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Review article

Heavy Metals and Sericulture: Implications for Industry Sustainability

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ABSTRACT
Heavy metals have been a major environmental challenge and concern many researchers and environmental scientists. They are produced primarily through several anthropogenic activities and some natural processes. Since they are non-biodegradable and can withstand prolonged exposure to aquatic and terrestrial conditions, their highest toxicity can be sensed even at low concentrations (e.g., Arsenic, Lead, Mercury, Cadmium, Chromium, and Thallium). Some trace elements such as Selenium, Copper, and Zinc can negatively impact the biota, oxidation-reduction reactions, and vital enzymes. A rise in reactive oxygen species (ROS) is one of their harmful consequences. Sericulture, the synthesized science of silk production, provides financial security to millions of people in the country. The unit cost of raw silk is 20% greater than that of raw cotton, making it one of the costliest natural fibers. However, heavy metals have a detrimental effect on the silkworm life cycle, their survival, and their capacity to produce silk. The scientific community has been urged to investigate biotechnology, among other areas, to determine if heavy metal contamination of silkworms could be detected. This would assist in enhancing production and using the silkworm as a model organism for producing foreign protein. Hence, our key areas of interest are to review the contamination of silkworms with heavy metals, which will give an idea of how it would benefit poor countries economically and future sericulture research from this work.

Key words: Heavy metals, Lead, Mulberry, Silkworm, Sericulture, Toxicity

INTRODUCTION

Sericulture, the practice of cultivating silkworms to produce silk, has been an integral part of human civilization for centuries. Silk, "The Queen of Fibers," has a special position in the cultural tapestry of people worldwide and is revered for its luxurious texture, vibrant colors, and historical significance. Beyond its aesthetic appeal, sericulture has been pivotal in shaping economies, facilitating trade routes, and nurturing traditions across continents (Lee 2011, Longvah et al. 2011, Dutta et al. 2012, Gupta et al. 2015). India is the second largest producer of silk worldwide, producing all four varieties of commercial silk, viz., mulberry, eri, muga, and tasar. Sericulture today is the main source of livelihood, directly or indirectly, for many people. Majority of who are from economically retarded sections of the society, the Scheduled Castes (SCs) and Scheduled Tribes (STs).

Although silkworms are both domesticated and wild, they are reared and exposed to different xenobiotics through food contamination. The major food of *Bombyx mori* is *Morus alba* (mulberry) leaves, and wild variety silkworms feed on *Terminalia arjuna* (Arjun tree), *Ziziphus mauritiana* (Ber), *Terminalia catappa* (Badam tree), *Quercus* spp. (Oak), *Terminalia tomentosa* (Indian laurel) and *Shorea robusta* (Sal) are attacked by many insect pests like mites, grasshoppers, mealy bugs, beetles, and cutworms (Singh and Saratchandra 2002). To control these pests, various insecticides are sprayed on plants. Some other pesticides used in surrounding areas also reach mulberry and other plants through spray drift, runoff, and leaching. Throughout the world, Imidacloprid is a common insecticide used to manage chewing and sucking insect pests. It is transferred to the various portions of plants through the soil or leaves, where it is absorbed. Imidacloprid binds to the central nervous system's nicotinic acetylcholine receptors in insects, resulting in paralysis and death (Matsuda et al. 2001, 2005).

In a few decades, heavy metal pollution in the environment has increased many folds due to the shrinkage of forest area and climate change, along with increased industrial units, mining, agricultural activities, etc. As a result, toxic heavy metals and petroleum hydrocarbon (PHC) are accumulated in air, soil, and water bodies. The fate of heavy metals in soil is of great environmental concern. Heavy metals can persist for long periods in aquatic and terrestrial environments, adversely affecting the environment (Nouri et al. 2008). Especially in terrestrial ecosystems, higher plant-insect food chains are problematic because of their complexity and vulnerability to environmental contaminants. Although insects in terrestrial habitats are not typically exposed to acutely hazardous metal concentrations, they may do so in sub-lethal doses that can impact various vitality indices (Yu et al. 2016). Therefore, it is quite interesting to compare the metal concentrations in plants and the herbivorous insect larvae that feed on them (Lindqvist 1992). Numerous studies have sought to explain metal build-up in insects from polluted habitats. In this review, we describe an essential terrestrial food chain, consisting of the plants and the silkworms, because it can be used to examine the dynamic behaviour of heavy metals in terrestrial ecosystems, particularly in cases with a greater plant-insect hierarchy.

