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Review

Silkworm *Bombyx mori*—Sustainability and Economic Opportunity, Particularly for Romania

Mihaela Hăbeanu, Anca Gheorghe * and Teodor Mihalcea

Research Station for Sericulture Baneasa, 013685 Bucharest, Romania; mihaela.habeanu@scsbaneasa.ro (M.H.)
* Correspondence: anca.gheorghe@scsbaneasa.ro

Abstract: The main concerns and challenges of raising silkworms include economic value, mulberry management, biodiversity conservation of genetic resources, and developing highly productive breeds for genetic variety. This study investigated the relationship between the economic relevance of the products generated throughout the value chain, limitations, and opportunities to generate incomes for sericulture farmers, trends, and perspectives worldwide, particularly in Romania. Seventy-seven publications were considered from online databases. The diversification of products generated at each level of the value chain of silkworm rearing and their multipurpose applications impact social and economic life. Hence, silk is well known as a valuable biomaterial for industry, suitable for textile and medicine. There are several arguments to use silkworms in human food even though they are not yet authorized as edible insects at the European level. Thus, as a nutrient-rich by-product, silkworm pupae (extract, cakes, and oil) have medicinal properties and can be used for human and animal nutrition. Sericin, silk fibroin, and chitin are bioactive compounds in cocoons and pupae with pharmacological implications and drug composition, while biomass is suitable for biodiesel and excreta for compost. The farmers' attitudes and mentality associated with political circumstances influence the perspectives for the sericulture field. Due to the high likelihood of using their products, small-medium-scale farmers might benefit sericulture by identifying new sales marketplaces and finding new beneficiaries for directing their multiple products. The funds allotted by government subventions for supporting this fascinating activity and opportunities for jobs may aid in encouraging to start of a new sericulture business or to contribute developing the existing one.

Keywords: mulberry; silkworm; pupae; silk; economic; biodiversity; conservation

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1. Introduction

Climate change, biodiversity as an important driver of food safety and security, population increase, and the identification of novel protein alternatives to those derived from animals are the main issues currently on a worldwide scale.

Insects have been consumed for thousands of years and can be utilized as an alternative source of protein and for waste disposal [1]. For example, insects such as the black soldier fly, which can digest waste materials and generate high-protein larvae, are employed in modern systems [2]. Fisheries may be maintained using insects that can substitute for fishmeal in an aquaculture diet. The use of insects for livestock feeding was described previously by several authors [3–6].

Among insects, the silkworm *Bombyx mori* occupies a special position, being an excellent lepidopteran species representative of numerous scientific investigations [7]. *B. mori* was domesticated and developed by human-driven selection from a wild origin since ancient times. Many years ago, silkworm genetic stocks were conserved in research facilities [8].

The silkworm can be considered from the economic point of view to be one of the most significant insects. It has been providing important benefits to humans, and it has continued developing thanks to its many practical applications, including using it as a model organism for medical purposes [6,9–11].

Presently, UNESCO has designated sericulture as an intangible cultural heritage. In addition to producing several beneficial by-products for human society (pupae, biomass, excreta, mulberry leaves extract, etc.) and adding value through a wide range of applications in economic sectors [12,13], sericulture is required to produce silk fibre for fashionable clothing, shoes, bags, wallpapers, and other fabric items [14].

The economic potential of the sericulture sector, which starts with the production of mulberries (*Morus* sp.) and continues with the rearing of silkworms (upstream) to obtain silk threads (downstream), depends on how this sector can add value and diversify the way of valorisation of the primary product and by-products [15].

It was acknowledged that the production of natural silk threads and the rearing of silkworms, both being historic traditional occupations in the world, would be comparable to a veritable endless "*gold mine*" if all the conditions for doing so would be exploited to the maximum possible extent. In this assumption, experts recognize that increasing and promoting the production of silkworm cocoons are essential to preserve the country's pedoclimatic conditions and the upgrading of this well-earned sector over many decades [16].

