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Agrochemicals in sericulture and silk industry, and their effects on the human health and environment

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Abstract

Sericulture is a labour-intensive textile industry that involves growing food plants for silkworms, raising them, reeling their silk, and performing various post-cocoon operations, including twisting, dying, weaving, printing, and finishing. It employs a huge number of rural people; the majority are small and marginal farmers or work in the tiny and home sector, mostly in the hand reeling and hand weaving sections. Despite the fact that silk is of natural origin, the silk industry uses some health-hazardous substances at all stages from mulberry farming through silk fabric finishing. Pesticides, fungicides, nematicides, bactericides, and herbicides are the most common in mulberry cultivation. Similar to mulberry agrochemicals, the pre-cocoon industry employs a wide range of disinfectants and bed disinfectants to protect the silkworm crop against infections. And also, a separate class of agrochemicals is utilised in dyeing, printing, and washing because it improves the reeling process and silk quality. However, these compounds create respiratory issues and are carcinogenic to humans, as indicated by dermatitis, skin lesions, back aches, bronchial asthma, coughs, gastrointestinal pains, ulcers, throat infections, thinning nails, dry skin, and hand and eye burning. In addition to human concerns, persistent chemicals endanger the ecosystem and contribute to the overall chemicalization of aquatic and terrestrial environments. As a result, whenever possible, the discharge of toxic compounds into the natural environment should be reduced. Unfortunately, in developing countries like India, where large quantities of these chemicals are generated and dumped into the environment, they are not properly managed because little is known about their potential risks and benefits if properly managed. In this article, we intend to explore the major sources of sericulture agrochemicals, their potential risks, and how they can be properly managed.

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Introduction

The Indian silk industry is critical to the world silk market, accounting for around 36.80% of total silk output. The sericulture area in the nation is approximately 4,39,086 hectares, with mulberry and vanya cultivation accounting for 53.52% and 46.47% of the total area, respectively. To fulfil local demand, the sector produces silkworms to produce around 25,853 MT of Mulberry, 1,456 MT of Tasar, 7,359 MT of Eri, and 255 MT of Muga silk every year, accounting for 0.17% of India's gross value contribution. Furthermore, the sector employs more than 7,52,600 farmers and 15,453 reelers in 51,000 communities, which is responsible for their long-term survival (Chauhan, 2002; Chauhan *et al.,* 2015; Anonymous, 2022). The gross value of fabric is shared among them as follows: 56.8% by the cocoon grower, 6.8% by the reeler, 9.1% by the twister, 10.7% by the weaver, and 16.6% by the trader (Mahanta and Komal, 2022). Since the enterprise has many stakeholder groups, each of these groups is intended to earn profits in its sector, and each of them uses advanced modern techniques to establish the profit. One of the major modern techniques is using agrochemicals to earn a profitable livelihood, but on the other side, these chemicals are detrimental to the entrepreneur and the environment.

Mulberry cultivation is the primary sector, which supplies food for silkworms. But the mulberry crop is prone to pests, resulting in crop loss throughout the year. Some of the major sap sucking mulberry pests that can cause crop loss are mealy bugs (19.2%), spiralling white flies (12.62%), jassies (9.08%), thrips (17.18%), and scale insects (8.24%). Similarly, mulberry defoliating pests cause crop loss from leaf rollers (31.8%), bihar hairy caterpillars (21.72%), and cut worms (15.09%) (Govindaiah *et al.,* 2005). Along with these sap suckers and defoliators, some of the minor pests in a mulberry garden, such as the short-horned grasshopper, mulberry stem girdler, stem borers, termites, may-june beetles, spittle bug, wasp moth, mulberry bark borer, bell moth, and mites, pose a serious threat to crop loss. To combat these pressing issues, research institutes across India have recommended some of the chemicals to use for pest control. Farmers employ the recommended chemicals to lessen their occurrences; they are mainly Malathion, Chlorpyrifos, Formathion, Dicofol, and Dichlorvos/Dimethoate (DDVP). Similarly, diseases in the mulberry plantation can reduce crop loss, *viz.,* leaf spot (10-12%), powdry meldiews (20%) (Biswas *et al.,* 1996; Guptha, 2001), leaf rust (10-15%) (Gunashekar *et al.,* 1995), sooty mould (10-15%), leaf blight of bacteria and viruses, mulberry dwarf (5-10%), root knot (12%) (Sharma, 1998), and root rot (14%) (Philip, 1997). To combat the mulberry disease, many fungicides and bactericides are used, such as Bavistin (Carbendazium), Dithane M-45 (Benomyl), Karathane (Dinocap), Benlate (Benomyl), Kavach (Chlorothalonil), Sulphur Dust, Sreptocycline, and Furadan (Carbofuran). In addition, one more factor is the presence of 58 weed species belonging to 16 families, which causes severe problems in leaf production and therefore has an impact on the creation of cocoons and silk (Isaiarasu *et al.,* 2005; Setua *et al.,* 2008). Therefore, farmers are now moving to weedicides including Glyphosate, Paraquat, Gramoxone, Ammonium Sulphate, Glycerin, and 2-4-D to quickly handle the weed issues.

Silkworm rearing is the second-most important sector; these sectors are responsible for producing silk's primary product, the cocoon. But due to their highly domesticated nature, they are most frequently fatal in the rearing of silkworms: grasseries, flacheries, muscardines, and pebrine, which are caused, respectively, by viruses, bacteria, fungi, and microsporidia. Each disease, viz., fungal disease (green and white muscardine) associated with 5-20% crop loss, virus (NPV- nuclear polyhedrosis virus, CPV- cytoplasmic polyhedrosis virus, DNV- densonucliosis virus, IFV/Kenchu-infectious flacheri virus) causing 15-20% crop loss, bacteria (Bacterial disease of the digestive organ, Septicemia, and Sotto) induced 10-15% crop loss, and protozoa (pebrine) causes 5-10% crop loss annually (Govindan *et al.,* 1998). Therefore, several disinfectants and bed disinfectants have been advised to fight against the illnesses in silkworm rearing.