HEAVY METAL SOURCES

Any metallic element with a high density and a high level of toxicity or poisonousness is referred to as a “heavy metal,” even at low concentrations (Mishra et al. 2022). Through both natural and anthropogenic processes, heavy metals enter our environment and build up in various environmental components, including the air, water, soil, etc. Industries like mining, smelting, and agriculture have contaminated a large portion of the world. Since heavy metals are formed in the Earth’s crust, their natural existence in the soil is merely a result of weathering (Sharma and Agrawal 2005).

Natural sources of heavy metals

Under specific and various environmental conditions, heavy metals naturally escape from their endemic region and into our background compartments. Geologic parent material or rock outcroppings are the primary natural source of heavy metals. In general, Chromium (Cr), Manganese (Mn), Cobalt (Co), Nickel (Ni), Copper (Cu), Indium (In), Cadmium (Cd), Tin (Sn), Mercury (Hg), and Lead (Pb) are present in significant quantities in geologic parent materials. In addition to hazardous and damaging gases, high levels of Aluminum (AI), Indium (In), Manganese (Mn), Lead (Pb), Nickel (Ni), Copper (Cu), and Mercury (Hg) have been recorded to be released by volcanoes. Heavy metal emissions into the air come from prairie and forest fires (Fig. 1). Heavy metals that are flammable, such as Mercury (Hg) and Selenium (Se), are present in the carbonaceous material created by the fire. High levels of Iron (Fe) and lower concentrations of Mn, In, Cr, Ni, and Pb can be found in wind dust, which is produced in desert regions like the Sahara (Ross 1994). Natural vegetation releases heavy metals into the soil and atmosphere through leaching from leaves and stems, decay, and volatilization. Due to sea sprays and aerosols produced by marine activity, many heavy metals have been found in inland coastal locations (Mohammed et al. 2011, He et al. 2013).

Anthropogenic sources of heavy metals

Manmade activities have been found to contribute to heavy metal contamination due to the daily manufacturing of goods to meet the requirements of the large population. Excess utilization of mines and smelters, the combustion of fossil fuel, application of metal containing fertilizers and pesticides, metal-based paints, metal bearing sewage water in agricultural use, metallurgical industries, military training processes, domestic sewages, manufacture, use, and disposal of electronic things, as well as clinical or hospital products etc., are the important anthropogenic emergence which radically adds to the heavy metal contaminations in the environment (Alloway 1995, Tsakona et al. 2007, Sitaramaiah and Kumari 2014).

IMPACT OF SOIL HEAVY METALS ON SILKWORMS

The heavy metal concentrations finally detected in the soil may be hazardous to plants and animals due to direct toxic effects or consequences on the food chain (Hunter and Johnson 1982). Industrial processes include mining and smelting of metalliferous ores, electroplating, petrol exhaust,

