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Arti Sharma
Ph.D. Scholar, Division of Sericulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India

Rakesh Kumar Gupta
Professor and Head, Division of Sericulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India

Palvi Sharma
Ph.D. Scholar, Division of Sericulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India

Duwa
Ph.D. Scholar, Division of Food Science & Technology, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India

Kapil Attri
M.Sc. Student, Division of Sericulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India.

RS Bandral
Professor, Division of Sericulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India.

Kamlesh Bali
Associate Professor, Division of Sericulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India.

Corresponding Author
Arti Sharma
Ph.D. Scholar, Division of Sericulture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, Jammu and Kashmir, India

Silkworm as an edible insect: A review

Arti Sharma, Rakesh Kumar Gupta, Palvi Sharma, Duwa, Kapil Attri, RS Bandral and Kamlesh Bali

Abstract
Silkworm is a lepidopteran holometabolous economic insect, that completes its life cycle by undergoing into four stages i.e. egg, larvae, pupa and adult. From the nutritional point of view silkworm larval and pupal stage enjoys the privilege of being edible insect and consumed by the peoples of China, Japan, Korea, Thailand and Northeastern India. Silkworms are the only identified insects that provide food, fiber, and have biomedical significance. Silkworm pupae have a proportionate nutrient profile, making them appropriate as human food. Fried pupae make a good edible dish. Pupal proteins received more attention in the food industry owing to its high protein, minerals and vitamin contents. Silkworm pupal oil, chitin and chitosan have immense applications in various fields such as food industry, cosmetics, agriculture, water treatment, biomedicine, textile, biotechnology, wound healing agents etc. This review primarily focus silkworm as an edible insect by viewing its nutritional and medicinal applications.

Keywords: Silkworm pupae, edible insect, chitin and chitosan, pupal oil

1. Introduction

Food demand within the world is additionally increasing with quick and rapid growing population. The Food and Agricultural Organization of the United Nations estimated that the world has to increase its food production by 2050 so as to serve a world population of nine billion (Thangjam *et al.*, 2020) [51]. This population would require a supply of protein from innovative and sustainable sources and insects have been recognized as among the novel alternative sources that could fulfill the protein demands within the future. Insects are among the most diversified group of animals that may be found in nearly all environments including the oceans. Insects constitute a class of animals within the arthropod group that have a chitinous exoskeleton, a three-part body i.e. head, thorax and abdomen, three pairs of disjointed legs, compound eyes and a pair of antennae (Ademola *et al.*, 2017) [1]. Insects are a rich source of essential nutrients, such as proteins, fats, minerals, and vitamins, and of micronutrients, such as copper, iron, manganese, and riboflavin.

Entomophagy is defined as the practice of eating insects by human as food and is derived from the two Greek words “entomon” means “insect” and “phagein” means “to eat” (Haldhar *et al.*, 2021) [13]. Insects are consumed by humans for thousands of years as emergency food, as a staple food and as delicacies in different circumstances. Worldwide around two billion people eat insect frequently. The selection of edible insects as an alternative food supply arises from its richness in protein, and minerals and the nutritional benefit they provide to human. Edible insects have a number of comparative advantages than farm animal. They have high reproduction rate, emit lesser amount of greenhouse gases, very low environment pollution, low cost of production with relatively low water consumption and per kilogram more protein that beef or pork. In distinction to domestic food animals, whose bones, blood and offal are almost unusable as food the entire insect can be used or processed into food. Tribal communities in the states of Kerala, Odisha, Jharkhand, Karnataka, Tamil Nadu, Chhattisgarh, Madhya Pradesh and North East India mainly practised entomophagy in India (Gahukar, 2018) [12].

According to FAO (2013) [10] more than 1900 insect species are currently used as a part of the diets for at least two billion people around the globe. Coleoptera (31%), Lepidoptera (18%), Hymenoptera (14%), Orthoptera (13%), Hemiptera (10%) and 3% each of Isoptera, Odonata and Diptera orders contains insects that are the most commonly consumed worldwide. In Asia, Africa, Australia and Latin America entomophagy is predominantly practised. In India, entomophagy is mostly practised in North Eastern states. The states of North Eastern India have different food habits from the rest of mainland India.

