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Potential use of sericultural by products: A review

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Abstract
Sericulture is an agro-based industry that mainly focuses at rearing of silkworms with the main objective of silk production. In addition to the silk, a chain of secondary products have also been produced, having excellent economic value. Sericulture by-products have remarkable application as in preparation of compost, in human medicine, handicrafts, cosmetics etc. Proper utilization of sericulture and silk waste adds a value of up to 40 per cent to the silk industry. Sericulture waste upon enrichment can be converted to high value manures. Mulberry, *Morus* sp. is sole food plant of silkworm *Bombyx mori* L. Apart from being used as a source of nutrition to silkworm, every part of mulberry plant have potential to be used in pharmaceutical and food industry. High protein content in silkworm pupae make it a nutritionally rich food for humans and livestock mainly poultry, pigs and fish. Cocoon craft is one of the very remarkable utility of by-products of sericulture which can provide scope to develop human skills by generating self-employment and revenue.

Keywords: By-products, compost, cosmetics, pharmaceuticals

1. Introduction
India has a rich and complex history in the silk production and its silk trade back to 15th century. Approximately 8.8 million people in rural and semi-urban areas in India are employed by the sericulture industry. Of these, a large number of workers belong to the economically weaker sections of society. The silk cocoon production is the most important source of income for sericulture farmers. The main product of sericulture is cocoon which act as raw material for textile industry. Besides the main product, chain of by products also produced at large scale. These by-products and wastes can be converted into new commercial products with a high useful value.

The by-products are produced during different activities of sericulture. Rearing of 100 disease free Layings of silkworm requires 1000 kg of mulberry leaves which results in production of approximately 300 kg of litter and 500 kg of leftover mulberry waste comprising of dried leaves, veins of leaves, leaf stalks etc. (Mala and Chandrashekhar, 2020) [17] that comprise of rich source of nutrients to mulberry fields. One kg of raw silk produces 8.014 kg wet and 2 kg of dry pupa that is of no further use in sericulture industry but can be use in food industry. The gummy protein *i.e.* sericin which is removed from cocoon during degumming is also a waste in textiles however can be use in cosmetics and medicinal industry. India produces approximately 1600 tons of silk every year, leaving behind approximately 250-300 tons of sericin (Rajput *et al*., 2015) [21]. Thus, sericulture by-products regarded as wastes can be put into better use in the production of value-based commodities.

2. Uses of by-products of sericulture
2.1 By products of silkworm rearing: By-products from silkworm rearing includes leftover mulberry leaves and silkworm excreta in the rearing bed which in combination with other farm waste can be use in vermicomposting whereas silkworm litter alone can be used in bio-gas production and pharmaceutical industry.

- **Rearing and other farm waste for vermicomposting:** From one hectare of mulberry farm, about 15 MT of sericultural waste is generated yearly in the form of silkworm rearing waste and other farm waste which is equivalent to 280-300 kg of nitrogen, 90-100 kg of phosphorus and 150-200 kg of potash (Das *et al*., 1997) [4]. Utilization of these wastes as raw material for vermicomposting serves as organic manure which can considerably decrease the expenditure on chemical fertilizers and helps in improvement of soil health and nutrient accessibility to mulberry plants leading to leaf quality enhancement.

