Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
Impact Factor (RJIF): 5.83
www.entomoljournal.com
JEZS 2025; 13(5): 11-19

Received: 08-06-2025
Accepted: 10-07-2025

Anirban Mandal
Department of Biotechnology, Institute of Genetic Engineering, Madhyamgram, West Bengal, India

Jaydip Mukherjee
Department of Life Sciences, Chanchal Siddheswari Institution (H.S.), Chanchal, Malda, West Bengal, India

Sudip Some
Department of Life Sciences, Mohitnagar Colony T.P. High School (H.S.), Mohitnagar, Jalpaiguri, West Bengal, India

Corresponding Author:
Sudip Some
Department of Life Sciences, Mohitnagar Colony T.P. High School (H.S.), Mohitnagar, Jalpaiguri, West Bengal, India

Microbial infections in mulberry silkworm: Challenges and sustainable management strategies

Anirban Mandal, Jaydip Mukherjee and Sudip Some

DOI: https://www.doi.org/10.22271/j.ento.2025.v13.i5a.9597

Abstract
For centuries, silk has played a pivotal role in global economic development. Renowned as the *queen of fabrics* for its exceptional quality, silk is highly valued for its thermostatic properties. Among the various types of silk, mulberry silk is the most economically significant due to its large-scale production worldwide. The mulberry silkworm (*Bombyx mori* L.; Lepidoptera: Bombycidae) is highly susceptible to various diseases due to its poikilothermic nature. Flacherie, Grasserie, Muscardine, and Pebrine are common microbial diseases affecting mulberry silkworms. Studies indicate that an artificial diet disrupts metabolic homeostasis, weakening the immune system and making silkworms more vulnerable to microbial infections. Additionally, unfavorable climatic and environmental conditions contribute to disease outbreaks, while poor hygiene in rearing houses further increases infection rates. Consequently, microbial infections negatively impact the quality and yield of silk production. Early disease detection and effective management strategies are crucial in preventing infections. Biological control has developed as the most eco-friendly and non-harmful approach in silk industry. Due to a number of beneficial characteristics, such as reasonable breeding expenses, big offspring size, quick generation time, and a well-defined genetic background, *Bombyx mori* has been developed as a model organism for scientific research. Combating these microbial threats requires a holistic approach, integrating genetic and molecular research with strict hygiene practices in the silk industry. Given the high mortality rate of silkworms, improving disease control measures remains a major challenge for researchers to enhance the cost-benefit ratio of silk production.

Keywords: sericulture, mulberry silk, *Bombyx mori*, microbial infection, disease management, model organism

1. Introduction
Sericulture is a primary source of income for farmers in many emerging nations, including China, India, Brazil, Vietnam, and Thailand. In most developing countries, silkworm cultivation is practiced on an economic scale, with the primary goal of producing silk fibre. India is the world's second-largest silk producer country [1, 2]. The earliest known written record of sericulture is the Chinese text *Can-Jing*, which attributes the practice to the queen of the Huang-Di Empire. However, sericulture likely existed in China even before the Huang-Di dynasty, which dates back to approximately 2650 BC. The craft of sericulture spread beyond China via the *Silk Road*. By the third century BC, it had reached the Korean Peninsula and Japan. It later expanded westward from India to Persia and Central Asia. In 550 AD, silkworm eggs were reportedly gifted to the Eastern Roman Emperor, marking the introduction of sericulture to Europe. Silk was a highly valuable commodity along the Silk Road, often traded for its weight in gold. The silk trade not only fuelled economic exchange but also played a significant role in fostering cultural interactions between the East and the West [3].
The mulberry silkworm, *Bombyx mori* L. is the most economically significant insect in sericulture. As a domesticated silk moth, it belongs to the order Lepidoptera under the family Bombycidae, relying exclusively on mulberry leaves (*Morus* sp.) to complete its life cycle [4]. Studies have shown that the quality of silk cocoons is directly influenced by the quality of mulberry leaves [5]. Furthermore, artificial diets negatively impact the metabolic activities of silkworms compared to fresh mulberry leaves [6]. In India, sericulture has significantly contributed to the socio-economic upliftment of rural communities, with more than 80% of

rural populations benefiting from this agro-cottage-based industry [7]. However, as poikilothermic organisms, mulberry silkworms are highly susceptible to pathogens such as bacteria, fungi, protozoa, and viruses, which exploit temperature fluctuations to invade the host. Infections occurring during the rearing stages severely reduce silk yield [8]. Consequently, silkworm diseases pose a major challenge to economic growth in sericulture [9]. Silkworm diseases account for approximately 10% of total crop losses in developing countries [10]. In India, disease-related crop losses range from 15% to 47% [11].