Many communities of this region accept insects as the part of their diets and considered it as a delicacy. Over 200 species of edible insects are documented so far and out of which 92 different species are consumed in Nagaland, 69 species Manipur, 67 species in Assam, 65 in Arunachal Pradesh and few insect species in Meghalaya, Mizoram and Tripura. Silkworm is one of them (Thangjam *et al.*, 2020) [51].

Additionally, insect's are also a source of financial gain because the production of silkworm alone generated over US dollar 50 million to the Thailand economy in 2004 and a number of other processing techniques have been developed to explore the delicacy in Korea. The worth of insects as food item is undisputed. In the broader sense, insects have enormous economic value in terms of the ecological services they provide. A recent study within the United States found that the annual value of insects services amounted to more than US dollar of 57 billion (Losey and Vaughan, 2006) [32].

2. Silkworm as an Edible Insect

Sericulture is an ancient, agro-based, labour intensive cottage industry in India, dating back to the least second century BC concerned with the production of silk (Jadhav *et al.*, 2011) [20]. India is the second largest producer and the largest consumer of silk in the world, next to China. All five known commercial varieties of silk i.e. mulberry silk, tropical tasar silk, oak tasar silk, eri silk and muga silk, the golden silk being the unique monopoly of India, are produced in India. Silkworm is a complete holometabolous insect that consists of four stages in its life cycle *viz.* egg, larvae, pupa and adult. Apart from silk, each stage offers different by products and waste products that have a variety of applications in pharmaceutical industry, in cosmetics and in the paper and leather industry the eggs, larvae, pupae and faeces have significant usage (Anonymous, 1996).

Silkworms, including mulberry and non-mulberry silkworm pupae are a typical Asian food consumed from ancient times due to their high protein content. Some of the edible insects are reared commercially for their valuable products and silkworm is one of them. It is considered as a commercially viable product, eaten and sold traditionally in many markets of North-Eastern India. Silkworm caterpillar and pupa occupies one of the major groups among 100 species of edible insect consumed by the indigenous peoples of North-east India (Shantibala *et al.*, 2013) [47]. In Assam, among the silkworm species, consumption of eri is highest (87.7%), followed by muga (57.4%) and mulberry (24.6%) (Mishra *et al.*, 2013) [34]. In North East India, silkworms are reared both for consumption purposed as well as for trading. In various local markets of North-east India such as Nagaland, Assam etc. value added well packed pickle form of eri pupae are sold (Reddy, 2008) [41]. It is widely accepted that the insects are a good source of proteins and fats and entomophagy is widely practised not only for food but also as medicinal and a part of the culture in different ethnic tribes in North East India (Lokeshwari and Singh, 2019) [30].

Silkworm has high nutritional, medicinal, and economic value. As we know, for each kilogram of body weight a human need to consume 1g of protein every day. A large egg provides 6g of protein, average weight of silkworm pupae is 0.09 g. One piece of silkworm pupa contains 18 kinds of amino acids, and 8 of them are essential amino acids for human beings, 14.59% of total protein and 40% of total amino acids (Qian, 1997) [39]. The human body needs eight kinds of essential amino acids absorbed from food, their contents in silkworms are two times higher than those of pork and four times than those of egg and milk.