- Venugopal *et al*. (2010) [31] revealed that final product of vermicompost produced out of sericultural farm residue using mixed culture of juvenile earthworms (*Eudrilus eugeniae*, *Eisenia foetida* and *Perionyx excavatus*) contains 1.8-2.0 per cent nitrogen, 0.6-0.9 per cent phosphorus and 1.0-1.5 per cent potash besides various micronutrients and microorganisms. This was found to be much superior to farm yard manure (Dandin *et al*. 2006) [3].
- **Silkworm excreta as substrate for bio-gas production:** Biogas is an essential form of energy in agricultural and rural areas, obtained from the processing of organic waste through anaerobic digestion. Studies showed that, both breeding waste and caterpillar excreta generate a biogas yield comparable to other substrates of agricultural origin, such as cattle, pig and chicken manures. Fermented silkworm excreta under mesophilic conditions produces 167.32 m^3/Mg TS of methane and 331.97 m^3/Mg TS of biogas, while fermentation of silkworm breeding waste yields 256.59 m^3/Mg TS of methane and 489.24 m^3/Mg TS of biogas (Lochynska and Frankowski, 2018) [14].
- **Pharmaceutical potential of silkworm excreta:** Silkworm excreta or faeces are considered to be a major waste product of sericulture. Physically, silkworm excreta has a cylindrical shape of 2-3 mm in length with a deep green colour (Vimolmangkang *et al*., 2013) [33] and have equally pharmaceutical and food industrial uses. In traditional medicine, silkworm faeces have been used as a therapeutic agent in China, Korea and some Eastern Asian countries to treat infectious diseases, headache and abdominal pain (Tulp and Bohlin, 2004) [29]. The chemical constituents of silkworm excreta that have principally been reported are chlorophyll and chlorophyll derivatives, xanthophylls, carotenoid and flavonoids (Park *et al*., 2011) [19]. Chlorophyll derivatives (CpD-A, -B, -C, and -D) were extracted from silkworm (*Bombyx mori*) excreta, among them CpD-A was extensively studied to clarify its role as a "photosensitizer" for photodynamic therapy (PDT) of tumors *in vitro* (Lee *et al*., 1990) [13]. Three bioactive compounds have been isolated from excreta *viz.*, 1-tritriacontanol, lupeol and β-sitosterol. Of these lupeol and β-sitosterol are derivative of mulberry leaves on which silkworm fed and are excreted in an unchanged form and are used in treating inflammation, while 1-tritriacontanol is likely synthesized in the silkworm intestine (Vimolmangkang *et al*., 2013) [33]. Moreover, silkworm excreta are also a good source of natural colorant for the food industry. Vila *et al.* 2018 [32] studied that silk and polyamide fabrics can be easily dyed with the natural dye extracted from the excrement of the silkworm, obtaining yellowish brown colour.

2.2 By-products generated from silk reeling: In the silk industry, the term silk waste refers specifically to silk fibres that are not continuous and long enough for reeling as silk reeling. The innermost layer of the cocoon is known as pelade layer which is discarded in the reeling process along with the pupa as basin refuse. Silk sericin also discarded in silk industry during degumming process to improve the value of silk as a textile fiber and simply regarded as waste.

- **Silkworm pupa in human medicine and food industry:** Silkworm pupa is an immediate by-product of reeling industry, obtained after reeling. Annually India produces about 40,000 MT of silkworm pupae on dry weight basis (Priyadharshini *et al*., 2017) [20]. Pupa contains crude 50-60 per cent proteins, 25-35 per cent fats, 5-8 per cent free amino acids, 8-10 per cent sugars, E, B1, B2 vitamins, calcium and phosphorus. 75 per cent daily protein necessity of human individual can be obtain from 100g of dried silkworm pupae (Singh and Suryanarayana, 2003) [26]. The vitamins like pyridoxal, riboflavin, thiamine, ascorbic acid, folic acid and nicotonic acid, pantothenic acid and minerals like calcium, selenium and phosphorus make the pupae more nutritive (Koundeniya and Thangavaleu, 2005) [10]. Silkworm pupae contain edible lipids of high quality that are use as raw material in medicine (Shanker *et al*., 2006) [24]. Silkworm pupae regulate plasma lipid and lipoprotein levels in the serum of rats by activating apoproteins and lipid-metabolizing enzymes. Thus, it could be used to treat hyperlipidemia (Hu and Chen, 2011) [5]. Lecithin is also present in silkworm pupae which act as an antioxidant.

Silkworm pupae are considered as premium source of animal protein and represent as only insect food in the list of Novel Food Resources published by Ministry of Health of China and is widely used in dietary supplements, medicines and animal feed in China and Korea (Kim *et al*., 2008) [7]. Silkworm pupae can be consumed in human diet as whole pupa, pupal oil and pupal powder. The proteins of silkworm pupae are considered as complete proteins because of their high content of essential amino acids. In fact, silkworm contains all the amino acids required by the human body and in the appropriate proportions based on the recommendations of World Health Organisation (WHO) (Kohler *et al*., 2019) [9]. About 70-80 per cent of the fatty acid content of silkworm pupae is unsaturated, while about 1% is unsaponifiable matter in oil, including campesterol, β-sitosterol and cholesterol. Silkworm pupal powder can be utilized for making masala cookies with 7 per cent silkworm pupal residue powder containing 16.6g protein, 79.3g carbohydrate, 51.3g fat, 854 kcal energy, 114.5 mg calcium and 6.6mg iron (Vishaka *et al*., 2020) [34].

