Anthropogenic pollution and its impact on silkworm health and silk production

Abstract:

Sericulture, a vital agro-based industry in India, faces a significant threat from escalating environmental pollution. This abstract synthesizes a review of the harmful effects of industrial, vehicular, and agricultural pollutants on both the silkworm and its host plant. Pollutants like fluoride, sulfur dioxide, and heavy metals directly disrupt the silkworm's physiology, leading to stunted growth, reduced survival rates, and poor silk quality. Pesticides further compromise the larvae's health and productivity. The review underscores the urgent need to address this pollution to ensure the sustainability of India's sericulture sector and protect the livelihoods it supports.

Keywords: anthropogenic, host plant, pollution, sericulture, silk, silkworm

Introduction

Sericulture is an important agro-based cottage industry in India, providing employment and income, particularly to rural populations. As the world's second-largest producer of raw silk after China, India is uniquely positioned due to its ability to cultivate all four major types of silkworms—mulberry, eri, muga, and tasar; due to its diverse environmental conditions. However, this vital industry is highly susceptible to various factors, with anthropogenic activities, particularly pollution, posing a significant threat. The impact of pollution, which has escalated dramatically since the Industrial Revolution, includes the harmful effects of industrial smoke, vehicular dust, and pesticides on both silkworms and their host plants. This highlights the critical need to address these environmental challenges to sustain and protect India's sericulture sector.

Effect of pollution on host plants of silkworm:

Environmental pollution significantly impairs plant health, with airborne, soil, and water pollutants entering plants through their leaves, roots, and surfaces. This exposure leads to rapid and direct effects like oxidative bursts, as well as long-term metabolic interference, which disrupts photosynthesis, nutrient uptake, and circulation. Ultimately, these issues result in stunted growth, reduced yields, and economic losses.

A major source of pollution comes from the petroleum and automobile industries, which release pollutants such as carbon monoxide, nitrogen oxides, and hydrocarbons. When exposed to sunlight, nitrogen oxides and hydrocarbons react to form photochemical smog, a toxic brown haze composed primarily of ozone (O_3) and peroxyacetyl nitrate (PAN). Ozone heightens leaf respiration, which can kill plants, while PAN obstructs the "Hill reaction," effectively halting photosynthesis and food production (Kakati, 1994).

Furthermore, the combustion of fossil fuels in thermal power plants releases large amounts of sulfur dioxide. When *Morus alba* (mulberry) trees were exposed to 1 ppm SO_2, brownish-red interveinal spots appeared on mature leaves after ~82 hours; at 2 ppm, symptoms appeared in ~28 hours. Damage corresponded to sulfur intake around 0.4-0.5% dry weight. Leaves with sulfur content under ~0.2% caused no adverse effects in silkworm larvae, but when sulfur exceeded ~0.3%, negative effects on larval growth, cocoon quality, and silk yield were observed. Heavy metals likewise affect mulberry: soil cadmium levels of ~75.8 mg/kg began reducing leaf yield; leaf Cd of ~1.98 mg/kg lowered ingestion by silkworms, ~5.17 mg/kg reduced cocoon weight and silk reeling. Fluoride deposition over ~1.5 μg dm^{-2} per day causes >30 ppm in mulberry leaves (threshold for silkworm injury), while >80 ppm severely inhibits cocoon production. Even low-level NO_2 (~4 μLL^{-1}) can, under certain conditions, improve photosynthetic efficiency via enhanced nitrogen metabolism—but such effects may reverse under higher or prolonged exposure (Chen *et al*., 1988; Wang *et al*., 2004; Wang *et al*., 2019).

