, lipid and blood sugar-regulating, immunomodulatory, and hepatoprotective [13].

Potential applications as natural antioxidants in functional meals to help prevent disease brought on by oxidative stress were demonstrated by significant ROS scavenging activity in silkworm pupae of *Bombyx mori, Antheraea mylitta,* and *Antheraea assamensis* functional components [22].

Animal studies have shown that utilising silkworm pupal oil can help prevent ethanol-induced stomach ulcers. The models were pretreated with silkworm pupal or chrysalis oil, then treated with ordinary diet, saline, medications, a high dose of pupal oil, and a low dose of pupal oil. As a result, bigger doses of pupal oil cause less stomach ulcers than smaller amounts [21].

Fig. 4. Dried silkworm larvae

Fig. 5. Some pupal processed health benefit products

Silk pupae can be used to cultivate useful mushrooms that fight cancer and enhance the immune system, while silk fibers have anti-bacterial properties and can be used in bioactive textiles [23].

5. MEDICINAL VALUE OF SILK MOTH

The silk moth likewise goes through a non-feeding stage before emerging from its cocoon to mate and deposit eggs for the following generation. Unused silk moth for seed production and the dead moths are typically thrown in a pit and allowed to decompose without any ulterior intent. In accordance with traditional Chinese medicine, silk moths that are discarded after emerging or mating are now used to make therapeutic wines. The Shaanxi Sericultural Technology Station's male silkworm moth wine is the most well-known. Impotence, irregular menstruation, and menopausal symptoms can all be treated with this drink. The silkworm moths are used to produce another form of special oil that is 75% fatty oils. Superior soaps and textile dyes can be made from the oil. Silkworm moth oil can be utilized to produce high-quality textile colors and soaps [24]. The extraction residue can be utilized to produce monosodium glutamate or as feed. The butterflies can also release cellular cytochrome C for medicinal application, uric acid or hormones, and sex messengers of the PTTH (hormone of the central nervous system) and DH type sexual hormone [25].

The leftovers from the extraction process can be fed to animals as hay. The moths are also capable of producing cellular cytochrome C, uric acid, and a few hormones, all of which are vital ingredients in the creation of pharmaceuticals.

6. MEDICINAL VALUE OF COCOON SILK

Late stage larvae spin a protective coating known as a cocoon in order to mature into non-motile pupae. Fibroin, sericin, and other impurities (pigments, waxes, sugars, and phytochemicals) account up the majority (75.38%), a small minority (17-25%), and a tiny minority (about 1-4%) of cocoon components, respectively. The cosmetics industry has also benefited from cocoons. The cocoon is divided into one portion and soaked in hot water before being massaged onto the face with the aid of fingers because sericin, which is considered to have moisture-retaining characteristics in it. Cocoon powder is used in a variety of cosmetic products, including face wash and masks. Cocoon powder is used as a wound dressing for third-degree burns [19]. Silk proteins are utilised in a range of cosmetic goods, including silk lotion, silk cream, silk night cream, silk hand cream, silk baby cream, and silk toothpaste, as research has shown that they may retain moisture and prevent UV radiation. Silk extracts are also used in health drinks [5]. In biomedical applications, silkworm silk fibers have been the predominant source of silk-like material, especially for sutures. Silk fibers have been used for decades and have shown to be useful in a variety of therapeutic applications. A silk fibroin-based wound dressing that might hasten healing and be peeled off without harming the newly formed skin was created by Tsubouchi [26]. The non-crystalline fibrin layer covering the wound had a thickness of 10-100 μM with a water content ranging from 3-16%. A combination of both fibroin and subsequently, the wound dressing

along with sericin [27]. In addition to being able to shape hair by making it soft and flexible, the silk protein sericin has the potential to be used as a skin moisturizer, anti-irritant, anti-wrinkle, and sun protector due to its saturation, revitalizing, and UV ray absorption qualities [28] By sulfonating sericin and fibroin, silk protein can be transformed into a biomaterial with anticoagulant qualities [29]. The first proof of the silk protein's antioxidant activity was shown by Kato et al. [30], who demonstrated that sericin inhibited lipid peroxidation in vitro. Moreover, it was discovered that sericin inhibits tyrosinase activity. These findings implied that sericin is a valuable natural food and cosmetic component.