Silk production accounts for around 0.24% of all fibre use or about 202,000 metric tonnes annually. *B. mori* provides probably 99% of the silk production [17], although it is challenging to determine the exact global value due to the absence of accurate statistics on completed silk products in the majority of importing nations. China is the leader in production, followed by India, which together account for 95% of global silk manufacturing [18]. On the other hand, although silk thread together with cotton, jute, linen, wool (natural fibres), and nylon and rayon (artificial fibres) is among the most popular known types of fibres, competition among them on the market is obvious, and quality is frequently sacrificed in favour of the price criteria factor when making purchasing decisions.

Silk is a valuable biomaterial that can become more significant in the current textile/fashion value chain framework, although the production of the world's total textiles is relatively low [19]. Under the new market conditions based especially on artificial fibres, silk fibres declined, unable to compete, if we consider the purchasing power of a significant market segment, even though there are several other factors, such as its natural protein fibres. Furthermore, the preservation value of *B. mori* species can support the sustainability of the sericulture sector.

The by-products resulted at each phase along the technological value chain contribute substantially to opening new perspectives for development.

The pupae are a highly nutrient-dense by-product recommended as an edible by-product from the silkworm, which is left after reeling silk. The pupae are utilized in pharmaceutical research after being further treated to extract nutrients and active substances. Silkworm pupae bioactive compounds act for health. The varied medicinal benefits can be remarkable.

The future of sericulture depends on a paradigm shift toward reducing environmental effects and enhancing economic and social life by valuing all products produced by this sector.

This paper investigated the relationship between the economic relevance of the products generated throughout the value chain, limitations, and opportunities to generate incomes for sericulture farmers, trends, and perspectives worldwide, particularly in Romania. We also pointed out the perspective of seeing silkworms as a contributor to decrease *protein hunger* being recommended as suitable alternative protein sources.

2. Materials and Methods

To explore the potential applications of the diverse range of products and by-products generated from sericulture associated with economic and biodiversity implications, we considered publications accessible in Elsevier, MDPI, PubMed, Web of Science, Research

Gate, Springer, and Wiley Online Library databases. For easier searching, we used the following key words: "mulberry", "silkworm", "pupae", "silk", "economic trend in sericulture", "biodiversity", "conservation", "compost", "silkworm larvae", "edible insects", "silkworm by-products", "environment", and "silkworm market". The criteria for selecting the publications consisted of the topic of the papers, the English language or bilingual edition with one language being English, and the years. The articles between 2012 and 2023, with few exceptions, were selected attempting to meet the eligibility criteria. The data were collected from over 100 publications, and finally, 83 studies were considered.

3. From the Past to the Present State of Sericulture

The current uncertainty could be clarified with a quick trip into the past. The molecular analyses showed that the silkworm *B. mori* originated from the *B. mandarina* around 4600 years ago in China [20] (quoted by [21]).

The history of silk manufacturing and weaving is reflected in folklore. Undoubtedly, this industry started about 3000 years BC in China. When it was found that approximately 1 km (1000 yards) of thread that makes up a silkworm's cocoon could be reeled out, spun, and woven, the sericulture industry in rural China rapidly gained popularity. According to the Chinese tradition, Lei Zu, the mythical wife of Huangdi, the Yellow Emperor, taught the Chinese people the technique; throughout the history, the empress was symbolically linked to sericulture [14,22,23].

Since approximately 2000 years ago, when the so-called "*Silk Road*" connected Europe to Asia, the silk trade was considered a significant industry preparing the globalization's beginning [19].

Due to industrial development, pollution, and the silkworm disease (pebrine), the sericulture industry has declined since approximately 1873, particularly in Europe. Thus, similar to other species, *B. mori* became endangered, leading to a detrimental effect on biodiversity preservation. The mulberry trees were neglected, and the dead ones have yet to be replaced. The output was restricted to meeting local demands.

Tanase [24] pointed out that the heritage of the silkworm breed depends on mulberry management, maintenance, and utilization of modern techniques necessary to obtain up to 30 tons/ha of leaves.

According to Pau et al. [25], cited by Pop et al. [26], Romania possessed a variety of mulberry species, comprising 49 foreign breeds and hybrids from Japan, China, Russia, Bulgaria, and India in addition to roughly 10 local types.

Over the 20th century, this sector's development experienced significant variations. High levels of hazardous gases, liquid chemicals, and non-biodegradable solid waste were discharged into the nature from household buildings, cars, and industry due to increasing urbanization and the rising human population [27]. Sericulture is one of the industries that was impacted. After this period, silkworm growth developed steadily until the beginning of the 21st century. The specific activities remained at a lower level.