Beyond its traditional role in silk textile production, sericulture has numerous applications that benefit humanity. It contributes to human health by providing valuable food supplements, while silk protein plays a crucial role in drug delivery systems, biopharmaceuticals, and bioactive materials. Its bio-adhesive properties make it useful in enzyme immobilization and tissue engineering. Sericulture also promotes sustainability through waste utilization. By-products such as silkworm pupae and breeding waste can be converted into biogas and biofuels at a low cost, reducing environmental pollution while enhancing the profitability of sericulture farms. Additionally, waste from sericulture can be repurposed into bio-fertilizers and compost, further supporting sustainable agricultural practices [2]. In this context, the biology of silkworms has been extensively discussed in the literature. However, a comprehensive explanation falls beyond the scope of this analysis, as the present article focuses exclusively on microbial infections in mulberry silkworms. This article provides a concise overview of microbial diseases affecting silkworms, along with their potential remedies.

2. Microbial diseases of the mulberry silkworm

Flacherie, Grasserie, Muscardine, and Pebrine are common microbial infections affecting mulberry silkworms. Temperature fluctuations, humidity, and low-quality mulberry leaves are major predisposing factors for disease outbreaks [12]. Studies indicate that autumn is the most favourable season for disease outbreaks in northwest India [11]. In 1845, microbial infections caused a severe epidemic among mulberry silkworms in France [9]. This outbreak prompted Louis Pasteur to develop his ideas on vaccination against infectious microbes [13]. Flacherie, a prevalent bacterial infection in silkworms, is caused by several bacteria, including *Escherichia coli*, *Pseudomonas fluorescens*, *Klebsiella cloacae*, *Staphylococcus aureus*, *Streptococcus pneumoniae*, *Bacillus subtilis*, and *Bacillus cereus* [14]. Viral pathogens are also sometimes responsible for it [15]. Another bacterial infection, *Sappe*, has significantly impacted the agro-cottage industry in Mysore, India. It is associated with bacteria such as *Escherichia freundii*, *Achromobacter superficialis*, *Achromobacter delmarvae*, *Aerobacter cloacae*, *Pseudomonas boreopolis*, *Pseudomonas ovalis*, and *Staphylococcus albus* [16]. Grasserie, also known as nucleopolyhedrosis, is a major cause of economic loss in sericulture [17]. It predominantly occurs during the monsoon season in Maharashtra, India [18]. Muscardine, a fungal infection, reduces both the quantity and quality of cocoons [19]. Pebrine, or microsporidiosis, affects larval and pupal development in *Bombyx mori*, as observed in a study conducted in West Bengal, India [20]. Certain silkworm races, such as NB4D2 × SH6, NB4D2 × KA, J121 × J122, and Hawlak, are particularly susceptible to Pebrine, with larval mortality recorded at 5% in Jammu & Kashmir [21]. An *Enterobacter* sp. strain (ASE) was identified from the gut of infected mulberry silkworms, exhibiting 99.65% similarity with *Enterobacter hormaechei* subsp. *hormaechei* ATCC 49162 (GenBank accession number MT023436) [22].