Disinfectants that are used in sericulture include bleaching powder, slaked lime, Sanitech/Serichlor, Asthra, Sanitech Super, and Serifit. Currently, bed disinfectants like Vijetha, Bundh powder, active lime, Captan, Dithane M-45, RKO, Ankush, Vijetha Supplement, Resham jyothi, Labex, and formalin chaff are available on the market to control the silkworm disease (Konwar *et al.,* 2022).

The last and largest sector of commerce is the post-cocoon sector industries, which encompass the silk reeling, spinning, dyeing, and fabric-making industries. For all these subsectors in the post - cocoon sector, water is the main material required for silk processing, and its quality has an influence on the quality of the silk they produce. To maintain the normal quality of the water, many chemical treatments are done to it. Among these chemicals are disodium salt-EDTA (Ethylenediaminetetraacetic Acid) to reduce metal ion concentration, lime soda to treat temporary hardness, and oxalic acid to treat hardness and alkalinity (Mahadevappa *et al.,* 2000). To remove natural gum and bleach the silk in silk processing, saop, alkali soda, enzymes like trypsin, papine, biopil 50, chymotrypsin, etc., and strong reducing agents like potassium permanganate, sodium peroxide, and hydrogen peroxide are heavily used. Similarly, during the silk thread dying process, dyes like acid dyes, viz., acid dyes, direct dyes, metal complex dyes, milling dyes, basic dyes, vats, solubilized vats, azoic dyes, and mordant dyes, are used (Sonwalkar and Tammanna, 1993). Over 10,000 different synthetic dyes and pigments are widely used in the textile industry (Al-Tohamy *et al.*, 2020a, 2020b, Ali *et al.,* 2021, Ali *et al.,* 2022). However, the majority of these chemicals are used unscientifically in the reeling, degumming, bleaching, and dying of the silk in the process of fabric making. The unjustified use of weedicides, pesticides, fungicides, bactericides, disinfectants, bed disinfectants, and chemicals from post-cocoon sector (Fig. 1) industries causes the chemicals to bio-accumulate or be biomagnified in the environment. As a result, the present article, which compiles information on seri-agrochemicals and their human and environmental impacts, becomes critical.

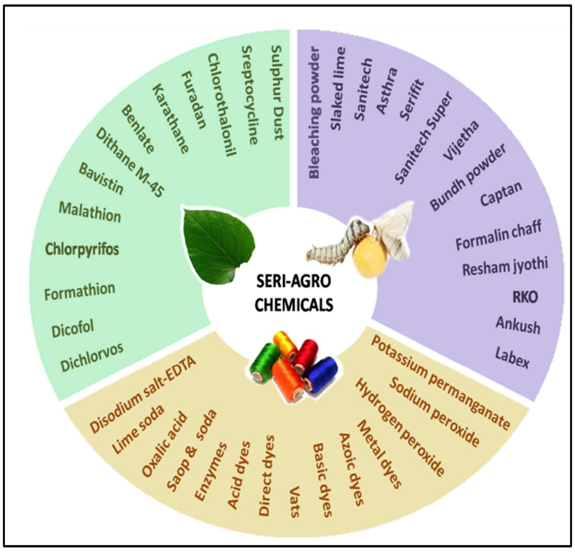

Fig. 1. Agrochemical usage in sericulture and silk industry.

Current Scenario on Seri-agrochemical usage in India

India, which holds the second-largest market share in the world, is the only nation in which every form of silkworm cocoon is manufactured. Among them, mulberry (*Morus spp*.), the only food plant of silkworms, is cultivated over 2.3 lakh hectares and exploited greatly for silkworm rearing and the production of mulberry silk. It is a perennial crop that can be grown continuously for about 15-20 years, with cocoon productivity and profitability primarily determined by the quantity and quality of mulberry leaves produced. But the qualitative and quantitative leaves are reduced due to several factors like disease (24%), pests (18%), weeds (7%), and other miscellaneous factors. To have fast control over weeds, 600 litres of powerful weedicide are necessary for a one-hectare mulberry garden. Taking this into account, a total volume of 1,380 lakh litres is required for one mulberry crop in India. Since over 300 insect and non-insect pest species are known to infest mulberry trees in varying degrees at various stages of the crop and seasons, controlling these pests has become critical. To avoid these pests, the pesticide formulation is sprayed at 150 litres (Anonymous, 2023), which is necessary for a one-hectare mulberry garden. Insecticides are generally applied twice per crop, i.e., once 10-12 days after pruning and again at an interval of 10 days, and fungicides are used only when foliar diseases are noticed.

Therefore, a mulberry garden receives minimum 10-12 sprays per year. Taking this into account, a total volume of 375 lakh litres is required for one mulberry crop in India. Under the advanced package of practices for silkworm rearing with mulberry shoots, approximately 3-4 MT of foliage is removed from one acre of mulberry garden at each harvest. However, under irrigated conditions, the plants are capable to rejuvenate the foliage shortly by devouring soil nutrients and become ready for subsequent harvests a month after each pruning. It causes the depletion of about 28kg of nitrogen (N), 11kg of phosphorous (P) and 11kg of potash (K). Therefore, the farmers need to replenish the soil nutrients with the recommended dosage of 140kg of ammonium sulphate, 70kg of single super phosphate and 18kg of muriate of potash/acre/crop for sustainable production of quality mulberry leaves. Farmers could harvest shoots from the mulberry garden 5-6 times in year at a bimonthly interval to take up silkworm rearing. Hence, an annual input of 1.40 MT of chemical fertilizers is applied to one acre of plantation. Such continuous overuse of chemical fertilizers pollutes the soil and ground water, alters the physical and chemical properties of the soil, depletes the naturally available essential nutrients besides deleterious effect on beneficial micro and macro organisms, which play a vital role in soil health and plant growth (Sakthivel *et al.,* 2014).