4. Climatic Conditions

No populations of *B. mori* still exist in the wild due to their intense domestication [28], which led to the difficulty of adapting to unfavourable climatic conditions, particularly high temperatures.

According to Rohela et al. [27], mulberry trees are widely distributed across the continents in various environments (from temperate to tropical surfaces), suggesting that they are more tolerant of changing environmental conditions. Hence, mulberry can adapt to different climates, soil types, and altitudes (up to 4000 m above sea level); however, it is resistant only with the ensured light, temperature, water, wind, and other climatic factors [29].

Mulberry trees have a high rate of carbon sequestration that makes it excellent for removing gaseous carbon emissions from the environment [27]. Giacomin et al. [30] and

Hăbeanu et al. [6] mentioned that mulberry trees produce leaves for silkworm larvae intake, and more of that can retain carbon. *B. mori* is also very sensitive to pesticides.

One kilogram of raw silk requires approximately 200 kg of mulberry leaves to manufacture it. When the mulberry tree matures in the third year, it can produce around 2 kg of leaves. Mulberry fields per cultivated area reduce CO_2 eq. by about 735 times the weight of synthetic silk fibre. On the contrary, fresh pupae are by-products that pollute the environment and emit an unpleasant odour in the surrounding communities. In the space where silk is produced, large-scale pupae disposal can have detrimental environmental effects [6].

Romania has a mild climate between temperate and continental due to its location in the southeast part of the European continent. The country's diverse relief affects climatic conditions in specific ways. Its geological subregions, which encompass hill, plain, and mountainous areas, are related to climate fluctuation. In the south, the average annual temperature is 11 °C, while in the north, it is 8 °C.

The most important Romanian centres where sericulture is practised to high standards are the Research Station for Sericulture Baneasa, Bucharest, (RSSB) and the Global Centre of Excellence for Advance Research in Sericulture and Promotion of Silk Production (GCEARS-PSP). While the RSSB is situated in the southern lowland region characterized by a humid continental climate with an average annual temperature of 10.8 °C, the GCEARS-PSP is located in the heart of the Transylvania region characterized by a moderate continental environment with oceanic influence and an average annual temperature of 8.2 °C. The conserved genetic resources are the *B. mori* genus.

5. Mulberry Sustainability by Its Applications

Mulberry (genus *Morus*, family *Moraceae*) is a significant economic component in sericulture, the starting point since the quality of the cocoon and the quantity of leaves produced per unit of area are strongly correlated.

The mulberry tree is a perennial plant with significant traits, including higher leaf production, a shorter gestation time, and a greater capacity to adapt to the environment [27,31]. Ninety percent of the world's raw silk output comes from silk from silkworm *B. mori* [28]. This considerably improves many people's lives worldwide. Moreover, it has been stated that the mulberry plant offers a range of nutritional and therapeutic benefits, including its use in livestock feed and well-recognized medical advantages [32].

The mulberry leaves, fruits, and wood push the limits of sustainable development through multiple applications from an economic standpoint. Firstly, mulberry leaves are well known for being the only nourishment source for feeding and raising *B. mori* silkworms, although artificial diets have been adopted [33]. According to Srivastava et al. [34], leaves powder contains key nutrients, such as protein (5–7.3%), fat (2–5%), ash (14.59–17.24%), carbohydrates (9.70–30%), and energy (113–224 kcal/100 g). Cai et al. [35] found condensed tannins, jasmonic acid, anthocyanins, flavonoids, stilbene, and terpenoids, as bioactive compounds required as well for physiological processes in the larva body (growing, reproduction, silk production). One metric tonne of mulberry leaves will yield approximately 25 to 30 kg of cocoons [21].

Mulberry fruits, rich in protein and vitamins, have long been consumed worldwide in human and animal diets. Mulberry products, including juice, tea, wine, and jam, are worthy of inclusion in human diets because of their rich composition in antioxidants, vitamin C, potassium, magnesium, iron, and vitamins K and E.