Keratin and the biopolymer sericin are very affinistic. Many uses of fibroin in biomedicine have been investigated. Fibroin powder was treated in a way that preserved its inherent aesthetic appeal. This silk powder's ability to retain and release moisture in response to ambient temperature and humidity is one of its special qualities. Particularly suitable for use in pressed powders, blush, eye makeup, lipstick, and nail enamel is the incredibly fine powder (11.3 O sizes). In the field of medication delivery methods, sericin and fibroin have lately been investigated. Wu et al. [31] looked into the characteristics and use of silk fibroin-based wound protection membranes. Fibrin membranes are thought to have good wound-healing qualities.

According to Mattata et al. [32], fibroin hydrogels that are made by adding 30% glycerol or treating a 2% (w/v) silk fibroin aqueous solution at 4 °C can be utilized as scaffolds to encourage in situ bone repair. In vitro and in vivo studies are being conducted to determine the suitability of fibrin, a main silk protein, for use in controlled release type dose tablets. The anti-HIV-1 effect of sulphated silk fibroins in vitro appears to be attributed to their ability to obstruct virus particle adsorption onto CD4+ cells, since they totally prevented virus attachment to the cells at a concentration of 100 micro gm/ml [32].

7. MEDICINAL VALUE OF SILKWORM EXCRETA

Silkworm excreta or faeces are regarded as the primary waste product of silkworm production. Silkworm excreta are primarily used as compost due to the amount of nitrogen, phosphate, and potassium present; however, the litter can be used as raw materials in a biogas plant alongside cow manure to make fuel (Table 3). It is also used to feed livestock and fish. Bombyx mori excrement has long been employed in the pharmaceutical industry as a natural colourant. Large amounts of silkworm excreta are collected and used as a raw material to make a range of new products, with chlorophyll being particularly important because it is sought after in the pharmaceutical and food processing industries. Chlorophyll is extracted from forage grass and pine needles and used to colour soaps, food, waxes, and toothpaste. It is also used as a deodorant, healing agent, and pharmaceutical to stop bleeding from the teeth and gums caused by dental and gum diseases. Traditional Chinese medicine uses chlorophyll from silkworm dung to cure hepatitis and leukaemia. This drug is 95.6% effective for cancer patients who have lost white blood cells as a result of chemotherapy and radiotherapy [33-35].

Table 3. The silkworm excreta containing (Buhroo et. al; [23]

Content	Percentage
Water	7.35%
Crude protein	13.88%
Raw fats	1.44%
Raw cellulose	15.41%
Substances without nitrogen	47.15%

There is less information available about the bioactivity of pounds of silkworm excreta. The researchers recovered 1-tritriacontanol, a long-chain fatty alcohol, lupeol, a phytosterol, and β-sitosterol. Following polarity separation with numerous solvent mixtures, the compound was isolated from a crude acetone extract of silkworm excreta using vacuum liquid column chromatography. Silkworm excrement's anti-inflammatory qualities are due to lupeol and β-sitosterol, which are produced by mulberry leaves rather than silkworms. It is thus safe to investigate the safety of silkworm excreta for eating. Silkworm excreta have been utilised as food and dietary supplements. Vero cells, which represent a normal cell group, were used in the study to assess the cytotoxicity of the crude extract and 1-tritriacontanol on cancer cells as well as vero cells [36,37]. The extract was found to be safe for all cell types examined. Silkworm drops are now again used to produce healthy alcoholic beverages such as Sansha and tea powder (Fig. 5) [33].

Fig. 6. Cocoon as cosmetics

Fig. 7. Beverages from silkworm excreta

8. CONCLUSION

The ancient silk industry has traditionally focused solely on the manufacture of silk. Silk, a byproduct of sericulture, is greatly sought after both domestically and globally. Silkworm leftovers such as pupa, cocoons, and litter have been used as dietary supplements for both humans and animals. People's health beverages are produced with a proteic extract generated from vitamin and mineral-rich silkworm eggs. Although silkworms were first raised primarily for their silk, their larvae are now being examined as prospective laboratory animals for the development of numerous human medications, including anti-diabetic and anti-cancer ones. Silkworm pupae are the principal byproduct of the textile business once the silk is removed. These pupae contain more fatty acids than sunflower oil and amino acids than a chicken egg. These pupae are exceptionally valuable and nutrient-dense. Silkworm pupa are ingested medicinally in powder and oil form, as well as uncooked. Silk is used for surgical sutures and wound dressings. Silkworm excrements are used medicinally and as fertiliser in teas and alcoholic beverages, among other things. Silk moths are used in traditional Chinese remedies and wines, despite a dearth of research on the topic.

Functional sericulture, based on a new paradigm, has replaced silk-producing sericulture to better serve patients. In the future, sericulture's functional features will be refined and finally reborn into a true biotechnology-based sericulture, which will surely help the sector as a whole.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares 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.

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