2.1 Flacherie

Flacherie is commonly associated with *Bombyx mori Flacherie Virus* (BmFV), *Bombyx mori Densonucleosis Virus* (BmDV), or bacterial infections caused by *Staphylococcus* sp., *Streptococcus* sp., *Serratia marcescens*, and *Bacillus thuringiensis*, among others. Infection can be triggered by individual pathogens or a combination of both. The primary mode of transmission is through contaminated mulberry leaves, faecal matter, body fluids, and gut juices of infected larvae [23]. Infected larvae become flaccid and dull, vomit gut juice, and exhibit loose faeces. A rectal protrusion is also observed [24]. Flacherie is most common in summer and least in winter [25]. Cappellozza *et al* [26]. were the first to report *Enterococcus mundtii* as a causative agent of flacherie. In their study, the pathogen was isolated from contaminated mulberry leaves, and infection was traced to an artificial diet prepared from contaminated leaf dust. Ayoade *et al* [27]. identified *Citrobacter freundii*, *Citrobacter amalomaticus*, *Bacillus badius*, *Staphylococcus epidermidis*, *Staphylococcus marcescens*, and *Enterobacter cloacae* as primary bacterial agents responsible for severe infections in silk-rearing regions of southwest Nigeria. Another investigation in Karnataka, India, found *Pseudomonas fluorescens*, *Providencia rettgeri*, *Streptococcus pneumoniae*, *Staphylococcus aureus*, *Bacillus subtilis*, *Bacillus cereus*, *Enterobacter aerogenes*, *Klebsiella cloacae*, *Providencia vermicola*, and *Escherichia coli* in infected silkworm larvae [28]. Further studies identified Gram-positive bacteria such as *Bacillus sphaericus*, *Bacillus circulans*, *Bacillus cereus*, *Paenibacillus macerans*, *Streptococcus* spp., *Staphylococcus aureus*, and *Staphylococcus epidermidis* as major causes of flacherie. These pathogens exhibited resistance to various antibiotics including penicillin, chloramphenicol, quinolones, macrolides, tetracycline, and sulphonamides [29].

2.2 Grasserie

Grasserie is a severe viral disease caused by *Bombyx mori nucleopolyhedrovirus* (BmNPV). It is highly prevalent in tropical regions [30]. High temperature and humidity promote viral multiplication, leading to increased larval mortality [31]. The virus is transmitted through contaminated leaves containing polyhedral inclusion bodies (PIB) and enters through wounds on infected worms. Symptoms include yellowish body colour, whitish faces, skin shrinkage, and reduced appetite. Due to polyhedral body accumulation, the mid-gut appears opaque, and white or yellowish fluid oozes from wounds [23]. Deb[32]. identified occluded bodies (Obs) in the mid-gut as responsible for primary infections, while the budded virus (BV) facilitates cell-to-cell transmission. Furthermore, Torquato *et al* [33]. reported that BmNPV targets the central nervous system, and Etebari *et al* [34]. found that the virus disrupts protein metabolism. Similarly, Singaravelu *et al* [35]. noted that both protein and carbohydrate metabolism are affected by BmNPV infection.

2.3 Muscardine

Muscardine, a fungal infection, is classified into white and green muscardine. White muscardine is caused by *Beauveria*

bassiana, while *Metarhizium anisopliae* is responsible for green muscardine. White muscardine is more severe during rainy and winter seasons, whereas green muscardine thrives in hot and humid conditions. Infected larvae become inactive and are covered in white mycelium [36, 37]. Multivoltine breeds of *Bombyx mori* are less susceptible to *Beauveria bassiana* compared to bivoltine breeds in India [38]. Molecular data reveal high diversity among pathogenic *Beauveria bassiana* strains in southwest China [39]. Shanmugam and Seethapathy[40]. observed that white mycelium turns yellow in later stages, with conidia exhibiting spherical, oval, and non-septated shapes. *Metarhizium anisopliae* forms white mycelium with green conidia in culture [41]. The complete life cycle of *Beauveria bassiana* in *Bombyx mori* takes seven to eight days [42]. Santoro *et al* [43]. found that *Beauveria bassiana* conidia are sensitive to ultraviolet (UV) radiation. Additionally, sub-culturing of the fungus reduced virulence, conidial production, and temperature tolerance, but these properties were restored within the host.

2.4 Pebrine

Pebrine, or microsporidiosis, is a fatal parasitic disease caused by *Nosema bombycis* [9]. Symptoms include poor growth, reduced appetite, irregular moulting, unequal body size, discolouration (off-white, faint yellow, rustic brown), dark brown to black integument spots, and whitish tumour-like pustules along silk glands [44, 45]. The pathogen spreads horizontally through contaminated leaves [46]. or vertically via infected eggs [47]. Patil *et al* [48]. reported that *Nosema bombycis* spores are also transmitted through sexual mating.

