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Valuating the ecological footprint of sericulture: A comparative analysis with other textile industries

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Abstract

Sericulture is a sustainable and environmentally friendly industry, offering numerous advantages over conventional textile production methods, particularly in terms of its lower environmental footprint. This study investigates the environmental and economic benefits of sericulture, highlighting its reduced use of chemicals, waste minimisation, and positive contributions to biodiversity. The cultivation of mulberry trees, crucial to sericulture, promotes integrated cropping systems that optimise land use and enhance ecosystem health. Furthermore, the paper examines sericulture's role in preserving cultural heritage and providing economic opportunities for farmers. A comparison between sericulture and synthetic fibre production—especially polyester—demonstrates the former's relatively smaller carbon footprint, reduced waste, and potential for environmental sustainability. The study also addresses challenges, such as the effects of climate change on mulberry trees and silkworm health. In conclusion, the paper advocates for combining traditional sericulture practices with modern technologies to improve long-term ecological resilience.

Keywords: Sericulture, ecological footprint, textile industries

Introduction

Climate change is one of the most significant environmental challenges humanity has faced over the past century. It arises from the gradual accumulation of greenhouse gas (GHG) emissions, which contribute to global warming (Masson-Delmotte *et al.*, 2021) [10]. As awareness about low-carbon solutions increases, there is growing interest in reducing the carbon footprint of products. A key area of research involves evaluating GHG emissions throughout a product's life cycle, including production, consumption, and recycling (Wang *et al.*, 2018) [14]. It is essential to identify effective strategies to mitigate carbon emissions in order to address the consequences of climate change. The textile industry is a crucial sector, both as a daily necessity and a global trade commodity. However, due to its energy-intensive manufacturing processes and complex supply chains, the industry is a significant source of GHG emissions. It is responsible for around 1.2 billion tonnes of CO2 equivalent (CO2e) emissions annually, representing roughly 10% of global emissions (Leal Filho *et al.*, 2022; UNFCC, 2018) [9, 13]. As environmental concerns rise among both manufacturers and consumers, it is vital to identify the stages in the production process that lead to high energy consumption and pollution, and implement measures to reduce emissions.

Sericulture, the practice of silk farming, has proven to be both globally viable and beneficial to public and environmental health, providing a sustainable alternative to petrochemical products. As sericulture continues to expand in the global market, sustainable cultivation practices ensure that it remains environmentally friendly in both production and application. To assess the ecological footprint of sericulture, it is necessary to evaluate the environmental impacts associated with silkworm farming and silk production. Although sericulture is traditionally considered an eco-friendly industry, its impact can vary depending on the methods used and the geographical location of production. To compare its ecological footprint with that of other textile industries, it is essential to consider factors such as energy consumption, water usage, land use, chemical inputs, carbon emissions, waste generation, and the impact on biodiversity.

Energy Consumption

Energy is essential throughout the silk production process, beginning with manual irrigation during mulberry cultivation. In silk rearing, energy is used for temperature and environmental controls to maintain stable cocoon production and ensure high-quality silk. One of the most energy-consuming stages is transportation. The energy required for this phase depends on factors such as packaging materials, weight, and the method and distance of transportation, making it potentially very energy-intensive (Altman and Farrell, 2022) [1].

Life cycle analyses of silk production show that silk is up to 1000 times more energy-efficient in its formation compared to polyethylene (CFDA). However, the reliance on non-renewable energy sources in current silk production contributes to global warming, abiotic depletion (the depletion of fossil fuel reserves), ozone layer depletion, photochemical oxidation (smog), and continued dependence on non-renewable energy. As sericulture becomes more globalised, these impacts could increase unless silk production, transportation, and other elements of the supply chain transition to renewable energy sources, adopt less energy-intensive production methods, or use local sericulture cultivation with shorter transport networks (Altman and Farrell, 2022) [1].

Compared to synthetic textile industries, sericulture generally consumes less energy. Silk production itself is less energy-intensive than the creation of synthetic fibres such as polyester or nylon, which require significant energy for chemical processing and extrusion. However, while basic stages of sericulture, such as silkworm farming and cocoon harvesting, consume minimal energy, the weaving and dyeing stages still require energy input.