Effect of pollution on silkworm:

Pollution not only affects the host plant but also affects the silkworm. There are many factors which affect silkworm directly or indirectly. Some of them are-

i.Effect of factory exhaust gases:

Growing rural industries and increased vehicle exhaust have exacerbated environmental pollution, a problem now posing a serious threat to sericulture. Silkworms that consume leaves contaminated with industrial exhaust gases, such as hydrogen fluoride, sulfur dioxide, and chlorine, suffer from poisoning (Sengupta *et al*., 1990; Ping and Jie, 2011). In China, for example, rising atmospheric fluoride levels have contaminated mulberry leaves, leading to stunted silkworm development, failure to spin cocoons, and even death (Xu *et al*., 2006).

a. Effect of fluoride on silkworm:

Fluoride contamination from mulberry leaves significantly impacts silkworm health and productivity. The toxins reduce essential minerals like calcium and magnesium in the larval hemolymph while increasing the activity of certain enzymes, which disrupts energy supply and metabolism (Lin *et al*., 1994; Shun *et al*., 1994). This also affects cellular function, causing damage to the intestinal epithelial cells, body wall, and midgut, leading to poor digestion, malnutrition, and even cell death (Zang and Shunlin, 1995; Zhong, 1994). As a result, silkworms exposed to fluoride exhibit severe toxic symptoms, including uneven growth, weight loss, and dark spots on their bodies. In later stages, this toxicity leads to thinner body walls, reduced pupal and moth viability, and decreased egg production, with more unfertilized eggs (Tang *et al*., 2018). Studies on the fifth instar larvae confirmed that fluoride exposure negatively impacts key economic traits, such as larval growth, cocoon and shell weight, silk index, filament length, and the moth's fecundity (Ramakrishna *et al*., 2004).

b. Sulfide poisoning on silkworm:

Exposure to sulfide gases, specifically sulfur dioxide (SO_2) and hydrogen sulfide (H_2S), poses a direct and severe threat to silkworms. These gases, primarily emitted from industrial factories and the combustion of coal, are far more toxic to silkworms than consuming contaminated leaves. Their main mode of action is to attack and destroy the silkworm's respiratory system, disrupting the process of gas exchange essential for their survival.

This respiratory damage leads to developmental disorders, as the silkworms are unable to get the oxygen needed for proper growth and metabolism. The compromised physiological state eventually results in their death, often characterized by softening symptoms where their body tissues break down. This direct poisoning highlights a critical and immediate risk to sericulture in areas with high levels of industrial air pollution (Anon., 2021a).

c. Effect of chlorine:

While direct, detailed studies on the specific effects of chlorine (Cl_2) and hydrogen chloride (HCl) smoke on silkworms are limited, existing research on similar industrial pollutants and chemical treatments offers a strong basis for understanding the potential harm. The available literature suggests that these pollutants can poison silkworms when they consume contaminated mulberry leaves (Anon., 2021a).

The toxicity likely stems from the corrosive nature of these chemicals, which, like other acidic pollutants, would disrupt the silkworm's delicate physiology. Other studies show that pollutants can damage the midgut, interfere with digestion and absorption, and lead to malnutrition (Zhong, 1994). This physiological stress results in symptoms such as uneven growth, weight loss, and reduced vitality (Tang *et al*., 2018). The potential harm of chloride-based compounds is further supported by research into other chlorinated substances used in sericulture for disinfection, such as bleaching powder, which, while beneficial for killing pathogens, must be used at very specific, low concentrations to avoid harming the silkworms themselves (Baig *et al*., 1994). This highlights the dual nature of chlorine compounds, which are useful in controlled doses but highly toxic as environmental pollutants.

d. Effects of road dust:

Reports from the Kashmir valley highlight the detrimental effects of dust pollution on silkworm cultivation. A study found that silkworms consuming dust-laden mulberry leaves had an extended larval stage, became more susceptible to diseases, and produced silk with undesirable qualities, including doubled renditta (the ratio of fresh cocoons to raw silk) and a 26% reduction in reelability (Khan *et al*., 2013). Further research revealed that dust significantly reduces the silkworms' ability to consume, assimilate, and convert food into silk, especially during the crucial fourth and fifth instars (Ahanger *et al*., 2015). The widespread impact of this pollution, including from automobiles, is reflected in the significant decline of cocoon production in the region, which fell from 15 lakh kg in 1960 to just 8.32 lakh kg in 2009. While a portion of the production is used locally, the majority is sent elsewhere in India. This decline underscores the severe threat pollution poses to Kashmir's sericulture industry (Ahanger *et al*., 2016).

e. Effect of nanoparticles:

Nanotechnology holds great promise for sericulture by improving silkworm survival and silk quality, yet concerns remain about the toxicity of certain nanomaterials. While some studies show therapeutic effects, others highlight harmful impacts on silkworm tissues and organs (Fometu *et al*., 2021). For example, silver nanoparticles (AgNPs), a common antibacterial agent, have been shown to be toxic. Studies by Pandiarajan *et al*. (2016) found that silkworm larvae fed with AgNPs, especially at a concentration of 100 ppm, experienced high mortality after spinning. Lower concentrations (10 ppm) also led to low adult emergence, with many emerging pupae having malformed or vestigial wings. This suggests that even small amounts can disrupt development.