- **Silkworm pupae in compost:** Dried silkworm pupae contain 8 per cent of nitrogen. Since the pupa contain high amount of nitrogen and protein along with micronutrients like zinc, copper, magnesium and manganese, there is a prospective potential for the bioconversion of pupal waste to enriched compost and utilization as a nutrient source (Mahesh *et al*., 2020) [16]. Application of Silkworm pupae residual biocompost (SPRB) along with chemical fertilizers significantly increased both growth and yield parameters of mulberry (Mahesh *et al*., 2020) [16]. Karthikeyan and Sivakumar (2007) [6] cultivated in mass the biopesticide bacterium, *Bacillus thuringiensis* by utilizing silkworm pupal waste where viable spore count (VSC) was taken as a criterion for evaluating the efficiency of pupal waste medium.
- **Silkworm pupae as animal feed:** Waste silkworm pupae generate a lot of resources containing nutrients beneficial for livestock and poultry. The de-oiled pupae can improve the egg laying capacity in hens and fat free pupae used as feed of carps and fish for better yields. In silver barb fingerlings (*Barbonymus gonionotus*), highest growth rates were observed in fish fed in diet with about 38 per cent of total dietary protein replaced by silkworm

pupal meal (Mahata *et al*., 1994) [15]. Fermented silkworm pupae silage or untreated fresh silkworm pupae paste were integrated in carp feed formulations, replacing fish meal, in a poly-culture system containing the Indian Carp (*Catla catla*) and mrigal carp (*Hypophthalmichthys molitrix*), the survival rate, feed conversion ratio and specific growth rate were better for fermented silkworm pupae silage than for untreated silkworm pupae of fish meal (Rangacharyulu *et al*., 2003) [22]. Due to richness in protein and fatty acids silkworm pupae are used as food in piggery, poultry and pisciculture and as dog feed. The dried pupal feed has improved growth rate and egg quality in hens and enhanced survival rate, feed conversion rate and specific growth rate in fish. The de-oiled feed of pupae made rabbits to increase weight and growth of fur (Velayudhan *et al*., 2008).

- **Use of pupal oil:** Silkworm (*Bombyx mori* L.) pupae have 4.8 per cent and 9.0 per cent oil content in males and females (Suresh *et al*., 2012) [27]. The yield of silkworm pupae oil is approximately 20 per cent on the dry weight of pupae. The oil extracted from silkworm pupae contains more than 70 per cent unsaturated fatty acids, particularly the α-linolenic acid and oleic acid accounting for a high percentage (Rao, 1994) [23]. Oil extracted from silkworm pupae by boiling is used in the cosmetics industries for making soaps and moisturizers (Winitchai *et al*., 2011) [36] and this soap was used for degumming of silk. The pupae oil can be used in jute industry for lubricating (presently rice bran oil is being used) and in leather processing (presently, fish oil is being used). Pupal oil also contains 1-Deoxynojirimycin (DNJ), which is a potent alpha glucosidase inhibitor used to treat diabetes (Kotake-Nara *et al*., 2002) [11]. Silkworm pupae and pupal oil are important materials as they are a rich source of essential omega-3 fatty acid and ALA (alpha linoleic acid), which are of great importance for human health (Tomotake *et al*., 2010) [28]. The valuable pupae oil is used in industrial products such as paints, varnishes, pharmaceuticals, soaps, candles, plastic and biofuel (Wang *et al*., 2013) [35].
- **Uses of sericin:** Sericin is a natural polymer, highly hydrophilic, with adhesive characteristics such as gelatin. Sericin allows the union of silk filaments to maintain the structural integrity of the cocoon during its formation. Structurally, sericin is a globular protein consisting of random coil and β-sheets (Sharma *et al*., 2022) [25]. In total, 18 amino acids are present in sericin where serine (32%), aspartic acid (18%) and glycine (16%) are the most significant compounds. Sericin has been use potentially in cosmetics, biomedical, pharmaceutical and food industries during recent years.