Similarly, disease-related cocoon crop loss in India was found to be 15-20%. Bed disinfectants and hydrated lime are often used in India to prevent mulberry silkworm diseases. Among them, lime is crucial; the amount of dusted lime required for cross-breeds and CSR hybrid cocoon development is around 1.53-1.63kg for 100 DFLs in leaf and shoot rearing, respectively (Lakshmanan *et al.,* 2010). Since, in India, a total of 356.20 lakh DFLs (1 DFL = 400 to 600 silkworm eggs) are brushed, the total quantity of lime utilized is 5449.86 to 9831.12 MT. Similar to lime, according to Rajan and Himantaraj (2005), commercial rearers need to dust 0.9kg, 1.9kg, and 3.0kg of bed disinfectants per 100 dfl during the third, fourth, and fifth instars, respectively. As a result of these calculations, 2065.96 MT of disinfectants are required to disinfect 356.20 lakh DFLs. Since many silkworm diseases are avoided prior to raising, by employing disinfectants, following the adage that prevention is better than cure, 140 ml of disinfectant are required for each square feet; the estimated yearly disinfection for 356.20 lakh DFLs (each DFL requires 6-7 square feet for both BV and CB) is 299.20 to 349.07 lakh litres.

The post-cocoon sector runs only in the presence of water and produces about 70-75% of the total raw silk produced in our country using multi-end reeling machinery (MERMs) and automatic silk reeling machinery (ARMs). Producing one kilogramme of silk in MERM and ARMs requires 100-120 litres and 120-200 litres of water, respectively (Mahadevappa *et al.,* 2000; Sonwalkar and Tammanna, 1993). Therefore, 17,922 to 35,844 lakh litres of water are required annually to produce raw silk in India. Since the majority of Indian waters suffer from hardness and other problems, entrepreneurs use chemicals to find a solution. But once the water is used, the water from the reeling basins is directly drained to the rivers or agricultural fields without any chemical treatment. Similarly, during dyeing, once the coloration of silk cloths is complete, the dyed rest in the basins is drained into the environment without justification. Therefore, the silk industry regularly adds chemicals to the environment without noticing their impact.

Hence, these sericultural agrochemicals, viz., disinfectants, pesticides, bactericides, fungicides, weedicides, and chemical effluents from the post-cocoon sector, are responsible for profit in the sericulture industrial sector. But still, they can potentially affect the environment if they are applied incorrectly to the field rather than the real quantum. This causes harm not just to the organisms that influence sericulture but also to humans and the environment.

Effect of different Seri-agrochemical on human health and environment

Mulberry production Agrochemicals.

Although the desired economic advantages are received directly by farmers, the use of these agrochemicals has an indirect impact on them both personally and environmentally. Glyphosate and 2-4-D are the two major herbicides used to manage weeds in mulberry habitats. Both herbicides produce potentially carcinogenic chemicals. Over the last 40 years, hundreds of studies have found a link between the herbicide 2,4-Dichlorophenoxyacetic acid (2,4-D) and blood malignancies. (Von Stackelberg, 2013). Glyphosate is recently designated as Class 2A, possibly carcinogenic to humans, by the International Agency for Research on Cancer (IARC) (Guyton *et al.,* 2015). It also induces endocrine disruption and reproductive consequences in human cell lines (Gasnier *et al.,* 2009; Cassault-Meyer *et al.,* 2014). These Gyphosytes, along with the ammonium sulphate, cause irritation to the respiratory tract and cause coughing and shortness of breath. Along with that, it also causes irritation to the gastrointestinal tract, like nausea, vomiting, and diarrhoea. Kools *et al.,* (2005) also reported a positive correlation between Glyphosate degradation rates and soil metal pollution. Though farmers prefer to use weedicides in mulberry gardens for management of weeds due to their effectiveness and economy under the prevailing situation of scarce agriculture labours and hikes in wage rates. But the drift of herbicides sprayed in the garden directly affects the physiological parameters of mulberry plants and leaf yield. The adverse effect of weedicides on mulberry are often visible in many gardens. The residues of weedicides applied in the mulberry garden pollute the soil as well as ground water, affect beneficial organisms and soil health. The indiscriminate use of herbicides deteriorates the soil's health, texture, and the residual toxicity causes adverse effects on beneficial microorganisms and silkworms. And some of the natural soil bacteria showed different sensitivity to Glyphosate-based herbicides (Sihtmäe *et al.,* 2013).

The principal pesticides used in mulberry plantations are primarily chlorpyrifos, dicofol, and dichlorvos (DDVP). Chlorpyrifos is primarily employed to control termites in the mulberry crop ecosystem. The poisonous gas emitted by chlorpyrifos affects the central nervous system, cardiovascular system, and respiratory system in people and animals, as well as causing skin and eye irritation. Repeated applications of chlorpyrifos modify the soil microbial community structure and pose potential health risks to other non-targets. Chlorpyrifos has been reported as the second most commonly detected pesticide in food and water (John *et al.,* 2015). Similarly, another common chemical, dichlorvos (DDVP), one of the organophosphate insecticides, is used to combat the majority of the mulberry insect pests. But pesticide exposure occurs mostly through the cutaneous pathway during spray preparation and through the dermal and inhalation routes during application. They are highly acute toxic neurotoxins that chemically combine with a crucial enzyme, acetylcholinesterase, and inhibit brain activity. This causes depressed motor function and respiration, nausea, headaches, seizures, coma, and death to the farmer who is exposed at the time of application. A recent report also revealed that many of the poisonings occur in many countries, including China, India, and Korea; residues in food have caused poisoning in Turkey, and in some reports, they are used for suicide, e.g., in Nepal (Watts, 2014). Chronic exposure to highly hazardous pesticides results in negative effects on the skin, eyes, nervous system, cardiovascular system, gastrointestinal tract, liver, kidneys, reproductive system, endocrine system, and blood. Also, these are highly toxic to terrestrial organisms like birds, bees, and beneficial insects, and wildlife poisonings have been reported in Africa (Ogada, 2014). Similarly, these chemicals are volatile and likely to drift; residues inside houses do not break down easily; they are found in water and sediment in rivers in Thailand (Sangchan *et al*., 2014).