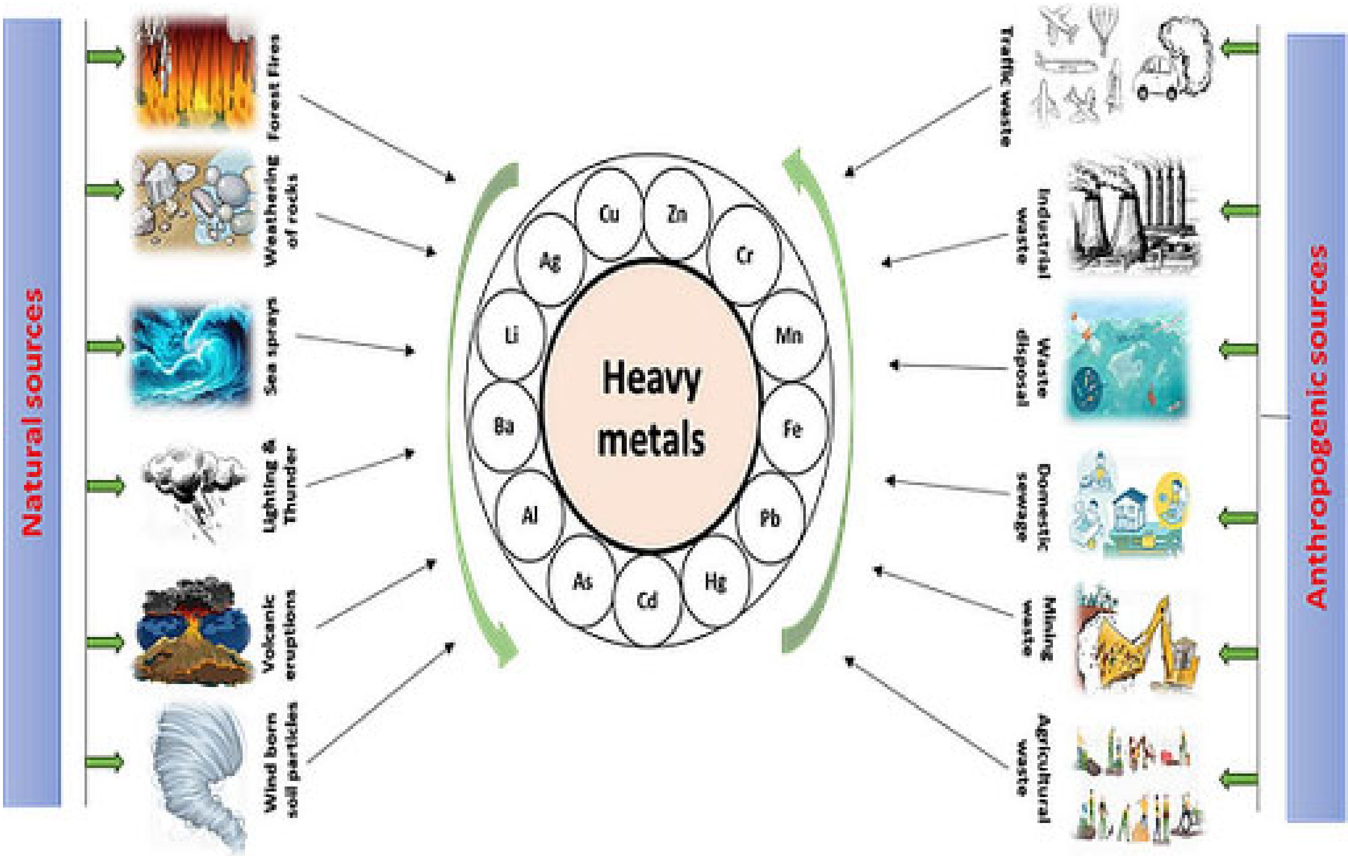

Figure 1. Heavy metals production from both natural and anthropogenic sources

energy and fuel production, the use of fertilizers and pesticides, and the creation of municipal garbage are the most common anthropogenic sources of contamination that increase Pb, Cr, As, Cd, Cu, Hg as depicted in (Fig. 2) (Kabata-Pendias 2000, Liu et al. 2013, Chen et al. 2015, Karim et al. 2015). Several heavy metals are vital micronutrients for plants, but if they exceed the phytotoxicity threshold, they can harm plant growth (Bennett 1993). For example, Zn (II) becomes hazardous when its maximum soil content exceeds 400 mg/kg (Kabata-Pendias and Pendias 1992). Heavy metals absorbed through the root systems cause chlorosis in the leaves and inhibit the growth and penetration of the roots (Scott 1992). Phytoremediation is a novel method regarded as a cost-effective, eco-friendly technology with greater public acceptance.

Some silkworm-rearing plants, including *Morus alba* (mulberry) trees (Zhou et al. 2015, Jiang et al. 2017), Arjun tree (Wijeyaratne and Shanthamareen 2020) and Oak tree (Poguberoviæ et al. 2016), may be able to extract or detoxify metals from contaminated soils and have the reutilization potential of heavy metals-contaminated paddy soils high biomass, quick growth, and deep root systems. Furthermore, it has been demonstrated that feeding silkworms leaves from heavy metals-polluted areas caused certain variations in the silkworms' (*Bombyx mori*) growth and development, as well as the quantity and quality of their cocoons (Zhou et al. 2015, Jiang et al. 2017) (Table 1). Previous research found that around 10% of the Cd the mulberry root absorbed from the soil was deposited in the leaf. The soluble portion of the mulberry leaf and the cell wall of the mulberry root both contained significant amounts (53.3 - 70.2%) of Cd (Huang et al. 2018). Therefore, some Cd enters the human body through the soil – mulberry silk worms' food chain (Fig. 3). Similarly, Tucker et al. (2003) discovered that Qiufeng Baiyu and Qingsong Haoyue growth was severely inhibited and that both silkworm races experienced high death rates even at low doses of 400 mg/L Cr(III) or Cr(VI) ions. The worst issues facing the globe now are environmental pollution and degradation.