Further research by Meng *et al*. (2017) revealed the deeper mechanisms behind AgNP toxicity. They found that AgNPs interfere with key biological processes, including metabolic cycles, signal transduction, and ion transport. This interference weakens the silkworm's metabolic function, reduces its ability to handle oxidative stress, and disrupts cell death processes and detoxification proteins, ultimately leading to severe negative health effects.

f. Effect of heavy metals:

Heavy metals like arsenic (As), lead (Pb), mercury (Hg), and cadmium (Cd) are toxic substances with a high density, primarily found in soil and water (Islam *et al*., 2019). Their presence in the environment is largely due to industrial activities, such as metal smelters and chemical plants, which release contaminated waste gas and water. Silkworms can become poisoned when they consume host plants that have absorbed excessive amounts of these metals from polluted soil or water (Anon., 2021a).

The accumulation of heavy metals through the food chain can cause irreversible damage to silkworms. For instance, lead (Pb) and cadmium (Cd) have been shown to inhibit the growth and photosynthesis of mulberry plants, which are the primary food source for silkworms (Si *et al*., 2020). Studies confirm that these metals have inhibitory effects on the silkworms themselves, significantly reducing their body length and weight. Furthermore, a study on muga silkworms revealed that heavy metal exposure extended the larval duration and resulted in a lower body weight. Specifically, the accumulation of Cd, Pb, and manganese (Mn) was negatively correlated with pupal weight, demonstrating the severe impact of these pollutants on silkworm development and productivity (Islam *et al*., 2019).

g. Effect of pesticides:

Pesticides, designed to eliminate pests, are widely used in agriculture but have a significant negative impact on non-target organisms like silkworms (Sitaramaraju *et al*., 2014). It is estimated that a large percentage of these chemicals miss their intended target, leading to their accumulation and biomagnification in the environment (Kalita and Devi, 2016).

Pesticides poison silkworms through various methods, including direct contact, ingestion, and fumigation (Bora *et al*., 2012). Residues can remain in the soil from previous crops, be absorbed by mulberry plants, and then ingested by silkworms. This leads to a range of symptoms and poor outcomes, even if the larvae appear to develop normally initially.

According to several studies, pesticide exposure can cause the following symptoms:

Sl.No.	Symptoms	Source
1.	Abnormal behavior: Symptoms like body shrinkage, erratic movement, and vomiting	Jyothi, 2019; Kuribayashi, 1988
2.	Developmental failure: Larvae may fail to spin cocoons, undergo incomplete metamorphosis, or die during the spinning stage	Jyothi, 2019; Park *et al*., 2007
3.	Reduced productivity: The growth and development of the larvae are retarded, and their ability to spin silk is reduced. Moths may also show lower fecundity.	Stanley and Gnanadhas, 2016
4.	Significant economic losses: In China, pesticide use was linked to a 30% reduction in annual silk production	Li, 2010

Table 1- Pesticide exposure can cause the above symptoms, and their sources are in the above table

These effects are consistent across various pesticide types, including organophosphorus, organochlorine, and organonitrogen compounds, with direct food intake being a key route of poisoning (Narayanamma, 2017; Kordy, 2014; Munhoz *et al*., 2013). The accumulation of pesticides in the environment thus poses a critical threat to the sericulture industry globally.

Effect of pollution on muga silkworm:

Activities such as railway tracks and brick kilns near food plants negatively impact muga silkworms (*Antheraea assamensis* Helfer) (Chowdhury, 1982). A more significant threat, however, is the widespread use of pesticides in nearby tea gardens and agricultural fields. According to Neog *et al*. (2021), this poses a severe risk, potentially leading to the extinction of Assam's muga silk heritage by 2040 if left unaddressed.