Similarly, in the same contest, another major mulberry plantation pesticide is Dicofol, an organochlorine miticide that goes through all the problems discussed for DDVP. Dicofol is a dangerous substance for most birds. It is tied to eggshell thinning and reduced fertility. Quails, pheasants, doves, and screech owls are among the affected birds. Long- or short-term intake of residual dicofol is unlikely to present any danger to human health, according to the Environmental Protection Agency. These miticides are most likely to cause water pollution through erosion or improper application (Christopher, 2015). The greater issue with insecticides in relation to pest management is the development of resistance in the pests while their natural enemies are wiped out due to their high sensitivity to the chemicals. Therefore, repeated chemical applications often resulted in outbreaks of pests in the mulberry ecosystem, in addition to pollution and hazardous effects on humans and beneficial organisms.

Concomitantly, mulberry disease is controlled by the fungicides Bavistin (Carbendazim), Karathane (Dinocap), Kavach (Chlorothalonil), Dithane M-45, and Carbofuran (Furadan). The fungicide carbendazim is most frequently used to control the fungal disease of mulberries, which has been frequently detected in soil, water, air, and food samples and disrupted soil and water ecosystem balances and functions. The carbendazim could induce embryonic, reproductive, developmental, and haematological toxicities in different model animals. Carbendazim contamination can be remediated by photodegradation and chemical and microbial degradation. Carbendazim could enter the human body through food, drinking water, or skin contact (Zhou *et al.,* 2022). Similar to Carbandizeum, dinocarp is a fungicide that is not considered persistent in soil and is non-mobile. Based on its physico-chemical parameters, Dinocap is not expected to leach into groundwater (Lewis *et al.,* 2016). It is moderately toxic to mammals, earthworms, and bees but considered highly toxic to fish and aquatic invertebrates. Limited data is available on its toxicity to humans, but some reports suggest it is a possible reproductive or developmental toxin. Chlorothalonil is a broad-spectrum organochloride pesticide classified as a moderately toxic chemical of class II that is primarily used as a fungicide, bactericide, and nematicide against mulberry disease (Raman, 2014). Mozzachio *et al.,* (2008) investigated the incidence of chemical applicators who were both exposed to chlorothalonil and were diagnosed with cancer. They found no direct link to applicators with colon, lung, or prostate cancer; approximately 3,600 applicators used chlorothalonil on average for 3.5 days per year (Whitacre and David, 2014). Similarly, Caux *et al.*, (1996) reported that these chemicals have acute and chronic toxicity data available for rodents, rabbits, dogs, monkeys, and cows. Another important fungicide is Captan, which has a low potential to produce fumes or volatilize. It also breaks down quickly in soil. The half-life in soil ranges from less than 1 to 4 days and up to 24 days in field studies. Captan can be harmful to the eyes if used frequently. Concentrated captan has been shown to cause permanent eye damage in rabbits. In one instance, if a person consumed captan for an indirect purpose, symptoms included nausea, weakness, arm numbness, and lower chest pain. In an earthworm (a farmer's friend) study, worm reproduction rates were lower in soils with high enough amounts of captan. However, captan did not affect the survival of mature earthworms, which is allaying symptoms to reduce its usage in agricultural fields (Strid *et al.,* 2018). Another common nematicide against root knots is carbofuran, which is particularly toxic to the earthworm (*Lumbricus terrestris* L.) under controlled conditions, causing high mortality and the appearance of segmental swellings, as well as harm to birds (Von-Gestel, 1992). Furthermore, common fungicides like Dithane M-45 had a deleterious effect on mycorrhizal spore number and percentage mycorrhizal root colonisation. Hence, it can be concluded that both pesticides, bactericides, and fungicides at high dosage rates caused remarkable adverse effects on the soil microflora and the animals that inhabit the area around the crop. Therefore, the use of chemicals in high doses as well as their continuous application to the soil should be done carefully and judiciously.

Silkworm rearing Agrochemicals

Silkworm disease epizootics have been documented for hundreds of years, concurrent with the domestication of the silkworm. Silkworm disease prevention measures have been carried out by farmers, but disease prevalence occurs throughout the year due to the prevalence of skill gap variability that exists in silkworm rearing among Indian farmers (Afroz *et al.,* 2018). In the history of sericulture, many disinfectants gained importance from time to time by altering their chemical composition. One among them is Farmaline, an effective disinfectant still used by farmers, but in the atmosphere, formaldehyde usually breaks down quickly to create formic acid and carbon monoxide, which can also be harmful substances. Which produces a strong irritative odour and weak penetrating power and causes serious problems for humans and their belongings (Department of Climate Change, Energy, the Environment and Water, 2018). Some of the report reveals that when the animals are exposed to formaldehyde, it can make them sick, affect their ability to breed, and reduce their life spans (National Research Council (US) Committee on Toxicology**,** 1980). Similarly, other major disinfectants, such as bleaching powder (chlorkalk or chlorinated lime), that release nascent oxygen, strong alkalinity, and Ca ions, have a germicidal effect.