Technological innovations, such as automated silk reeling machines and climate-controlled rearing houses, have improved efficiency, reducing both labour and energy demands while ensuring high-quality silk production. Genetic advancements have led to the development of high-yield, disease-resistant silkworm strains, enhancing productivity without a significant increase in energy consumption. The use of genetically modified naturally coloured silk reduces the need for energy-intensive dyeing processes, thus further lowering the environmental impact. In contrast, synthetic fibres such as polyester and nylon require substantial energy for chemical processing and extrusion, making them far more energy-demanding than natural fibres like silk (Kumar *et al*., 2022) [7]. Synthetic textile production involves high-temperature processes and heavy reliance on fossil fuels, resulting in greater energy consumption and environmental impact (Kumar *et al*., 2022) [7].

Sericulture has embraced sustainable practices, including organic farming and integrated pest management, which reduce both energy use and environmental harm. The recycling of sericultural waste into bio-composites and bioenergy provides eco-friendly alternatives to synthetic materials, further lowering the industry's energy footprint. While sericulture is generally less energy-intensive than synthetic textile production, it is important to consider the entire lifecycle of silk production. Although the weaving and dyeing stages require energy, they are less demanding than the processes used in synthetic textile production. Additionally, the environmental benefits of sericulture, such as reduced microplastic pollution and its potential role in carbon neutrality, underscore its contribution to addressing global environmental challenges (Kumar *et al*., 2022) [7].

Water Usage

Water usage in sericulture, especially in the cultivation of mulberry trees, is moderate when compared to cotton farming, which has a much higher water demand. Mulberry trees, the primary feed for silkworms, require significantly less water than cotton, making sericulture a more sustainable choice in terms of water consumption. However, the environmental impact of sericulture extends beyond water usage alone and also involves concerns regarding water scarcity and pollution. These aspects are discussed in greater detail in the following sections.

Mulberry cultivation, which is essential for sericulture, requires a moderate amount of water. In India, however, the expansion of mulberry cultivation has been linked to increasing water scarcity in certain areas, which has impacted millions of people (Ricciardi *et al*., 2020) [12]. In Malawi, sericulture has emerged as a viable alternative to traditional crops due to its higher economic productivity, although it also places additional pressure on local water resources (Hogeboom & Hoekstra, 2017) [6]. The silk production process itself is water-intensive, particularly during the reeling and dyeing stages. The water footprint of silk production is significant, with reeling contributing most to water consumption, as well as eutrophication due to organic and nitrogen-rich wastewater (Chen *et al*., 2020) [2].

Despite the moderate water use in mulberry cultivation, silk production's overall environmental impact includes water degradation through eutrophication, acidification, and ecotoxicity (Chen *et al*., 2020) [2]. In contrast, synthetic fibre production uses less water directly, but it still contributes to water pollution through chemical runoff during production and dyeing processes. The textile industry is actively exploring technologies that use less water, such as plasma processing and supercritical carbon dioxide dyeing, to mitigate these environmental impacts (Lakshmanan & Raghavendran, 2017) [8].

While sericulture offers a more water-efficient alternative to cotton farming, it still presents challenges related to water scarcity and environmental degradation. The expansion of mulberry cultivation can worsen water scarcity in certain regions, and the silk production process itself contributes to water pollution. On the other hand, synthetic fibres, while less water-intensive, have their own environmental concerns, emphasising the need for sustainable practices across all forms of textile production.

Land Use

Sericulture generally requires less land than cotton farming. Mulberry trees, which are the primary food source for silkworms, can be cultivated on smaller plots, making sericulture a more land-efficient practice. Additionally, sericulture is often integrated into mixed farming systems, which can optimise land use. This contrasts with cotton farming, which typically relies on monoculture practices and requires large tracts of land. When sericulture is integrated with other agricultural practices, it promotes more sustainable land usage. The ability to cultivate mulberry trees on smaller plots also makes sericulture a viable option in areas with limited land availability. This approach to land use in sericulture is more efficient and environmentally friendly compared to the large-scale land requirements of cotton farming, which tends to focus on monocultures.

Chemical Inputs

The use of chemicals in sericulture is primarily aimed at enhancing mulberry yield, protection, and quality, which in turn supports silk production. However, mulberry trees do not require chemical inputs to thrive, and chemicals can be costly, meaning that chemical fertilizers and pesticides are only occasionally applied in conventional sericulture practices (CFDA). Even when chemicals are used, the amount applied is significantly lower than in cotton farming or the cultivation of most other natural fibres (CFDA). This relatively lower chemical usage can be further reduced through effective supply chain management, which can help minimize or eliminate the use of synthetic fertilizers and pesticides.