Two of the most common types of pesticides used by farmers in Assam are organophosphates and pyrethroids (Bora *et al*., 2012). Organophosphates, such as malathion and phosphamidon, are highly toxic to silkworms, even at low doses, and are known to inhibit crucial enzymes (Tazima, 1978). This leads to a decrease in tissue weight and a reduction in total lipids, proteins, and glycogen in the larvae (Bora *et al*., 2012).

Pyrethroids, despite being considered relatively safe for general use, are also extremely toxic to muga silkworms. For example, while the synthetic pyrethroid deltamethrin is effective against silkworm parasitoids (*Exorista sorbillans*), it is far more lethal to the muga silkworm larvae themselves, highlighting a significant and unintended consequence of its use (Khanikor, 2011).

Effect of crude oil exploration sites of Assam on muga silkworm:

A study by the Regional Research Laboratory (RRL) in Assam investigated the impact of crude oil pollutants on muga silkworms. The research found that a semi-solid mixture of hydrocarbons and sulfur significantly altered the nutritional quality of the host plants, leading to a drastic decrease in the number of silkworms that could complete their life cycle (Bhattacharya and Baruah, 2006).

Specifically, the study noted several adverse effects on the silkworms:

- Reduced Survival: Fewer than 370 silkworms survived in the polluted area, compared to over 800 in the control group.
- Physiological Damage: The total haemocyte count (THC) and blood volume (BV) of the silkworms were significantly lower in the polluted insects, indicating compromised health.
- Poor Cocoon Quality: All cocoon characteristics were negatively affected.
- Fiber Degradation: Scanning Electron Microscope (SEM) analysis revealed deep cracks in the silk fibers from the polluted area, a stark contrast to the

minor cracks found in the control group's fibers (Bhattacharya and Baruah, 2006).

Preventive measures:

To protect sericulture from pollution, several preventive measures can be taken. Host plant gardens should be located away from traffic and industrial zones (at least 1 km). Factories should use filters on chimneys or increase their height. Other general steps include reducing forest fires, using eco-friendly products, and properly maintaining sewage systems.

For specific pollutants, there are targeted solutions. For fluoride contamination, silkworms can be fed leaves washed with lime solution, and certain fluoride-resistant silkworm races can be used (Zhao *et al.*, 1996). Antidotes like calcium salts can treat fluoride poisoning (Zouling and Cheng, 1994), while adrenaline hydrochloride and atropine sulfate are effective against specific pesticide poisonings (Wangliu, 1991; Wan, 2008). Additionally, adhering to safety periods for harvesting leaves after pesticide application is crucial to avoid contamination.

Conclusion:

Anthropogenic pollution from industry, agriculture, and vehicles poses a severe and multifaceted threat to India's sericulture industry. Pollutants such as fluoride, heavy metals, and pesticides directly poison silkworms and their host plants, leading to stunted growth, reduced survival rates, and poor silk quality. Studies have shown that dust and chemical residues on mulberry leaves negatively affect the larval ability to digest food and develop properly, resulting in economic losses. While nanotechnology offers potential benefits, certain nanomaterials like silver nanoparticles have been found to be toxic to silkworms. To mitigate these impacts, it is crucial to implement preventive measures like locating farms away from polluted areas, using chimney filters, and applying specific antidotes or cultivating pollution-resistant silkworm varieties. These actions are essential to protect this vital agro-based cottage industry.

Future Prospects

To secure the future of sericulture, a shift towards sustainable and eco-friendly practices is essential. This includes promoting organic farming to reduce pesticide and chemical use, which would directly benefit silkworm health. Developing and deploying silkworm races and mulberry varieties with enhanced resistance to specific pollutants, like those resistant to fluoride, offers a long-term solution.

Research into bio remediation using plants and microorganisms to clean up contaminated soil and water is another promising avenue. Furthermore, integrating advanced technologies like remote sensing and GIS can help monitor pollution levels in real-time, allowing farmers to take proactive measures. Finally, the development of safer, bio-based pest control methods that do not harm non-target species is critical.

By embracing these innovations, India can safeguard its unique sericulture heritage and ensure its continued growth in a changing environment.

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