Another disinfectant in sericulture is sodium hypochlorite, which has germicidal activity in the presence of chlorine but is harmful to the body, skin, and clothes of humans at higher concentrations. But these have some negative impacts, such as rusting on metallic goods and harmful textile goods in the silkworm rearing houses. Majorly recommended disinfectants in sericulture are Sanitech/Serichlor, Sanitech Super, and Serifit, which are all ClO2-based (Rajan and Himantaraj, 2005). Like many chemicals, chlorine dioxide, in high concentrations, can be considered hazardous (due to vapour). But if it is used judiciously and doesn't bioaccumulate or persist in the environment, ClO_2 is also considered one of the most environmentally friendly chemicals (Condie and Lyman, 1986). However, many of the currently available chemicals contain trade secrets and are also responsible for the death of harmful pathogens as well as environmental microbes.

Similar to the surface disinfectants, the bed disinfectants are chemicals, viz., Farmalin Chaff (one part formalin solution to ten parts paddy husk), Labex (97 parts slaked lime to three parts bleaching powder), and RKO Powder (stamped lime powder, benzoic acid, captan or diathane, and formaldehyde) (Lakshmanan *et al.,* 2010). However, some of the bed disinfectants, like lime, unknowingly cause irritation to the respiratory tract, ingestion causes a gastric irritant; oesophageal perforation may occur, irritation and pain may occur; and the bed may induce ulcerations of the corneal epithelium. Prolonged or repeated skin contact may produce severe irritation or dermatitis (Cement, 2005). Similarly, this lime and its derivatives in the silkworm waste mixture will hinder the fermentation process in composting by converting ammonium nitrogen to ammonia gas, which can create an odour problem as it escapes from the pile and reduce the nutrient content of the finished compost. Adding lime may also cause the pH of the finished compost to be higher than optimal for plant growth. Drenching directly the rearing waste without proper treatment in the mulberry field can kill beneficial soil microbes. Furthermore, carbon monoxide, known as a silent killer because it has no smell, colour, or taste and is produced by a faulty or poorly ventilated fuel-burning appliance such as the partially burnt coal sigri used in Kashmir and other temperate areas, causes nausea and vomiting. The other cause of accidental exposure to carbon monoxide (CO) is household appliances, such as cooking and heating devices, that have been damaged, incorrectly installed, or badly maintained. Death of rearers was observed in the rearing room due to CO levels beyond the tolerance level (100 ppm in Patnitop, J&K). Cherry-red lividity is seen in the human body due to CO poisoning (Wani *et al.,* 2011). Therefore, proper waste management in the rearing environment is mandatory.

Agrochemical in Silk reeling

The very next stakeholder is the silk reeling industry, where the workers in the natural silk industry may develop respiratory allergies featuring bronchial asthma, asthmatic form bronchitis, and/or allergic rhinitis due to the pollutants in the industries. Persons who are involved in reeling and throwing operations reach harmful levels of noise at the time of spinning and winding the silk threads and at looms where the fabric is woven. Areas in sericulture such as reeling and weaving also generate a great deal of noise pollution (Subramani *et al.,* 2015). To unwind the silk very tightly and to separate the silk from cocoons, one often uses an alkali solution, especially sodium hydroxide. During the course of reeling the reeler's hand, prolonged or repeated skin contact may cause dermatitis. And also during silk reeling, smoke is emitted from cocoon cooking stoves from firewood, and the stench from steam and vapour arising from fluids released from the pupa body leads to asthma. Few reports regarding the incidence of occupational asthma in sericulture in China and Japan are available (Ramanathan, 1997). Bronchial asthma was also observed among the workers of silk reeling units due to the airborne antigens originating from silkworm cocoons and pupae. Workers who boil the cocoons mentioned that they do not use any gloves or masks. They get severe headaches, gastric pain, and skin burning as they are always exposed to the fire and fumes emitted from the boiling (BCAS, 1997).

During the process of reeling, the quality of the water is maintained by treating it with EDTA (ethylenediaminetetraacetic acid), oxalic acid, and lime soda. The lime will react with the Mg and Ca ions responsible for forming calcium carbonates and magnesium hydroxides, which are insoluble in water and settle at the bottom of the tank (Mahadevappa, 2000). Once the reeling process is complete, the water-insoluble chemicals, sericin, and other insoluble reel waste get drained out of the reeling unit into a pond or agricultural field, causing side effects to the environment. Particularly, EDTA is classified as one of the major organic anthropogenic pollutants in Central Europe (Frimmel 1989; Pietsch *et al.,* 1995). Nishikawa and Okumura (1995) homogenised 1 g of fish sample, analysed it by gas chromatography-mass spectrometry, and attained 63% recovery. Taken together, chemicals from the reeling contribute to the general chemicalization of the aquatic environment. They can also cause several indirect and under extreme circumstances, direct effects in the aquatic environment. And also, the relling units of chemicals degrade the aesthetic quality of water bodies by increasing biochemical and chemical oxygen demand, impairing photosynthesis, inhibiting plant growth, entering the food chain, and promoting toxicity, mutagenicity, and carcinogenicity (Priyadharshini *et al.,* 2016).