Several studies have recently investigated the antioxidant potential of extracts from various mulberry plant components, including the leaves, roots, and fruits [36,37]. Furthermore, numerous studies have shown antioxidant, antiviral, anti-inflammatory, hypolipidemic, anti-hyperglycaemic, neuroprotective, anti-HIV, antihypertensive, and cytotoxic properties for mulberry leaves [6,38].

In conventional and contemporary medicine, fruits and leaves are recognized for their antidiabetic properties [21,39]. Traditional Chinese medicine uses mulberry leaf tea with flavonoids and polyphenol antioxidants. The tea has anti-inflammatory properties and reduces cholesterol. Recent studies have also shown mulberry leaf tea has therapeutic benefits for treating diabetes by decreasing blood sugar and inhibiting carbohydrate absorption [40].

Ghosh et al. [31] provided a detailed description of mulberry's economic importance. Thus, the protein-rich mulberry leaves of *Morus alba* can be used successfully as animal feed and can help in lowering blood pressure and cholesterol levels in humans.

Although they were considered waste, the mulberry leaf stalks, and leftovers, such as twigs and shoots, can add value to ruminants and monogastric diets [41–46]. The trunks' wood is valuable for manufacturing paper, handicrafts, cabinetry, handles, and as a fuel source [21].

The main issues that affect the silkworm farmers include mulberry and silkworm rearing management practices, mulberry field area, low quality of silkworm breeds, inadequate infrastructure, a lack of room for raising silkworms, a lack of sufficient start-up equipment for farmers, and low acceptance of new technologies [47].

6. Silkworm Products—Economic Impact

Although there has been a noticeable improvement in silkworm breeding and the creation of new varieties, sericulture development still faces substantial challenges both upstream and downstream. The availability of high-quality eggs, efficiency of farms, health management, a lack or insufficiency of governmental support, unsustainable production, and competition from imported products are the predominant impediments to its development on both the upstream and downstream levels [17]. Sericulture's profitability can be boosted by legislation, investments, and cutting-edge procedures and methods.

Throughout the technological flux of growing silkworms, products (silk thread, pupae cake, pupae oil, larvae and excreta, moths, eggs) are generated at each phase with excellent application in various fields. This increases the incomes of silk farmers and from other related industries.

For instance, the manufacturing of silkworm silk thread (the main product considered a natural protein filament and finest yarns) had a considerable impact on economic development since it formed the basis of rural and urban economy areas of Asia, Europe, and American countries.

According to the FAO report, at the global scale, between 70,000 and 900,000 M.T. of silk is produced yearly, while the demand is rising by 5%. The need for silk will grow due to the population growth and the increased desire for attractive clothing items brought on by rapidly changing fashion trends in highly developed nations.

The high value of silk yarns explains why they have been a crucial part of cross-continental commerce for many generations. Major economic, social, and cultural contacts have resulted from these exchanges over shifting continental and marine routes, but their geopolitical and symbolic long-term significance is still obvious today. The silk production, processing, and trade also serve as the foundation for a tangible cultural heritage by aiding in the development of skills, work organization techniques, encouraging technical and technological transfers, and designing rural and urban landscape types. These traits of sericulture activities make them especially well-suited for addressing economically important topics from a global viewpoint.

Data Bridge Market Research [48] reports that the textile sector has experienced tremendous expansion, leading to the increased demand for silk. Producing silk does not require sophisticated machinery and equipment. These elements support the market's growth. The global silk market is anticipated to grow by USD 32.06 billion by 2029 with a Compound Annual Growth Rate (CAGR) of 8.30% from 2022 to 2029. According to Market Data Forecast [49], the CAGR is predicted to reach 11.32% from 2023 to 2028, while Mordor Intelligence [50] forecasted a CAGR of 5.5% for the 2018–2028 period. The Observatory of Economic Complexity (OEC) [51] reported the total silk transaction amount of USD

1.27 billion in 2020, which contributed to making silk the 96th most traded product in the world. Raw silk exports increased from USD 245 million in 2020 to USD 269 million in 2021.

According to OEC statistics, Romanian silk exports represented 2.07% of the total export value, while imports comprised 13.9%.