Table 1. Impact of various heavy metals on silkworms

Heavy metals	Harmful effects	Species	References
Cadmium (Cd)	Decrease the body weight, body length, weight/length ratio of silkworms, change the larval duration, decrease pupa weight, impact fundamental process (digestion and absorption of food), epidermal shrinkage, Destroy the midgut structure, affect enzyme activity (GST, GPx, SOD, CAT)	*Bombyx mori* *Antheraea assamensis*	Chen et al. (2023),Si et al. (2021), Liu et al. (2021), Sahi et al. (2020), Islam et al. (2019), Hamido and Abdelghani (2018)
Lead (Pb)	Inhibit the body length, decrease weight growth of silkworm, reduce the ratio of weight to length, increase the mortality rate of larvae, decrease CAT activity, reduce cocoon weight and cocooning percentage, decrease pupa weight	*Bombyx mori* *Antheraea assamensis*	Si et al. (2021),Islam et al. (2019), Hamido and Abdelghani (2018), Nikolova et al. (2015)
Trivalent Chromium Cr(III)	Effects silk glands, change pH value, reduced body length and body weight, increase mortality rate of larvae	*Bombyx mori*	Ashfaq et al. (2012)
Hexavalent Chromium Cr(VI)	Effect on larval growth, silk glands, cuticle, alimentary canal, cellular stress, decreased cocoon weight, increased larval mortality rate, pH variation of larvae	*Bombyx mori*	Rong et al. (2023), Shoukat et al. (2014), Hamido and Abdelghani (2018)
Manganese (Mn)	Decrease pupa body weight, affect enzyme activity of larvae (SOD and CAT activity)	*Antheraea assamensis* *Bombyx mori* L.	Islam et al. (2019), Hamido and Abdelghani (2018)
Zinc (Zn)	Decrease GST and CAT activity, inhibits the ROS production	*Antheraea assamensis* *Bombyx mori*	Islam et al. (2019), Nikolova et al. (2015)
Uranium (U)	Effect fat bodies of the pupae, change and decrease antioxidant enzyme activity (MDA, SOD, CAT, GSH, GST, GSH-Px)	*Antheraea pernyi*	Zhang et al. (2021)
Fluorine (F)	Increase mortality rate of larvae, vomiting, decrease food consumption, decrease larvae weight and cocoon weight, changes ion concentrations (Ca^2z and Mg^2z), changes protein metabolisim and amino acid in haemolymph, affect enzyme activity(CAT and GDH activity), effect on cocoon production	*Bombyx mori*	Kuribayashi (1971), Jia-xi and Yong-Mei (1988), Yong-mei (1985), Miao et al. (2004), Miao et al. (2004)
Sulfur(S)	Motionless, agony, vomiting, rolling, death, affected cocoon and silk parameters	*Bombyx mori*	Kuribayashi (1971)