2.1 Nutritional value of Silkworm

Larval and pupal stage of silkworm is consumed most commonly in the North-eastern states of India, because of their high nutritional value. It is reported that protein energy malnutrition contributed to more than 50% of the deaths of the children beneath 5 years all over the developing countries (Pelleitier *et al.*, 1995) [37]. Protein, which is very essential nutrient for human growth and development, is present in silkworm in significant amount which can be used to mitigate the problem of protein malnutrition. Basically, silkworm pupae are an excellent source of protein, fat, minerals and vitamins. Compared to conventional food, they have higher content of three calorigenic nutrients (protein, fat and carbohydrates), providing up to 230 Kcal per 100g (Wu *et al.*, 2021) [54]. Silkworm pupae contain 55.60% of total protein and 32.2% lipid content by dry weight. High level of essential amino acids, namely methionine, valine, and phenylalanine are found in silkworm pupae. The essential amino acids content of silkworm pupae protein accomplish the requirements of FAO/WHO/UNU as they suggested in 2007 [9]. The amino acid score and protein digestibility-corrected amino acid source of silkworm pupae are 100 and 86, respectively (Longvah *et al.*, 2011) [31]. Furthermore, the amino acid score of proteins in silkworm pupae was 100 with respect to the amino acid profile of a 2-5 year old child (FAO/WHO, 1985) [8] (Longvah *et al.*, 2011) [31]. Consequently, silkworm is a high-quality source of protein that could be used as an alternative dietary source of protein for human nutrition.

The proximate composition of silkworm pupae of the *Antheraea pernyi* is moisture (7.6%), crude protein (71.9%), and ash content (4.0%) (Zhou and Han, 2006) [59]. Dry silkworm pupae have a fat content of 25%-30% (Longvah *et al.*, 2011) [31]. They are a rich source of functional fatty acids. Silkworm pupae are a good source of calcium and iron and have high potassium content (34.0mg/g), with a low Na/K ratio (0.08), and high zinc content (36 µg/g) (Zhou and Han, 2006) [59], all of which are important for human health and nutrition. Silkworm pupae also have a good amount of thiamin, riboflavin, and niacin. They contain about 10 mg tocopherols per 100 g, which is a much higher than that found in other common foods. Taken as a whole, silkworm pupae are a excellent source of protein, lipids, minerals and vitamins, all of which are all vital components of the human diet. Different attempts have been made by different workers around the world to analyze the amino acid composition of silkworm egg, silkworm larvae, mulberry silkworm pupae, tasar silkworm pupae and of eri silkworm pupae (Table 1) (Ademola *et al.*, 2017; Rao, 1994; Zhou and Han, 2006; Longvah *et al.*, 2011) [1, 40, 59, 31]

Table 1: Amino acid composition of silkworm egg, silkworm larvae, mulberry silkworm pupae, tasar silkworm pupae and of eri silkworm pupae

Amino acid composition (g/100g)	Silkworm Egg	Silkworm Larvae	Mulberry silkworm pupae	Tasar silkworm pupae	Eri silkworm pupae
Aspartic acid	8.92	8.65	10.9	6.41	9.89
Threonine	4.47	4.03	5.4	4.64	4.75
Serine	6.72	3.79	4.7	4.64	5.25
Glutamic acid	12.1	14.9	14.9	12.7	12.9
Proline	3.38	4.13	4.0	12.2	6.46
Glycine	3.02	5.71	4.6	4.42	4.94
Alanine	5.03	7.57	5.5	6.26	6.14
Cystine	1.90	2.12	1.4	1.5	0.53
Valine	5.42	4.42	5.6	6.63	5.36
Methionine	2.81	2.51	4.6	1.47	2.31
Isoleucine	4.88	5.37	5.7	7.95	4.42
Leucine	8.11	7.88	8.3	3.24	6.63
Tyrosine	3.81	2.85	5.4	2.06	6.40
Phenylalanine	4.82	3.69	5.1	8.1	5.24
Histidine	2.09	2.16	2.5	2.94	2.67
Lysine	6.59	8.67	7.5	4.54	6.54
Arginine	1.72	6.28	6.8	12.2	4.41

2.2 Silkworm Egg
Silkworm eggs contain albumin, fats, sugars, glycoproteins, vitamins B1 and B2 vitamins etc. in significant quantity that are processed into proteic extract that is successfully employed within the pharmaceutical industry for the preparation of medicines having hepatoproteanic, hypolipidic and hypoglycaemic action, serving as male sexual stimulator and also in the food industry. In some countries like Bulgaria some populace believe that the silkworm eggs, if consumed by alcohol drinkers, quit drinking totally as a result of feeling alcohol disgust. However reality has not been proven scientifically (Buhroo *et al.,* 2018) [4].