Silk fibrous proteins (sericin and fibroin) are beneficial compounds produced in the sericogenic glands of the silkworm through biosynthesis. Sericin, which makes up 25–30% of the protein, surrounds the fibroin fibre with a series of sticky layers that contribute to forming the cocoon. Sericin binds the silk threads around each other, ensuring the cohesiveness of the cocoon [52]. Biodegradable polymers that are favourable to the environment can be produced by mixing sericin with other resins. Sericin and fibroin can be used to create membranes for separation procedures [53].

According to Saric and Scheibel [53], researchers from several fields are looking into using recombinant silk proteins as green bio-polymers. Silk materials may also be macroscopically functionalized to create composite materials that offer remarkable versatility, such as for medical uses in diagnostics, biosensors, or tissue regeneration. Silk is also promising for various clinical and biological applications [54]. Similarly, Kundu et al. [54] highlighted fascinating technical progress made by using bioengineering in implantable optics, photonics, and electronics.

Silkworm pupa characteristics, nutritional value, and applications in different fields were detailed in our previous paper [6]. Thus, we focused on the excellent nutritional characteristics emphasizing fatty acids beneficial to health (omega-3 particularly) and wide applicability in human food and animal feed, medicine, and environmental impact reduction. The varied and intricate medicinal benefits, such as immunomodulatory, antibacterial, anticancer, antioxidant, hepatoprotective, antifatigue, and antiapoptotic actions, are also remarkable. Silkworm pupa bioactive compounds act by reducing plasma triglycerides. These bio-compounds act to treat wounds and control blood sugar levels, lower blood pressure, prevent thrombosis and arteriosclerosis, boost cell vitality, and enhance the body's defences in metabolic disorders [6,55,56].

Among the benefits of silkworm proteins and hydrolysed peptides are increased immunity and anticancer and antioxidant properties [57].

From a dietary perspective, the larvae and pupae are edible parts of the silkworms and are eaten by the inhabitants of China, Japan, Korea, Thailand, and Northeast India [58]. Due to their high protein content, silkworm pupae have been sold for centuries in various marketplaces and are regarded as an economically viable commodity [15].

Sericulture focuses on many methods that might boost the farms' incomes by manufacturing cocoons. Small-scale farmers need to identify new revenue streams, including the sale of cocoons and other applications of by-products. Silkworm rearing allows for a cheap supply of biomass, which is potentially a beneficial source for biogas generation [59]. In a study in 2019, Łochyńska and Frankowski [60] presented an option with encouraging results of fertilizer organic hemp culture (*Cannabis sativa* L.) with larva excrements.

Traditional Asian medicine has employed excreta therapeutically to treat various diseases [59]. Since it contains a lot of flavonoids, chlorophyll, alkaloids, carotenoids, and lutein, silkworm excreta may have considerable antioxidant action [6].

The litter of silkworms (leftover leaves and faeces) can be used as organic manure [61].

Over time, due to concerns about animal welfare, scientists have been obliged to restrict the number of vertebrates used as experimental animal models. Consequently, other animal models that do not need ethics committee approval have been considered. A richness of genetic resources, an evident genetic pedigree, and a short generation period with a 25–30-day larval stage are some traits that make using silkworms a more favourable, simpler, and less expensive model for studies [10]. Kodama et al. [62], quoted by Meng et al. [10], developed the first silkworm larva viral infection model for medication therapy. The findings of injecting the virus into the silkworm's haemolymph showed that nalidixic acid might suppress the growth of the flacherie virus and nuclear polyhedrosis virus (BmNPV) and shield silkworms against infection with related viruses.

Due to their great susceptibility to pesticides, antibiotics, pathogenic fungi, and germs that are harmful to humans, silkworms have become a paradigm for natural immune activation, drug screening and kinetic testing [10]. In addition, research on the pathophysiology and human microorganism toxicity has rapidly improved in recent decades. It was discovered that the chitosan isolated from silkworm pupae improved economic parameters. Hence, efficient pupa reutilization might be employed to produce a high-potential raw material for numerous biomedical processes by turning it into beneficial bioproducts [63].

In contemporary research, the silkworm is used as a model organism to investigate human tumours, degenerative diseases, and metabolic diseases.