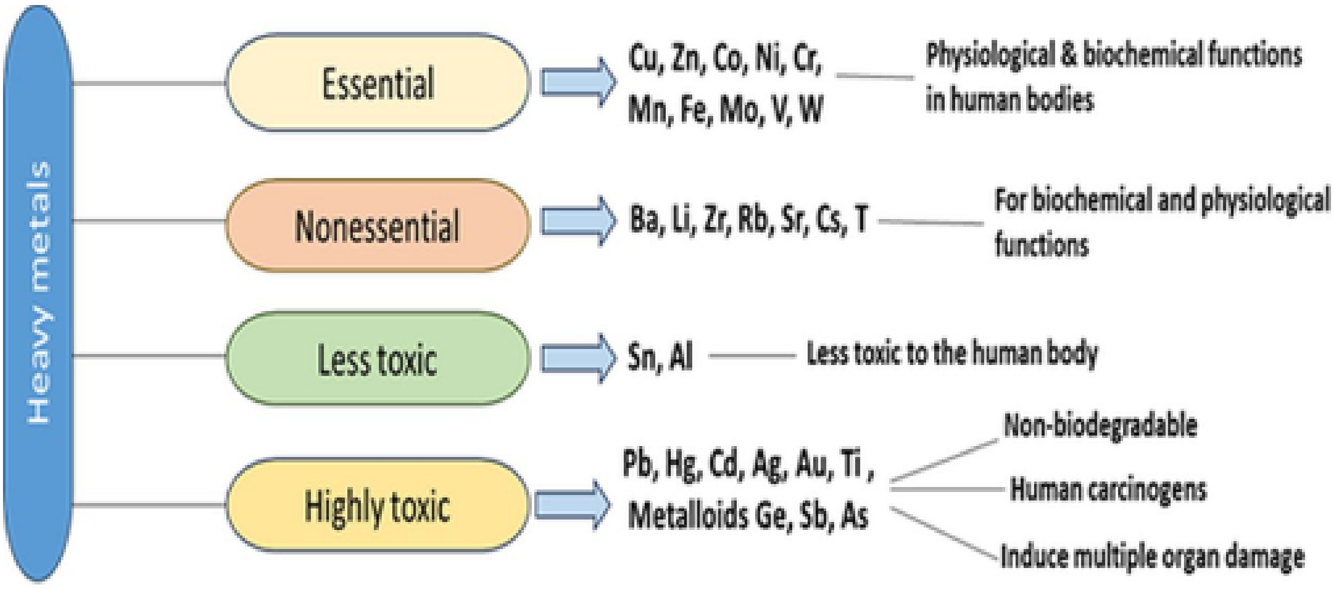

Figure 2. Classification of heavy metals according to how they interact with living things