When fertilizers are used for mulberry cultivation, they typically consist of nitrogen, sulfates, phosphates, potash (potassium-based), lime, and organic manure. While these fertilizers can support plant growth, their application often leads to environmental issues such as the release of nitrous oxide (N_2O) into the atmosphere and the leaching of nitrates (NO_3) into waterways. These consequences are not unique to sericulture but also affect other agricultural practices. However, the application of synthetic fertilizers in sericulture is relatively less intense than in other crops, such as cotton, where the impact is more pronounced. To mitigate these impacts, nutrient management techniques such as planting field buffers and employing conservation drainage practices can be used, helping to reduce fertilizer leaching and minimize environmental damage (Clark, 2014; Helmers *et al*., 2008) [3, 6].

A more sustainable alternative to synthetic fertilizers is the use of silkworm waste as natural fertilizer. This not only supports the sustainability of sericulture but also reduces the reliance on external chemical inputs. However, it is important to note that even organic waste from silkworms can result in environmental contamination through leaching. The decomposition of silkworm waste produces methane and nitrous oxide emissions, which contribute to greenhouse gas emissions. To address this, composting offers a more eco-friendly alternative to landfilling, contributing to carbon sequestration and avoiding synthetic chemicals, thus aligning with sustainability goals in sericulture.

In addition to fertilizers, pesticides and herbicides are occasionally used in sericulture to protect mulberry trees and silkworms from pathogens, parasites, and competitors. These chemicals are typically applied to the leaves or soil, but their use is not always necessary. In fact, Integrated Pest Management (IPM), a sustainable approach to pest control, focuses on reducing pesticide use by favouring environmentally friendly, botanical, or bio-based alternatives. IPM practices are seen as a sustainable parallel to organic farming methods and help maintain the ecological balance while ensuring high crop yields (Nuruzzaman *et al*., 2019) [11]. This approach not only minimizes chemical usage but also supports long-term sustainability in sericulture.

The use of chemicals extends beyond mulberry cultivation into the silkworm rearing phase, where disinfectants such as sodium hypochlorite, lime, naphthalene (mothballs), and formaldehyde are commonly used to reduce the risk of disease and infection. While these chemicals do not significantly contribute to eutrophication or acidification, their environmental impact, as well as their potential effects on workers and end consumers, requires careful management. In this regard, agreements between suppliers and processors often limit the application of harmful chemicals to ensure the safety of the manufacturing process and to reduce risks associated with chemical exposure.

Despite the use of chemicals at various stages of sericulture, it is important to recognise that the environmental footprint of sericulture is relatively lower compared to conventional cotton farming and synthetic fibre production. Cotton farming often relies heavily on pesticides and fertilizers, leading to greater environmental degradation. Similarly, synthetic fibre production, particularly polyester, involves substantial chemical processes that contribute significantly to pollution. In comparison, sericulture presents a more sustainable option with lower chemical inputs and less environmental impact, highlighting its potential as an environmentally friendly alternative to other textile production methods. As the sericulture industry continues to expand globally, adopting sustainable cultivation practices can further reduce its environmental footprint. By shifting towards more eco-friendly practices, sericulture has the opportunity to establish itself as a sustainable, viable alternative to petrochemical-based textile production, contributing positively to both public health and environmental well-being.

Carbon Emissions

The carbon footprints (CFs) of each emission source during the production of an A1 silk quilt are shown in Figure 8. During the stage of producing white silk yarns, steam is the largest source of carbon emissions, contributing 88.16% of the CF in reeling from fresh cocoons (the left-hand column in Figure 8) and 83.45% in reeling from dry cocoons (the right-hand column in Figure 8). This is followed by electricity consumption for equipment driving and lighting, which also contribute to the CF, although to a lesser extent. Other material inputs, such as water, contribute less than 1% to the CF. In the fabric production stage, electricity consumption dominates, accounting for 99.77% of the CF, while the contribution from other materials is negligible. This trend is similar in the production of silk wadding, where steam use for boiling, degumming, and drying accounts for approximately 79.06% of the CF. Electricity consumption for boiling, lighting, and other purposes follows with 9.15%, while materials contribute around 11.79% of the total CF. Hydrogen peroxide solution, used in the process, is the largest contributor at 74.63%, followed by caustic soda (19.58%), soda ash (3.44%), and glacial acetic acid (2.35%).