2.3 Silkworm Larvae
While the majority of us are conscious of the fact that silk is produced form silkworms, a small number of us recognize that these larvae have also been used for its so called health profits. It is employed in traditional medicine from a really very long time. Silkworm larvae of eri and muga silkworms are considered to be healthy and are consumed fried, roasted or raw in the Northeastern states of India. The silkworm's late instar larvae are eaten raw with salt and chilli or roasted with herbs as a snack. It is also used as source of animal protein in soups and sauce preparations in powder form. The conventional use of insects as food is widespread as they supply important nutritional and economical advantages to rural communities in Assam, Nagaland, Manipur, Arunachal Pradesh and Mizoram. Healthy silkworm larvae are sterilized and vaccum dried and sold as commercial food in Hong Kong, China, Korea and Japan.

2.3.1 Biomedical applications of Silkworm Larvae
Silkworm larvae of fifth instar can be processed into silkworm powder after freezing desiccation and porphyrization. Silkworm powder contains about 4-5% water, 60% protein, 9-13% fat and 6-7% of cellulose. Silkworm powder can be effortlessly digested and absorbed by human bodies. It also can encourage the physiological functions of the gastrointestinal tract. In addition, silkworm powder plays an exceptional role in lowering blood glucose levels (Buhroo *et al.,* 2018) [4]. The silkworm extract prepared from silkworm larvae enclose unsaturated fatty acids, vitamins, proteins, amino acids, cephalic and various other beneficial compounds. It is supposed to contain male hormones too. Each and every one of these components makes this extract helpful in nourishing the endocrine as well as the reproductive system of males. In addition, it is also effective in boosting sexual desire, especially in males. Silkworm extract is also believed to work wonders in treating conditions like migraine, carpal tunnel syndrome, osteoarthritis, rheumatoid arthritis and fibromyalgia. Even erectile dysfunction is said to be cured with this product (Qian, 1997) [39]. The enzyme, named serrapeptase found in the intestine of silkworms is good for enhancing blood circulation and in treating arterial plaque, by acting on non living tissues Serrapeptase is claimed to be advantageous for treating inflammatory conditions too (Feng, 2004) [11].

Processed silkworm larvae are used in special diets for cardiac and diabetic patients attributable to its low cholesterol content. The silkworm larvae can function as a bioreactor for the production of low cost vaccines against various infectious diseases. Processed larvae of *Bombyx mori* infected with the fungus *Beauveria bassiana* is one in every of the constituents of various Chinese decoctions used for the treatment of bronchial asthma, facial palsy and pain, primary trigeminal neuralgia, vocal nodules and vocal polyps. Silkworm larvae are freeze-dried at $\leq$-30˚C, created into a powder/film and incorporated into food. The additive protects the liver and prevents diseases among the aged (Buhroo *et al*., 2018) [4].

Several chemical constituents for instance insulin-like growth factor-II (IGF-II), adipokinetic hormone (AKH), chymotrypsin inhibitors, β-N-acetylglucosaminidase, DOPA, quinine amine conversion factor and sex pheromone bombykol have been reported from the silkworm larvae. A lutein binding protein has also been purified from fifth instar larvae. The extract of the larvae is one of the constituents of an anti-acne cream with minimal side effects and high clinical efficacy. Besides spinning cocoons silkworm larvae are also used in the pharmaceutical industry for the preparation of medicines having anti-diabetic action and in the food industry as supplementary nutraceutical. Besides this, a special type of thread is obtained from its gut which is used in surgical purposes. Silkworms have maximum blood-glucose lowering effect and the substances were found to be the four blood glucose-lowering substances as well as the major component, DNJ (1-deoxynojirimycin), which are nitrogen compounds (Ryu *et al.,* 1997) [43].