Epigenetics investigates genetic variation at the chromatin and DNA alteration levels without variations in gene sequence [64]. In cutting-edge research and technology, it is a crucial information carrier. Sericulture research advanced in 2010 by creating the first silkworm methylation map (as an epigenetics marker).

Aznar-Cervantes et al. [65] showed that it was possible to use the silkworm to assess the hypoglycaemic activity of various products originating from sericulture by dietary addition after promoting glucose or sucrose-induced hyperglycaemia.

Future directions and targets may be established and investigated as science continuously develops.

7. Edible Silkworm—Mentality and Perspectives

7.1. Silkworm as a Source of Food

A 60% increase in the requirement for food is anticipated by 2050 [66,67]. Since the Novel Food Regulation was enacted on 1 January 2018, EFSA [68] has received many applications covering various novel and traditional food sources. They include foods made from algae, non-indigenous fruits, herbal compounds derived from plants, and different edible insect species. Silkworms *B. mori* have been considered as a suitable insect for human consumption as a substitute for animal protein, but did not yet receive official authorization as edible insects.

Edible insects are a distinct food ingredient that continues to gain value in improving global food security and providing an attractive alternative to meat. Insects can contribute to food production and reduce the adverse effects of climate change [69]. More than 2000 edible insect species, including silkworms, are consumed globally [67] in raw or processed form [69].

A comprehensive nutritional comparison between *B. mori* and meat from different species was provided by Orkusz et al. [67]. Accordingly, the energy value (kcal/100 g) of edible parts of *B. mori* ranges between 171.27 and 229, for horse meat it is 109, for pork shoulder 13.2, for beef shoulder 112, for rabbit carcass 123.24, for goose carcass 140.63, for duck carcass 199.04, for turkey breast 83, for chicken breast 98, and for chicken drumstick 125. Regarding protein level (g/100 g), the higher value was reported for *B. mori* (17.9–23.1), followed by chicken breast and horse meat (21.5%), while the lower value was found in the goose carcass. For the poor rural population especially, *B. mori* represents a source more attractive from the nutritional point of view than meat. The advantages include fast growth, more efficient feed conversion, and minimum resource requirement.

Although insects present many advantages, most consumers are wary of their safety in most developed nations and reluctant to include insects in their diets. However, the studies concerning edible insects are limited.

In Romania, similar to many Western countries, there is a strong mentality against consuming edible insects, despite the EU opinion and advice due to respect for culinary traditions, mentality, and lack of sufficient information. Zugravu et al. [70] pointed out the importance of knowledge as a determinant factor for accepting the intake of edible insects. The study of Zugravu et al. [70], including Romania, as part of a global investigation, used a questionnaire translated into Romanian to assess attitudes against eating insects and find modifiable factors associated with reluctance or aversion. Even though most people do not find insects appetizing, those who know more about them may be willing to try these novel food products because they relate them to protein or other nutrients content. Nonetheless, overcoming aversion will be crucial in accepting insect ingestion, as eating patterns change hesitantly and gradually.

As an argument, the FAO [71], cited by Zugravu et al. [70], reported that a significant portion of the population will not have enough water by 2025. Raising and processing insects requires less water. Certain insects, such as the yellow and smaller mealworms and silkworms, can withstand drought.

According to Wu et al. [57], 26 proteins from silkworm pupae have been identified as allergens. Phytate, phytic phosphorus, tannic acid, alkaloid, flavonoids, saponin, and oxalate are some of the antinutrients in silkworm pupae that have drawn the attention of several authors; however, their levels do not present a risk to humans [6,72,73].

The WHO and International Union of Immunological Societies (WHO/IUIS) Allergen Nomenclature Sub-Committee (www.allergen.org) [74] have not officially confirmed or registered any allergens of silkworm pupae aside from this arginine kinase (formally known as Bomb m 1). Therefore, a thorough risk evaluation of possible allergic risks is necessary before establishing silkworm pupae as a food source. Few studies evaluate silkworm pupa allergens, and most tend to base them on case reports rather than regularly using standardized tests. Although 26 silkworm pupa proteins have been identified as allergens, little is known about their immunological characteristics [57].