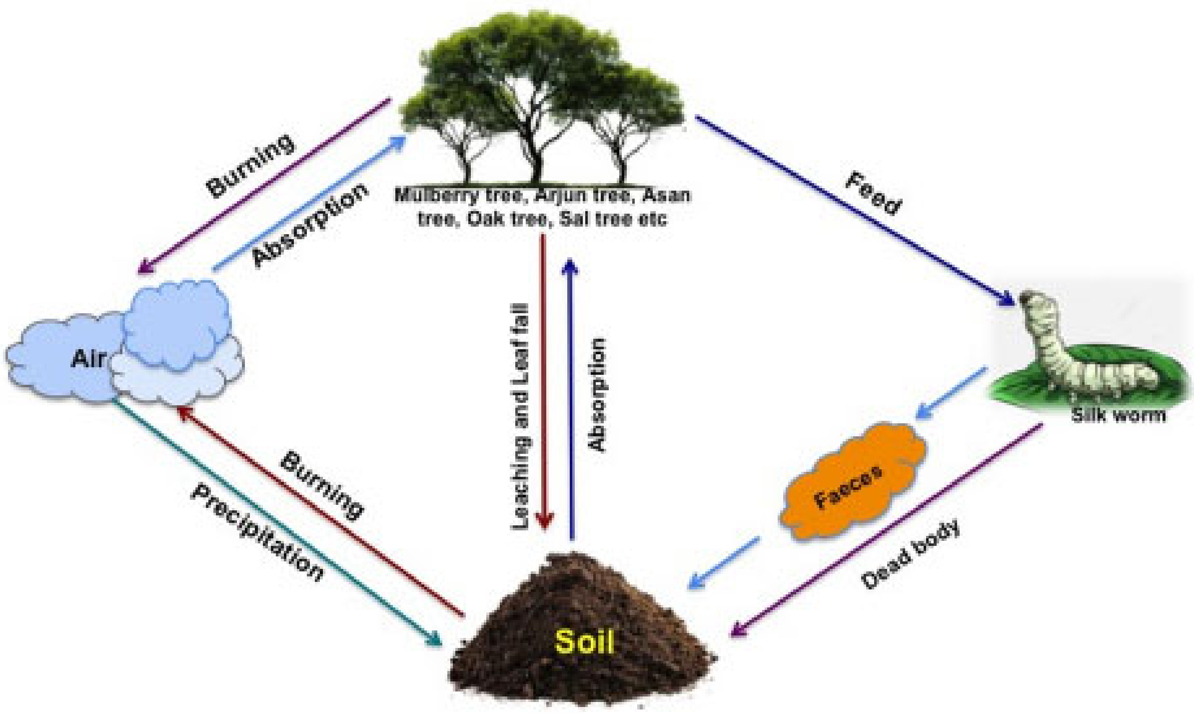

Figure 3. Heavy metals in mulberry and non-mulberry silkworm ecosystems

IMPACT OF AIRBORNE HEAVY METALS ON SILKWORMS

Air contamination has been attributed to both primary (direct) and secondary (indirect) effects on insect populations. The best-developed literature describes the effects on silkworms and other insects (Alstad et al. 1982, Hain 1987, Ryalls et al. 2022). Prominent examples include those in which a commercially valuable insect is poisoned. Silkworms mostly ingest fluoride through mulberry leaves, and 30 ppm is sufficient to result in silkworm poisoning, which is characterized by decreased food intake, lengthened lifespans, and lighter pigmentation (Jia-xi and Yong-Mei 1988). Kamilova and Tsarev (2008) reported that in Uzbekistan, high levels of chemical inputs and air pollution have caused fluorides and toxic metals to accumulate in the soils and water bodies of the area, and sediments that are released from these sources are likely to be quite harmful. In the polluted area, it was discovered that soils, silkworm dung, and cocoons had accumulated levels of dangerous metals such as zinc, nickel, mercury, antimony, and many more. Airborne pesticides harm hundred thirty tonnes of cocoons per year (Kuribayashi 1971). Damage from air pollution has the unique property of appearing to harm silkworm cocoons as well as mulberry tree leaves. The mulberry tree absorbs the airborne contaminants released into the soil from manufacturers. Healthy silkworms sustain damage quickly (Table 1). Brown patches at leaf tips and edges are the visual symptoms caused by hydrogen fluoride gas concentrations of 150–200 ppm (Kuribayashi 1969). Silk can be killed at levels that are half as low. Silkworms with chlorine gas burns exhibit decreased appetite and occasionally vomit silk thread. The growth of mulberry trees is severely hampered by gaseous impurities, typically sticky and insoluble in water. They also contain stacked smoke and carbon particles. Depending on their size and composition, dust and suspended particles from nearby plants have varying effects.

SERICULTURE WORKERS HEALTH RISK ASSESSMENT

Heavy metal deposition in soil and aquatic environments is significantly greater than atmospheric deposition, caused mainly by anthropogenic activity. Recent efforts have been the most severe in casting doubt on the safety of humans and other organisms on Earth. Therefore, this circumstance necessitates inventing and applying unique and effective approaches to find and eliminate or minimize metal pollutants from our environment (Eriyamremu et al. 2005, Muchuweti et al. 2006).

As primary contributors to silk production, silkworms are susceptible to heavy metal exposure through their diet, which may result in incorporating these contaminants into the silk fibers they produce. This threatens the quality of the silk and poses a potential health risk to the workers involved in the various stages of sericulture, from rearing silkworms to harvesting silk. These workers, often near heavy metal-contaminated environments, face a range of health risks. Prolonged exposure to heavy metals can lead to respiratory issues, skin ailments, and more severe conditions such as heavy metal poisoning (Vaajasaari et al. 2002). Additionally, many workers in the sericulture industry may not have adequate access to protective gear or training on safe handling practices, compounding their vulnerability.

POTENTIAL MITIGATION STRATEGIES

Mitigating the impact of heavy metals on the sericulture industry is imperative to ensure the sustainability of this vital sector. Several potential strategies can be deployed to address this challenge comprehensively. Soil testing and remediation techniques offer an initial line of defense, enabling the identification and treatment of heavy metal-contaminated soils. Careful crop selection, emphasizing the cultivation of heavy metal-resistant mulberry varieties, can minimize metal uptake. Good Agricultural Practices (GAP) prevents contamination by promoting responsible land management and safe agricultural practices. Implementing effective effluent treatment systems is paramount to ensure that heavy metal-laden wastewater does not infiltrate the environment. Robust monitoring and regulatory frameworks must be implemented, backed by educational initiatives to raise awareness among sericulture stakeholders. Furthermore, research and innovation should be encouraged to develop cutting-edge technologies and sustainable practices for a heavy metal-free sericulture industry. In essence, these strategies form a comprehensive approach to safeguard the sericulture industry from the adverse effects of heavy metal contamination while promoting its long-term viability.

CONCLUSIONS

In conclusion, the heavy metal impact on the sericulture industry represents a complex and multifaceted challenge that demands immediate attention and concerted efforts. Our investigation has shed light on the far-reaching consequences of heavy metal contamination, affecting the quality of silk production and posing significant risks to the environment and human health. However, there is hope for mitigating these adverse effects through diligent research, innovative solutions, and collaborative actions. Our review will provide general information about the impact of heavy metals on the sericulture industry, contribute to the spread of anti-pollution awareness, and be useful for future research perspectives.

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Authors' contributions: B. Patra along with J. Pradhan conceptualized and drafted the manuscript. B. Baishakhi revised the manuscript. All authors read and approved the manuscript.

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