2.4 Silkworm Pupa
A silkworm pupa is an interesting by-product of sericulture

industry, which is obtained after the reeling process of silk threads, with an interesting nutritional profile, especially in terms of proteins. It is estimated that from 1 kg of raw silk, about 8 kg of wet pupae and about 2 kg of dry pupae are obtained. Huge quantity of silkworm pupa is generated as a major by-product in sericulture industry. Pupa which constitutes the major portion of the cocoon weight, is an inevitable by-product generated in large quantity (75-85%) during the green cocoon production. The pupae of mulberry and non-mulberry silkworm have been in consideration as new available source of protein that contains all the essential amino acids required for human health and can be used as fertilizer, animal feed, poultry feed and edible insects in many countries across the world, such as China, Korea, Thailand and India (Kumar *et al.*, 2015) [27]. Silkworm pupae occupied one of the major groups among 200 species of edible insect consumed by the indigenous peoples of North East India for its taste, flavor and culture. In North East India, silkworms are reared both for consumption purpose as well as for trading. Silkworm pupal protein is a complete edible insect protein and its amino acid composition meet the requirement of essential amino acid recommended by FAO/WHO standards. Silkworm pupal proteins have recently received more attention in the food industry owing to its high protein, minerals and vitamin contents. Silkworm pupa contains crude proteins, fats, free amino acids, sugars, E, B1, B2 vitamins, calcium, phosphorous and about 100g of dried silkworm pupae can supply 75% daily protein requirement of human individual (Singh and Suryanarayana, 2003) [50]. The protein of silkworm pupae is rated higher than the protein of soyabean, fish or beef. Silkworm pupal cakes of high nutritive value are common in Japan. The pupal odor is removed by a process of fermentation and deodorization.

Pupae contain 48.7% protein and 30% fat while spent pupae contain 26% oil and 75% protein. Fat constitutes about 30% of the total dry weight of pupae. Analysis of pupae shows that they contain ether extractives 31.1%, crude protein 51.6% in addition to amino acids such as lysine and methionine. The content of oleic acid and linoleic acids in the fat are similar to those of animal fats. The indigenous population of northeast India uses eri and muga silkworm pupae as a traditional source of food. The consumption was highest for eri (87%), followed by muga (57.4%) and mulberry (24.6%) (Mishra *et al.*, 2003) [34]. Crude protein content of eri silkworm and muga silkworm pupae was around 52% and 54% respectively which is higher than the 48.7% reported for spent silkworm pupae (Rao, 1994). Crude fat content of eri silkworm and muga silkworm pupae was around 20% and 16% respectively.

Table 2: Composition of pupae of muga and eri silkworm (Deori *et al.*, 2014) [7]

Component	Muga pupae	Eri pupae
Moisture g%	71.38	72.48
Protein g%	54.2	52.53
Fat g%	16.66	20.54
Ash g%	1.45	1.01
Crude fibre g%	3.05	3.25
Carbohydrate g%	1.62	1.24

2.4.1 Silkworm pupae products and their applications

In Asian countries from a long time ago silkworm pupae are used as food and medicine. It is assumed that silkworm could encourage the body life energy while balancing the nervous system. Moreover, it's been consumed as health food particularly for cardiac and diabetic patients, bronchial asthma, primary trigeminal neuralgia, facial palsy, pain vocal nodules and polyps. In addition, it is also possessed antijuvenoid (Saha *et al.*, 2007) [44], immune booster (Chen *et al.*, 2006) [6], antioxidant (Kwon *et al.*, 2013) [29] and estrogenic effects (Yang *et al.*, 2010) [55].