7.2. Silkworm, a Valuable Feedstuff for Animal Feeding

There is an increased interest in using silkworms in animal feeding due to their protein levels and protein digestibility (76–98%), lipids, and essential fatty acids [6], which emphasize their significance in the current trends in feed science and related sectors. The effects of using silkworm pupae in ruminants and monogastric species, including chickens, pigs, rabbits, and fish, were studied by many authors [75–78]. Silkworm pupae are the potential to replace soybean meal or fish meal in animal feeding. Silkworm pupa meal is a valuable and less expensive alternative protein source having a little lower quality than fish meal. The properties of hen eggs and yolk colour improved when silkworm pupae were used as a protein supplement [5]. In monogastric diets, silkworm pupae did not significantly impact growth and feed efficiency parameters.

The results demonstrated that silkworm pupae can stimulate rainbow trout's immune system and cause some anaemia-related symptoms.

There is little information available about using silkworm pupae in pig diets. However, the pupal powder is advised for pig feeding due to its high protein content [79], albeit the increased oil content may cause an adverse reaction. Interestingly, the protein in pupae is superior to that in fish and soybean meal [5].

8. Employment Opportunity

Sericulture is a low-start-up-cost, employment-focused industry that generates income. The agro-based economic development is depicted as bridging the gap between market-oriented development and various development policy issues and goals, particularly poverty reduction, climate change adaptation, and ecological and economic transformation. Every strategy, action, and link in the value chain must consider the broader structure having as central point humans and their needs. The sericulture industry would significantly impact the modern economies of many nations worldwide.

Commercial silk offers a high return to the producers who live in rural areas of developing nations, and the silk industry requires only modest capital. Thanks to the sericulture sector, millions of people from rural areas are provided with jobs, which prevents and reduces migration to urban areas. More than this, the development of the silk trade was aided by the expansion of the global market, which ensured significant financial inflows into the payment systems of developing nations [80].

Each stage of the technological process involved in sericulture provides products and by-products with a wide range of applications that have been identified and become accessible over time. The question raised is how farmers who use sericulture wastes might benefit.

According to a statement established by the EU in October 2007, applicable in Romania, sericulture producers can obtain funding from the EU of about 134 euros for each carton of silkworm eggs if they deliver the products to a licensed processing centre.

To be eligible for the financial support, breeders must purchase boxes containing a minimum of 20,000 eggs from licensed distributors (e.g., in Romania, Research Station for Sericulture Baneasa, Bucharest), then procure and distribute a minimum of 15–20 kg of silkworm cocoons per box to an authorized processing centre. Breeders must also be members of a sericulture association.

9. Sericulture Development Policy—Perspectives

The practice of eating insects is known as entomophagy, and historical evidence supports this assertion [81].

For a higher economic impact, some more productive mulberry varieties, conservation of silkworm genetic resources, obtaining a new silkworm breed resistant to harmful climatic conditions and diseases, and biodiversity conservation are major challenges. At many national and international forums, the concerns of the access to genetic resources, their sustainable use, benefit sharing, and the farmers' rights are being debated.

At present, few farmers practice sericulture, and even significant subsidies may be obtained. The current government policy is directed to encourage and support the start-up of businesses, particularly in rural areas.

Romania's decision-making factors involved adopting measures to revive the sector, implying specialists for know-how transfer.

Moise et al. [82] and Dezmirean et al. [83] emphasized the significance of the Romanian GCEARS-PSP Centre, which has been recognized by the International Sericulture Commission since 2014, and whose main objectives include developing cutting-edge sericulture research and analyses by using modern methods, building a gene pool for various silkworm breeds, and trying to promote silk output. The revitalization of the Romanian sericulture industry is the primary goal of GCEARS-PSP. A framework for restarting the activity at the Research Station for Sericulture Baneasa, Bucharest, (RSSB) was also established in 2022 due to a government directive using updated coordinates.

Given the importance of raising silkworms via their diversity of products along the value chain and their wide range of possible applications with economic relevance, the involvement of policies, and the expertise of specialists in the sector's relaunch, the projection may be seen as a positive one (Figure 1). A key component of future development is offering technical support for research activities.

Given the financial assistance received by those engaged (specialists, farmers, and processors), silkworm breeding in Romania has great potential. However, it is crucial to keep in mind that the magnitude of subsidies and the development of economic variables are correlated, but it is necessary to keep in mind that the extent of subsidies and the development of financial elements are related.