When comparing carbon emissions across different materials, sericulture tends to have a lower carbon footprint than synthetic fibres, which are derived from petroleum. The carbon emissions in sericulture are largely linked to energy use during the silk processing stages. This contrasts with the production of synthetic fibres, particularly polyester, which generates high emissions due to the extraction and processing of fossil fuels. Although cotton farming is not as carbon-intensive as synthetic fibre production, it still contributes to carbon emissions, particularly through the use of fertilisers, irrigation systems, and transportation. Thus, while sericulture offers a more sustainable option in terms of carbon emissions compared to synthetic fibres, challenges remain in minimising emissions across all stages of the production process.

Waste and By-products

One of the key advantages of sericulture is the minimal waste generated during its production processes. The primary by-product, the cocoon shell, can be repurposed for various uses, such as biodegradable products or even cosmetics, contributing to a more sustainable cycle. In contrast, synthetic fibre production generates substantial waste, particularly in the form of microplastics, which pose significant environmental threats, especially to aquatic ecosystems. While cotton farming also generates waste, it is generally less problematic than the waste associated with synthetic fibres. The sericulture industry, by effectively utilizing by-products such as spun silk fabric, not only contributes to sustainability but also creates additional income streams, enhancing the economic viability of the practice. However, while sericulture offers notable advantages in terms of land efficiency and sustainability, it faces challenges that need to be addressed for long-term viability. Climate change, for instance, poses a threat to sericulture by affecting the growth of mulberry trees and the health of silkworms, both of which are essential for silk production. These climate-related challenges could negatively impact productivity and overall sustainability in sericulture. To ensure the continued resilience of the industry, ongoing innovation and adaptation are required to mitigate the effects of climate change and maintain the sustainability of sericulture practices (Reddy & Parasuramudu, 2024) [20].

Biodiversity Impact

Sericulture, when integrated into farming systems, can play a vital role in supporting biodiversity, offering a more environmentally friendly alternative to cotton farming and synthetic fiber production. The cultivation of mulberry trees, which are essential for sericulture, is often part of diverse cropping systems that enhance ecosystem health. This integration not only promotes biodiversity but also provides economic and cultural benefits. For example, mulberry trees are frequently grown alongside other crops, such as vegetables, in integrated systems that maximize land use efficiency. This practice creates habitats for a variety of species, thus supporting local biodiversity. Additionally, traditional sericulture practices typically involve organic farming and agroforestry, both of which encourage the conservation of biodiversity and contribute to healthier ecosystems. Furthermore, the cultivation of mulberry trees improves soil health and reduces habitat disruption, fostering more resilient ecosystems. In contrast, cotton farming and synthetic fiber production can have significant negative environmental impacts. Cotton farming often relies on large-scale monocultures, which degrade soil quality and reduce biodiversity due to the excessive use of agrochemicals. Similarly, the production of synthetic fibers, which involves the extraction of petroleum and other raw materials, contributes to habitat destruction and broader environmental degradation. Beyond its environmental benefits, sericulture also holds economic and cultural significance. The production of silk and other mulberry-based products provides a sustainable income source for farmers, particularly in regions where other agricultural options may be limited (Grześkowiak, 2023) [4]. Moreover, the cultivation of mulberry trees and the practice of silk production are deeply embedded in the cultural heritage of many communities, preserving traditional farming and craftsmanship methods that have been passed down through generations (Grześkowiak, 2023) [6]. While sericulture offers many advantages in terms of biodiversity conservation and cultural preservation, it is important to balance these traditional practices with modern innovations to ensure long-term ecological sustainability. By combining traditional knowledge with contemporary technologies, it is possible to maintain the ecological balance of sericulture systems and enhance their resilience to changing environmental conditions.

Conclusion

Sericulture offers a viable solution to the environmental issues associated with traditional fibre production methods, such as cotton farming and synthetic fibres. Its minimal use of chemicals, waste repurposing, and positive effects on biodiversity make it a more sustainable option for textile manufacturing. Integrated cropping systems in mulberry cultivation not only support biodiversity but also contribute economically and culturally, benefiting rural communities. Although factors like climate change present challenges to sericulture's productivity, ongoing innovation and adaptation to new technologies can help mitigate these threats. By blending traditional techniques with modern scientific advancements, sericulture can enhance its ecological and economic contributions. This sector presents a promising pathway towards a cleaner, more sustainable bioeconomy, positioning sericulture as an environmentally responsible alternative for the global textile industry.

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