2.4.1.1 Pupal oil and pupal powder: At commercial level, the silkworm pupae are marketed as silkworm pupal powder and pupal oil. The percentage of total protein and lipid contents by dry weight in silkworm pupal powder is 55.6 and 32.2% respectively. Silkworm pupae powder had high levels of essential amino acids such as valine, methionine and phenylalanine. In addition, they also possessed n-3 fatty acids, especially α-linolenic acid (36.3%) as a major component. In some Asian countries like Korea, China, Japan, Thailand, etc. the silkworm powder are used as delicious human food. In provisions of protein, fat, vitamins and calories the silkworm pupae are equivalent to meat and superior than the protein of soya bean, fish or beef and has been found used for improved lactation in tribal women (Koundinya and Thangavaleu, 2005; Singh and Suryanarayana, 2003) [26, 50].

Silkworm pupae have eaten by Chinese as food and Pectin, the pupal by product used as thickener in candy, jelly, jam, fruit juices and ice creams (Roychoudhury and Joshi, 1995) [42]. In Japan, silkworm pupal cakes are prepared and sold owing to their high nutritive value (Majumder, 1997) [33]. In India, the silkworm pupae are regarded as delicious food and are extensively eaten when the silk has been reeled off. The pupae are either cooked in hot water or roasted. They are in high demand in local markets of North-Eastern States. The silkworm pupal protein is of great value and can be better used in baking industry for preparation of protein rich biscuits. Silkworm pupae enriched protein biscuits contained 6% nitrogen and 37% protein.

Dry pupae contain 45-49% of protein and 23-24% of oil, therefore forming an important bio-source of oil and proteins. Pupal oil can successfully reduce triglycerides, prevent and treat fatty livers, protect the liver after consumption of alcohols, improve the blood quality and the environment within the blood vessel, effectively soften the blood vessels, lower blood pressure, and prevent arteriosclerosis and thrombosis (Harris *et al.*, 1997) [14]. The natural steroids contained in the oil can improve fertility and enhance sexual function, the unsaturated fatty acids in the oil which cannot be synthesized by humans can enhance the flexibility of immune cell membrane, increase the vitality of the immune cells, so that the barriers to human health are more robust, and the occurrence of sub-health and disease is effectively prevented. The α-linolenic acid and other active substances present in pupal oil can join the synthesis of human tissue cell membranes, effectively prevent and mitigate symptoms like wrinkles, pigmentation, sallow skin, and premature aging of modern women. At the same time, it can improve the body superoxide dismutase activity and decrease free radical with good anti-aging effects (Kumar *et al.*, 2015) [27].

2.4.1.2 Chitin and Chitosan: After extraction of the proteins and oil, the remaining waste is used for the extraction of chitin, which is also another important by product from sericulture industry. Chitin, lined the silkworm pupae exoskeleton and exoskeleton such as spiracle and trachea. Silkworm pupae are a substitute source of chitin and as a result of chitosan (Zhang *et al.*, 2000) [58]. Importantly, chitosan is a biodegradable cationic biopolymer and could assist in reduction of pollutants in residual waters by absorption and chelating with heavy metallic ions and can also act in coagulation of colloidal particles and silkworm pupae chrysalides having anti-cancerous property (Kaizer *et al.,* 1989; Hursting *et al.,* 1990; Caygill *et al.,* 1996; Sasaki *et al.,* 1993) [22, 17, 5, 46]. The fatty acids of odd numbers contained in the silkworm chrysalis oil also have high antitumor activity. Chitin can be converted into various useful products like chitosan, chitin sulphate, chitin nitrate, chitin xanthate, sodium carboxymethyl chitin. The pupae yield chitin up to 4% of dry weight. In spite of this, chitin and chitosan are being exploited in a variety of biomedical applications, including drug delivery, tissue engineering, tissue scaffolds, and wound dressings (Jayakumar *et al.,* 2010) [21]. Austin & Brine (1977) [3] and Hirano (2001) [15], for the first time processed chitin in the form of films and fibers from silkworm pupae skin. However, the major development of chitin film and fiber is in pharmaceutical and medical applications as wound dressing material and controlled drug release. In addition, an interesting application is composite bone filling material, which forms a self-hardening paste for tissue regeneration in treatment of periodontal bony defects and its oligomers have been claimed as anticancer drugs. Chitin and chitosan have immense applications in various fields such as food industry, cosmetics, agriculture, water treatment, biomedicine, textile, biotechnology, paper industry; wound healing agents etc (Yusof *et al.,* 2003; Hudson, 1998; Kato *et al.,* 2003; Ito *et al.,* 1998) [16, 57, 23, 18]. Biocompatibility, hemostatic, bacteriostatic, fungistatic, spermicidal and anticholestermis are the biological properties of chitosan. Chitosan extracted by deproteinization, demineralization and deacetylation processes from silkworm pupae showed antibacterial activity and its application to silkworm reduced larval mortality which indicated disease resistance and increased economic parameters (Priyadharshini Pachiappan *et al.,* 2018) [37].