Silk and the natural fibres used in textiles use a large number of highly toxic chemicals at various stages of the process, such as sizing, softening, desizing, brightening, and finishing agents. Synthetic dyes such as azo, direct, reactive, mordant, acid, basic, disperse, and sulphide dyes are widely used by the textile industry. Similarly, some of the textile dyes and/or their effluents are used to irrigate their agricultural lands, altering soil chemistry and disrupting the balance of the soil microbial flora. Particularly during dyeing processes, for example, 15-50% of the azo dyes that are not bound to fibres and fabrics are released into the generated wastewater (Chung, 1983; Singha *et al.,* 2021). These pollutants also have a negative impact on plant flowering and germination as they are indicators of plant toxicity (Jiku *et al.,* 2021; Sojobi *et al.,* 2022). Similarly, textile dyes, which are highly toxic and potentially carcinogenic, have been linked to a variety of human and animal diseases (Tounsadi *et al.,* 2020; Jin *et al.,* 2021). For example, oral ingestion or direct skin contact of azo dyes (Manickam and Vijay, 2021) converts the human gut intestinal microflora in azo dyes into toxic amino acids, which have a negative impact on various tissues in the human body (Feng *et al.,* 2012). Furthermore, these textile dyes can cause diseases ranging from dermatitis to problems with the central nervous system. These problems may be caused by the substitution of enzyme cofactors, which results in the inactivation of the enzymes themselves (Wu *et al.,* 2021). Ingestion or inhalation of textile dyes can cause skin and eye irritation, especially if they are exposed to dust (Clark, 2011). Workers who handle reactive dyes are at risk of developing allergic reactions such as contact dermatitis, allergic conjunctivitis, rhinitis, and occupational asthma (Hanger, 2003). In addition to tessertial damage, the textile dyes, especially azo dyes, discharged into water as effluents reduce light penetration, impairing the performance of algae and aquatic plants. Furthermore, dyes ingested by fish and other living organisms can be metabolised in their bodies into toxic intermediates, which can have a negative impact on the health of both the fish and their predators (Elgarahy *et al.,* 2021). Owing to the large number of textile industries and the vast amounts of wastewater containing dyes, appropriate and effective management techniques are necessary in order to prevent the contamination of ecosystems and increase sustainability.

Similar to the dyes, Pentachlorophenol, which is used in spray starch before ironing silk garments to protect them from mould attack, also poses severe health problems. Formaldehyde resins routinely applied to silk to reduce shrinkage and wrinkles cause eczematous rashes. Contact with silk cloth with a pH outside the accepted range (5.5) turns the skin flora out of balance and causes irritation. Those are dermatitis, narcosis, dizziness, fatigue, nausea, headache, eye irritation, adverse reproductive hazards, including the risk of miscarriage, and serious neurological problems. These problems are even scene in screen printing activities, where toluene, xylene, and methyl ketone are used as solvents for the inks, thinners, and clean-up materials (Pandey, 2014). The colours and materials used in dyeing and tracing emit strong smells, affecting their eyes, throats, noses, hands, and possibly internal functions.

Tracing chemicals burns hands and eyes and stains fingers and nails. Trivalent chromium used to fix silk dyes undergoes oxidation into hexavalent chromium, leading to skin irritation, ulcers, sensitization, and allergic contact dermatitis. Lead acetate, used in dyeing silk cloth, is a neurotoxin. It affects the human brain as well as the reproductive system (BCAS, 1997). Workers cannot use gloves during tracing because the gloves melt from the kerosene and zinc oxide. Workers are not observed using gloves for mixing dyes either. However, they discharge unscientifically, which must be taken into consideration in choosing the most suitable treatment technology (Lellis *et al.,* 2019; Li *et al.,* 2022).

Strategies of eco-friendly sericulture

Mulberry cultivation

As science progresses and the demand for precision sericulture grows, the creation of organism-specific disinfectants must be trusted. Because India utilises a large amount of agrochemicals viz., pesticides, bactericides, fungicides, Miticides, nematicides, disinfectants, bed disinfectants, dyes, weedicides and other chemicals, there is a future scope to utilize ecofriendly materials to reduce the amount of agrochemical usage. Some of the currently available ecofriendly material to promote the organic sericulture are biofertilizer, biopesticies and biocontrol agents must be emplasized to reduce the environmental risk. The important organic resources and their utility for mulberry leaf production and protection are listed below.

The major manure sources are farmyard manure, vermicompost, sheep and goat droppings, and also poultry manure, which can be used to replace chemical fertilisers as they are associated with nutrition sources. Sheep and goat droppings containing 3% N, 1% P2O5, and 2% K2O can be used. Similarly, poultry droppings have nitrogen (4.55 to 5.46%), phosphorus (2.46 to 2.82%), potassium (2.02 to 2.32%), calcium (4.52 to 8.15%), magnesium (0.52 to 0.73%), and appreciable quantities of micronutrients like Cu, Zn, Fe, Mn, etc., besides cellulose (2.26 to 3.62%), hermicellulose (1.89 to 2.77%), and lignin (1.07 to 2.16%) can replace chemical fertiliser. Vermicompost is rich in plant nutrients, enzymes, antibiotics, plant growth hormones, and large beneficial microbial populations, which help to increase the quality and yield of mulberry leaves suitable for higher productivity of silk. Application of 10 MT/ha/year of vermicompost with a 50% reduction in the application of the recommended dose of chemical fertilizers. The pressmud thus composted is dark in colour with a narrow C:N ratio (about 12:1). It contains about 2.08% nitrogen, 3.63% P2O5, 1.40% KO2, and 22.38% organic carbon. All these nutrition sources can be utilised to make soil not only fertile but also productive (Sakthivel *et al.,* 2014).

Green manuring in mulberry with dhaincha (*Sesbania aculeata*) and sun hemp (*Crotalaria juncea*) @ 15kg seeds per acre is recommended for alkaline and neutral soil conditions, respectively. Green manuring can be defined as a practise of incorporating the soil with the undecomposed green plant tissues for improving its physical structure as well as fertility. The green-manure crop also supplies additional nitrogen due to its ability to fix nitrogen from the air with the help of its root nodule bacteria. It is a better alternative to FYM in the prevailing situation of its scarcity and high cost due to the decline in livestock farming in the recent past. The additional benefit of green manuring is that it prevents weed growth and saves on weeding costs (Sakthivel *et al.,* 2014).