Sericin has some marvelous properties like biocompatibility, biodegradability and wettability, which are use in the preparation of cosmetic products for skin, nails and hair (Padamwar & Pawar, 2003) [18]. Silk sericin has also anti-aging properties comparable to vitamin C, except for oxidative stress, where silk sericin was superior as sericin can stimulate synthesis of collagen type 1 which suppress the regulation of nitrate, which may induces oxidative stress, and up regulate the expression of b-cell lymphoma 2 (bcl-2) to inhibit cell apoptosis, without altering fibroblast growth kinetics or cellular ultra-structure (Kitisin *et al*., 2013) [8]. 8 per cent sericin can induce wound healing in the patients of second-degree burns (Aram wit *et al*., 2013) [1]. Cocoons of *Bombyx mori* L. can provide natural pigments typically flavonoids and carotenoids that accumulate in sericin layers (Kurioka and Yamazaki, 2002) [12]. These pigments are known for their biological properties as antioxidants and anti-tyrosinase. Sericin can also be used as food packaging material.

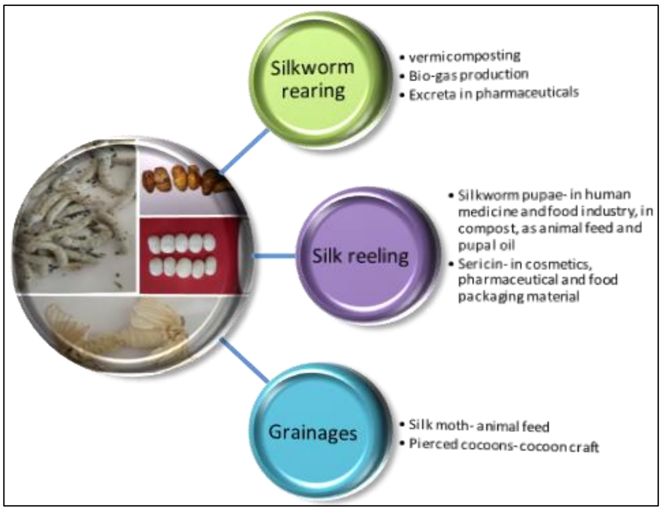

Fig 1: Sericultural by-products and their potential uses

2.3 By-products of grainage: Grainages are the egg producing centers. Quality silkworm egg is the basic living resource for successful sericulture industry. The grainages yields substantial quantity of moths of both sexes and pierced cocoons as a by-product in the process of egg production of parental lines or cross breeds. Aruga (1994) [2] reported that, silk moths could be used in the preparation of animal feed mixtures.

- **Use of defective cocoons in craft:** Cocoon craft is one of the very remarkable utility of by-products which can provide scope to develop human skills in adding up generating self-employment and revenue. The value addition in post cocoon sectors is predictable to generate income ranging from 10 to 25 per cent in total returns. Various products like garlands, flower vase, wreath, pen stand, dolls, jewellery, wall hangings, wall plates, clocks, bouquets and greeting cards are being prepared by using the waste silk cocoons (Vathsala, 1997) [30]. Some laboratories of Japan have produced silk paper in different colors for making craft products like flowers and lamp stands. A paint containing silk powder known as silk leather is used to decorate plastics, steel and fabrics.

3. Conclusion

The silk industry is an agro-based industry which provides considerable opportunities to improve rural livelihoods. Being a potential economic insect, silkworm, *Bombyx mori* L. needs proper attention and exploitation for the betterment of mankind. Sericulture by products upon improvement can be converted into valuable products like compost, human medicine, handicrafts and cosmetics etc. Proper utilization of sericulture and silk waste adds a value of up to 40% to the silk industry. The development of sericulture in this direction may be considered as an alternative way to solve the problem of declination of silk production through efficient utilization of the existing sericultural human capacity, research and production facilities by incorporating the by-products of sericulture into the market.

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