2.4.1.3 Lipoproteins: Silkworm pupal fat body and hemolymph are abundant in 30kDa family of lipoproteins (LPI-5) and are low molecular weight lipoproteins (Kim *et al.,* 2003) [24]. *In vivo* data demonstrated that oral feeding of the silkworm protein 30Kc6 dramatically improved the condition of atherosclerotic rabbits by decreasing serum levels of total triglyceride (TG), high density lipoprotein cholesterol (HDL-C), low density lipoprotein cholesterol (LDL-C), and total cholesterol (TC) (Yu *et al.,* 2013) [56].

2.4.1.4 Source of Vitamins: Studies demonstrated that silkworm pupae are a source of proteins and substances which are essential for the function of the nervous system such as vitamin B1, B2 and E (Singh and Jayasomu, 2002) [49]. Silkworm pupae contain vitamins, which can be important to avoid the serious effects of their deficiency (Kwon *et al.,* 2012) [28]. The metabolites of EPA and DHA, commonly known as Brain Gold, can promote the synthesis of nucleic acid and monoamine neurotransmitters in the brain and effectively enhance the mental memory (Kumar *et al.,* 2015) [27]. The vitamins like pyridoxal, riboflavin, thiamine, ascorbic acid, folic acid, nicotinic acid, pantothenic acid, and minerals like calcium, iron, copper, selenium and phosphorus make the pupae more nutritive and also found used for better lactation in tribal women (Koundinya and Thangavaleu, 2005) [26].

2.4.1.5 Antibacterial preparations: Live pupae are used as a medium to synthesize antibacterial peptides *in vivo*. Live healthy pupae are used in antibacterial protein preparations. A beneficial tar is obtained from the pupae. The bactericidal and antihistaminic activities of the tar are superior to those from plant sources (Chen *et al.,* 2006).

2.4.1.6 In Medical and Pharmaceutical industry: Silkworm pupae are natural enormous by products of the silk industry with excellent applications in the field of biomedical science and the pharmaceutical industry. The proteins extracted from silkworm pupae possess great medicinal value to cure diverse lethal diseases. Most importantly, functions of pupal protein include drug delivery, tissue engineering, tissue scaffolds, wound dressings, regulation of blood lipids and glucose, antiapoptotic, antioxidant, antigenotoxic, hepatoprotective activity, bioreactor and as anticancer agent (Kumar *et al.,* 2015) [27]. The pupae of silkworm used as food and as a source of oil for medicines. It contains vitamin B1, B2 and vitamin E. Chitin and triacontanol isolated from the exuviae are important chemicals (Majumder, 1997) [33]. Silkworm pupal oil extracted from pupae can be utilized to treat liver and blood diseases (Koul *et al.,* 1994) [25]. Silkworm pupae can be used for the extraction of pupal oil, amino acids and vitamins and as a poultry and fish feed and to prepare medicine for sterility. For humans silkworm pupae are a good source of nutrients. They are also valuable insect source of substances used in healthcare products, medicines, food additives, and animal feed. Wattanathorn *et al.,* 2012 [53] demonstrated that the cognitive enhancing effect of silkworm pupae occurred at least via the increased cholinergic function while its neuroprotective effect occurred via the decrease oxidative stress. It appeared that the silkworm pupae could be a potential functional food to protect against Alzheimer's disease.