A bio-fertiliser is a substance that contains living microorganisms that, when applied to seeds, plant surfaces, or soil, colonise the rhizosphere or interior of the plant and promote growth by increasing the supply or availability of primary nutrients to the plant. In the present scenario, biofertilizers are the inevitable alternative to chemical fertilisers. Certain common bacteria, like *Azotobacter chroococcum, Azospirillum spp. (A. brasilense, A. lipoferum, A. amazonense, A. halopraeferens,* and *irakense)* are capable of fixing atmospheric nitrogen (biological nitrogen fixation). However, the *Azospirillum* plays an additional role in that it secretes a growth promoting substance (indole acetic acid) in the soil and induces disease resistance and drought tolerance in the plants. Similarly, another bacterium, *Bacillus megaterium, is* called phosphorus solubilizing bacteria (PSB), which is capable of solubilizing insoluble phosphorus and making it available to the plant. Vesicular-arbuscular mycorrhizae are symbiotic fungi also called endomycorrhizae that have a harmonious relationship with mulberry roots. The VAM inoculation ensures a 50% curtailment of chemical phosphorus application in mulberry cultivation without any loss in leaf yield or quality (Sakthivel *et al.,* 2014). There are many available eco-friendly nutrient sources developed by in-state research for establishing mulberry plantations (Table 1).

Table 1. Biofertilizers in the India for mulberry plantation management.

SL	Biofertilizers	Usage	Developed institute
1.	Seri-Prakruthi	A nitrogen fixing biofertilizer for mulberry	Karnataka State Sericulture Research and Development Institute
2.	Seri-Multiphos	A phosphate solubilizing biofertilizer for phosphorus useefficiency in mulberry.	
3.	Seri-VAM	A phosphate mobilizing biofertilizer for mulberry.	
4.	Seri-Nematoguard	A biocontrol agent for root knot disease management in mulberry.	
5.	Seri-Bioguard	A biocontrol agent for root rot and stem canker disease management in mulberry	
6.	Seri-Mildewguard	A herbal biocontrol agent for powdery mildew disease management in mulberry	
7.	Seri-Comporich	A consortium of cellulolytic microorganisms for preparation of seri-waste based enriched compost	
8.	Seri-azo	Azotobacter bio-fertilizer to replace nitrogen fertilizer	Central Sericultural Research & Training Institute (CSRTI), Mysuru
9.	Seri-phos	Phosphate solubilizing bio-fertilizer	

Moreover, the mulberry ecosystem is ideal for implementing biological control of pests and diseases because of its perennial nature. Moreover, the usage of high-potency insecticides on a crop like mulberry is practically impossible due to their sensitivity to silkworms. Therefore, the biological method plays a significant and indispensable role in managing key pests of mulberry. Some of the effective predators and parasitoids for successful management of important insect pests of mulberry have been tabulated (Table 2).

Table 2. Biocontrol agents used against mulberry crop pest in the India.

SL	Name of the insect pest	Name of the biocontrol agent	Numbers to be released /ac/crop
1.	Pink mealybug *Maconellicoccus hirsutus*	Predators A) *Cryptolaemus montrouzieri* (or) B) *Scymnus coccivora*	 250 adults 500 adults
2.	Papaya mealy bug *Paracoccus marginatus*	Parasitoids A) *Acerophagus papayae (or)* B) *Pseudleptomastix mexicana (or)* C) *Anagyrus loecki*	50-100 adults
3.	Thrips *Pseudodendrothrips mori*	Predator *Chrysoperla* spp	4000-8000 eggs
4.	Spiralling whitefly *Aleurodicus disperses*	Predators A)*Axinoscymnus puttarudriahi* B)*Scymnus coccivora*	 250 adults 250 adults
5.	Leaf webber *Diaphania pulverulentalis*	Parasitoids A)*Trichogramma chilonis*- egg B)*Bracon brevicornis*- larval C)*Tetrastichus howardii*- pupa	 3 cc of eggs 200 adults 1lakh adults in 3 splits

(*Source - Sakthivel et al., 2014*)

Another eco-friendly technique is the spraying of a strong jet of water, which is one of the components of IPM and is generally recommended to manage sucking pests like thrips, aphids, mites, etc. Similarly, there are many biological sources to control and manage the major disease of mulberry. One such example is panchagavya, which has all macro- and micronutrients apart from the growth hormones (IAA and GA) essential for the production of quality mulberry leaves. It has a low pH value due to the production of organic acids by the fermentative microbes. Lactobacillus present in the panchagavya produces various beneficial metabolites such as organic acids, hydrogen peroxide, and antibiotics, which are effective against pathogenic microorganisms. Among the different organic sources, the non-edible oilcake(NOC)s in general and NOC in particular contain a high amount of plant nutrients and alkaloids, which induce immunity against pests and diseases in mulberry besides its higher nutrient content than other oilcakes (Sakthivel *et al.,* 2014). Some of the eco-friendly formulations produced by research institutes can also be utilised to reduce the chemical use in mulberry plantations (Table 3).

Table 3. Ecofriendly mulberry disease formulation in India.

SL	Biofertilizers	Usage	Developed institute
1.	Navinya	a plant based formulation for management of root rot disease of mulberry	Karnataka State Sericulture Research and Development Institute
2.	Nemahari	a plant based formulation for management of root knot disease of mulberry	
3.	Seri-Nematoguard	A biocontrol agent for root knot disease management in mulberry.	Central Sericultural Research & Training Institute (CSRTI), Mysuru
4.	Seri-Bioguard	A biocontrol agent for root rot and stem canker disease management in mulberry	
5.	Seri-Mildewguard	A herbal biocontrol agent for powdery mildew disease management in mulberry	

Weed management practices in mulberry garden has many drawbacks. Though hand-weeding is the most efficient method, but it is back-breaking, time consuming and costly. In this context, two effective, economic and eco-friendly packages of practices viz., Thermal Weeding and Black Polythene Mulching were developed and standardized for management of weed menace in mulberry gardens.