3. Isolation and characterization of pathogens

The *Bombyx mori infectious flacherie virus* (BmIFV) is a single-stranded RNA (ssRNA) virus. It has been rapidly detected using molecular techniques such as reverse transcription polymerase chain reaction (RT-PCR) and nested PCR. Mid-gut tissues of diseased larvae are commonly used for BmIFV detection. Early virus detection through these methods can help reduce crop losses [15]. Similarly, PCR techniques have been employed to detect *Bombyx mori nucleopolyhedrovirus* (BmNPV) in fifth-instar larvae [49, 50]. Tang *et al* [51]. isolated a novel BmNPV strain (BmNPV-YN1) from Yunnan, China. Molecular and phylogenetic analyses revealed that BmNPV-YN1 is closely related to BmNPV-Cubic and BmNPV-India. Roy *et al* [52]. utilized RNA polymerase primers in PCR for the early-stage detection of microsporidian parasites in *Bombyx mori*. Omar and Fathy[8]. standardized bacterial pathogen isolation techniques. In their study, fourth-instar infected larvae were surface-sterilized with 70% ethanol and rinsed twice with sterilized distilled water. Body fluid was extracted using a sterilized needle and homogenized in 0.1% peptone water. Pathogens were then inoculated using the serial dilution technique on nutrient agar, MacConkey agar, and Mannitol salt agar. After 24 hours of incubation at 37 °C, bacterial colonies were isolated and purified through dilution streaking method on nutrient agar. The isolates were identified based on colony morphology, Gram-staining, and biochemical characterization. Their study identified that *Bacillus cereus, Bacillus subtilis, Bacillus megaterium, Serratia marcescens, Staphylococcus aureus*, and *Escherichia coli* are predominant bacterial pathogens. In another study, surface sterilization was performed using a 2% sodium hypochlorite solution. Researchers isolated and characterized *Paenibacillus macerans* (*Bacillus macerans*), *Aeromonas* sp., *Bacillus megaterium, Bacillus circulans*, and *Bacillus licheniformis* from fourth- and fifth-instar infected larvae. These bacterial isolates were characterized based on morphological, biochemical, and physiological parameters [53]. Mohanta *et al* [54]. identified *Klebsiella granulomatis* from the hemolymph of silkworms, noting its resistance to multiple antibiotics. Jansi Rani *et al* [10]. isolated bacterial pathogens from the fore-gut, silk gland, reproductive system, and skin of the infected silkworms. Their study identified *Staphylococcus aureus, Staphylococcus albus, Staphylococcus epidermidis, Bacillus thuringiensis*, and *Bacillus orpheus*. Additionally, *Pseudomonas chlororaphis* subsp. *aurantiaca* was reported as a newly identified bacterial pathogen of *Bombyx mori* [55]. Priyadharshini *et al* [56]. isolated *Bacillus subtilis, Bacillus thuringiensis, Bacillus cereus, Klebsiella cloacae, Staphylococcus albus*, and *Staphylococcus aureus* from deceased silkworms. Fungal pathogens have also been studied in *Bombyx mori*. Potato dextrose agar (PDA) was used for the *in vitro* culture of fungal spores isolated from dead silkworms. Additionally, the efficacy of various fungicides was tested on PDA [57].

3.1 Detection of pathogens using biosensor

Biosensors are cutting-edge measurement tools capable of detecting various biomolecules and are widely used for identifying microbial infections. Nanoparticles, graphene quantum dots, and electrospun nanofibers are prominent biosensors in nanobiotechnology [58]. A biosensor can detect pathogens through electrochemical processes [59]. A study demonstrated that amplifying hemin/G-quadruplex-functionalized Pt@Pd nanowires enabled the fabrication of an ultrasensitive electrochemical immunosensor for detecting the spore wall protein of *Nosema bombycis*, a pathogen associated with Pebrine disease. The increased surface area of Pt@Pd nanowires enhanced the immobilization of hemin/G-quadruplex DNAzyme concatamers. These bio-conjugates, captured on the electrode surface in the presence of the target protein, generated a detectable electrochemical signal [60]. Another study introduced a pseudobienzyme electro-catalytically amplified immunosensor for detecting *Nosema bombycis* spore wall protein. This sensor used L-cysteine as an electro-catalyst to generate H_2O_2 in situ, facilitated by hemin/G-quadruplex concatemers loaded onto C60@Pt-Pd. Here, hemin/G-quadruplex also functioned as an output probe for electrochemical signals [61].