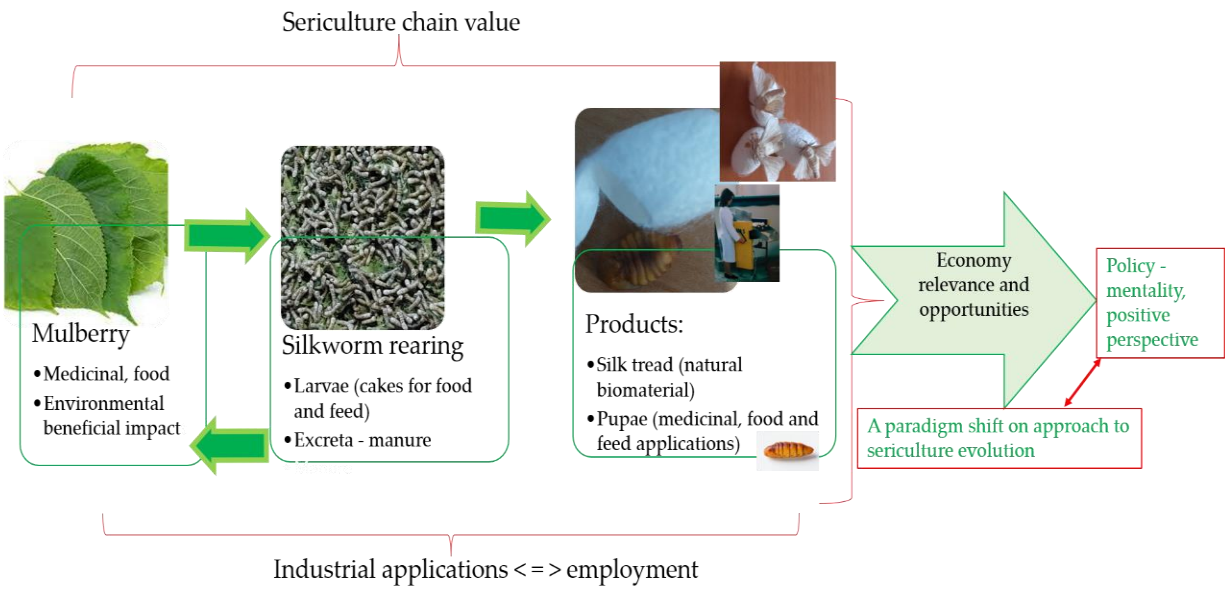

Figure 1. Economic opportunities and perspective of sericulture.

10. Conclusions and Future Directions

A paradigm shift on the approach to sericulture evolution is required. Although sericulture has seen a downturn, the paradox consists in the fact that its economic viability is strongly maintained by a number of factors. The economic potential of sericulture is determined by the ability to value its main output (silk thread) and by-products (pupae, excreta, mulberry leaves, etc.) in various ways (medicine, model insects in genetic and physiology research, food for humans and animal feeding, as compost, manure, biodiesel, etc.). The profitability depends firstly on the mulberry tree production, area, and preservation, and maintaining the habitat despite industrialization. Silkworms are an important contributor to biodiversity and become more and more important as a key factor for food safety and security.

Debatable economic topics include biodiversity conservation, searching for new markets for silk, sharing expertise, know-how transfer, adaptability and shifts in public perception, and regulations at both national and international levels. These issues may be overcome by considering the substantial economic potential of using different silkworm products, the opportunity for sericulture farmers to enhance their earnings, and the promotion and encouragement provided by considerable subsidies.

To increase the value of sericulture, it is also essential to preserve the habitat of the mulberry tree, which is the only feed supply for the silkworm *B. mori*.

Another crucial step is to market and find new applications for by-products such as pupae, excreta, and mulberry leaves, silk threads (as principal commodities).

Providing technical support for research activities is an essential point in future development.

From an economic point of view, another way to boost sericulture is to encourage people from rural areas to start or expand their silkworm-rearing businesses by supplying them with substantial subsidies.

As supplementary arguments, silkworm pupae, besides multiple effects on the medical field and in animal feeding, can provide an alternative to other animal proteins (such as meat, for example).

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