2.4.1.7 Silkworm pupae as astronaut food: Masamichi Ymashita, a researcher form Japan Aerospace Exploration Agency released a recipe for pupa cookies during the 36th scientific assembly of the committee on space research. This recipe consists of 3-6 g of silkworm pupal powder, 200 g of rice powder and 300 cubic centimeters of soymilk, soya sauce and salt. Astronauts may blend these materials with water and divide the mixture in to small pieces which is unappetizing but apparently healthy (Priyadharshini and Swathiga, 2021) [38].

2.4.1.8 Silkworm pupae as animal feed: Waste silkworm pupae generate vast resources of nutrients for livestock and poultry. It is one of the unconventional top class protein (65-75%) and lipid. Among many alternative protein sources, silkworm pupae proteins are considered as an important dietary protein source for poultry after processing at a reasonable cost (Iyengar, 2002) [19]. The de-oiled pupae fed hens improved their egg laying capacity with impact on the colour of the egg yolk and the fat free pupae used as feed of carps and fish for better yields. Silkworm pupae were used as food in piggery, poultry, and pisciculture and as dog feed due to their richness in protein and fatty acids. The dried pupal feed has enhanced growth rate and egg quality in hens and improved survival rate, feed conversion rate and specific growth rate in fish. The deoiled feed of pupae made rabbits to gain better weight and growth of fur (Velayudhan *et al.,* 2008) [52].

2.4.1.9 Silkworm pupae as compost: Silkworm pupae used as compost to obtain higher yields of agricultural crops. Sharma and Ganguly (2011) showed that, the silkworm pupal bio-waste can be converted into good quality fuels which may be used as biodiesel additives. The results of the experiment by Sangeetha *et al.* (2012) [45] clearly indicated that the application of silkworm litter-pupal waste + Vermicompost recorded significantly higher leaf yield (32,098.5 kg) and NPK content (3.11%, 0.39% and 2.48%) respectively.

2.5 Silkworm Moth/Adults

Another type of special oil (75% fatty oils) is obtained from the silkworm moths. The oil can be used to obtain textile dyes and superior soaps. The extraction residue can be used as fodder. The moths can also yield Cellular Cytochrome C, uric acid and few hormones for pharmaceutical use (Nazim *et al.*, 2017) [35].

3. Conclusion

The silkworm is an economic insect which is very beneficial for the human kind as it fulfills basic needs of clothing and food. Entomophagy of silkworm is widely practised not only for food but also as medicine in North East India. After extracting the silk thread, silkworm pupae are a by-product of the textile industry. These pupae are rich in nutrients and have high value. Many studies have shown that silkworm pupae are a good source of nutrients for humans, with various potential functions. The proteins extracted from silkworm pupae expressed great medicinal value to cure different deadly diseases. Most importantly, functions of pupal protein include drug delivery, tissue engineering, tissue scaffolds, wound dressings, regulation of blood lipids and glucose, antiapoptotic, antioxidant, antigenotoxic, hepatoprotective activity, bioreactor, and as anticancer agent. Recent studies have confirmed that silkworm food can provide better nutritional requirements to astronauts during their long term missions in the space owing to its high quality protein content, appropriate proportions of amino acids, unsaturated fatty acids and essential elements for humans. Pupa offers an immense scope for preparation of pupa protein concentrate of good quality protein that can be used in animal nutrition, especially for the pet food industry or poultry feed, thereby generating additional income in the silk industry. Therefore, intensive research towards product development, quality optimization and value addition through application of suitable technology are the need of the hour, so as to make use of the silkworm larvae as well as of pupae, for future generation.

4. References

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