Silkworm rearing

Silkworms are the most vulnerable entities in the insect world, as they are affected by all categories of pathogens. But farmers adoption of good sanitation and hygiene-rearing techniques plays a vital role in preventing pathogens from crossing the economic threshold. Though the chemical method of pest and pathogen control is effective, it has its own limitations, including being harmful to humans, nearby animals, buildings, and equipment. Therefore, farmers can use physical methods of disinfection to reduce the pathogen load in the rearing house. They include the burning or burying of diseased worms, steam disinfection, dry heat disinfection, and disinfection under the sun (Govindan *et al.,* 1998).

Disinfection by steam

This is not a popular method of disinfection. The rearing equipment is placed in a box, and steam is sent into the box, where the temperature is kept at 100°C for 30min.

Disinfection under the sunshine

In view of the presence of UV rays, sunlight has a strong disinfecting power against pathogens. Rearing equipment like stands, rearing trays, mountages, etc., is disinfected by exposing it to hot sun. Attention must be paid to exposing both surfaces of the equipment for effective disinfection. As per Shyamala *et al.,* (1987), Kenchu virus loses its infectivity when the contaminated rearing trays are exposed to hot sun for 20-30 hr.

Hygiene during rearing

Maintenance of hygiene during silkworm rearing and practising some simple measures help to a greater extent in preventing the access of the pathogens from outside to the rearing venue and also their spread in the rearing bed or room. The habits like burning or burying diseased worms away from the rearing house, avoiding lending of rearing equipment, regular cleaning and wiping of the rearing house, avoiding unnecessary entry into the rearing house, regular bed cleaning, etc. are best to prevent the disease in silkworms.

Use of disease-resistant or tolerant breed

Disease resilience, defined as an animal's ability to maintain productive performance in the face of infection, provides opportunities to manage the polymicrobial challenge. Disease resilience can deliver a number of benefits, including more sustainable production, improved animal health, and the potential for reduced antimicrobial use. Utilisation of disease-tolerant silkworm breeds developed by the research institutes can be beneficial to farmers as they prevent crop loss (Table 4).

Table 4. Popular disease tolerant breeds available in India.

SL	Name of Silkworm race/breed	Parentage	Origin: Source of collection/ evolved & year	Relevant trait
1.	S8N (Bivoltine)	MASN6	CSRTI-Mysuru	NPV tolerant
2.	$CSR_{52}N$ (Bivoltine)	CSR52xMASN6	CSRTI-Mysuru	NPV tolerant
3.	CSR16N (Bivoltine)	CSR16x5N	CSRTI-Mysuru	NPV tolerant
4.	CSR26N (Bivoltine)	CSR26x	CSRTI-Mysuru	NPV tolerant
5.	MASN4 (Bivoltine)	CSR2xSarupat	CSRTI-Mysuru	NPV tolerant (SSR marker)
6.	MASN6 (Bivoltine)	CSR2xSarupat	CSRTI-Mysuru	NPV tolerant (SSR marker)
7.	MASN7 (Bivoltine)	CSR2xSarupat	CSRTI-Mysuru	NPV tolerant (SSR marker)
8.	NDV6 (Multivoltine)	2000H, C. NICHI	CSRTI-Mysuru	Tolerant to BmDNV1

Source: CSGRC, Hosur

Silk reeling chemical

Apart from the cost-benefit analysis, the social cost-benefit analysis assumes manifold importance in any industrial activity, in view of protecting the environment. In a report by Harindranath *et al.* (1985), it was observed that 16.9%-36.2% of workers are at risk due to the continual release of silk allergens, viz., dyes, reeling basin water, and chemically treated water, to the environment. One remedy for synthetic dyes is the utilisation of natural materials such as plant leaves, roots, bark, insect secretions, and minerals, which were the only dyes available to mankind for the colouring of textiles. Textiles colored with natural dyes are preferred by environmentally conscious consumers, and today there is a niche market for such textiles. But the total share of natural dyes in the textile sector is approximately 1 percent due to certain technical and sustainability issues. Natural dyes are considered eco-friendly as they are obtained from renewable resources as compared to synthetic dyes, which are derived from nonrenewable petroleum resources. These are biodegradable, and the residual vegetal matter left after the extraction of dyes can be easily composted and used as fertiliser. Some of the natural dye sources reported as being of plant origin, animal origin, mineral origin, microbial origin, or fungal origin have been reported (Saxena *et al.,* 2014) can be used for silk dyeing. Furthermore, the reeling basin water treatment affects not only the quality but also the quantity of silk reeling. Therefore, use of natural resources like seeds of Drumstick (*Moringa oleifera*) (Bichi, 2013), Water Melon (*Citrullus lanatus*) (Misau *et al.,* 2015), Papaya (*Carica papaya*) (Muda *et al.,* 2020), *Strychnos potatorum* (Arunkumar *et al.,* 2019), etc. becomes important and can be utilised as a remedy for problematic water in the silk industry.

And lastly, the best strategy to safeguard workers is to remove or eliminate hazards from the workplace utilising the hazard reduction strategies. Substitute toxic chemicals that are damaging to both humans and the environment by less toxic material. Similarly, before being released into the environment, textile dyes and hazardous chemicals must be properly treated to lessen the poisonous to the environment.

Conclusion

Good preventive maintenance plays a major role in ensuring that hazard controls continue to function effectively. The article reveals the imperative need to build health consciousness among sericulture workers and environment. Training should be given to the workers in the industry about the possibility of health risks and their prevention. The health hazards control measures should be implemented with government and non-governmental agencies for mitigating the health hazards by the sericulture industry. Awareness programmes and local group discussions are essential for improving the health status of sericulture workers and environmental protection. Every sericulture unit should have a provision of protective equipment such as face masks, first aid facilities, gloves, and a proper uniform. As well as, hazardous chemicals must be properly treated to lessen the poisonous to the environment.

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