3.1 Molecular mechanisms of the host-pathogen interaction

The mulberry silkworm has been widely used to identify virulent genes in various pathogens through different experimental setups. Its immunological and genetic properties enable the development of defence mechanisms against infections. Several antimicrobial proteins, including cecropins, attacins, lebocin, moricin, gloverins, lysozyme, defensins, and hemolin, play a crucial role in silkworm's immune response [62]. Silkworms have been established as a model organism for scientific research due to several advantageous traits, including low breeding costs, large progeny size, short generation time, and a well-defined genetic background [63]. A schematic representation of *Bombyx mori* as a model organism and its potential for sustainable management is illustrated in Fig. 1.

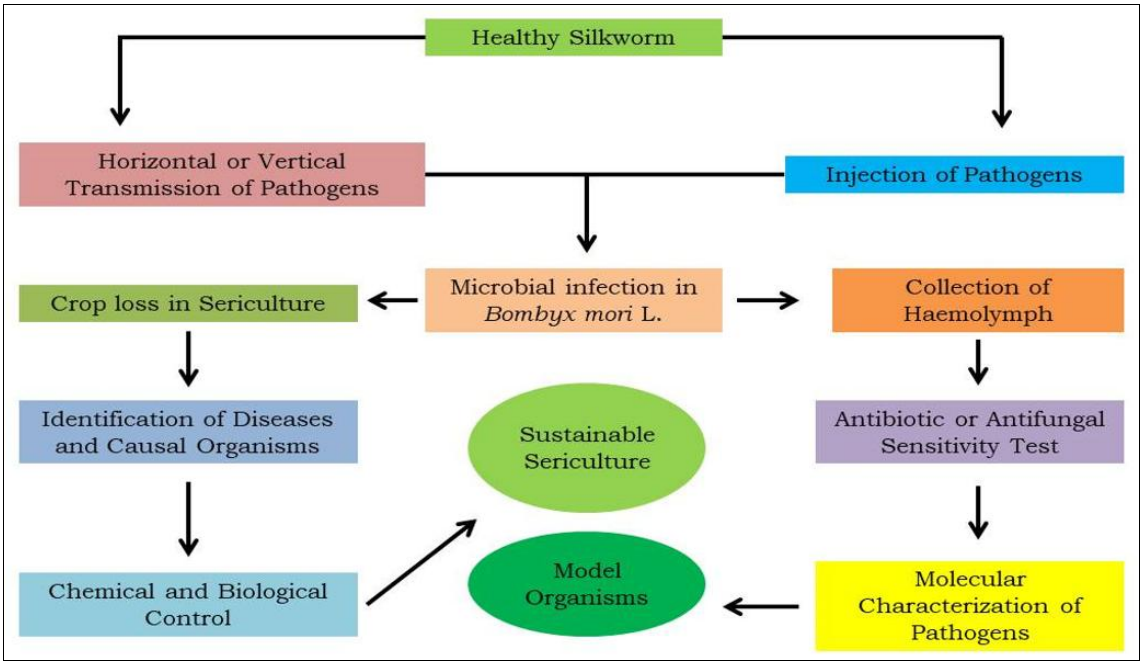

Fig 1: *Bombyx mori* as a model organisms and its opportunity for sustainable management

The mulberry silkworm has also been widely used to study the pathogenicity of various microbes. Research has shown that enzyme activity gradually decreases after *Staphylococcus aureus* is injected into the hemolymph of fifth-instar larvae [64]. In another study, the efficacy of antibiotics against several pathogenic bacteria was evaluated *in-vivo* using the silkworm model [65]. Similarly, the fungicidal and fungistatic effects of selected drugs against *Candida albicans* were assessed in fifth-instar larvae of *Bombyx mori* [66]. Several studies have explored bacterial virulence using the silkworm model. It was found that the *cvfC*, *cvfB*, and *cvfA* genes of *Staphylococcus aureus* contribute to hemolysin production in *Bombyx mori*. Additionally, the *cvfA* gene plays a role in attenuating the virulence of *Streptococcus pyogenes* [67]. Research has also demonstrated that superoxide dismutase (SOD) is a key factor in the virulence of *Pseudomonas aeruginosa* PAO1 against *Bombyx mori* [68]. Another experiment confirmed the virulent properties of exotoxin-A in a mutant strain of *Pseudomonas aeruginosa* using the silkworm model [69]. The silkworm model has also been instrumental in studying viral pathogenesis. It has been suggested that viral proteins such as IE2, CG30, PE38, and PK-1/2 play a crucial role in the interaction between *Bombyx mori nucleopolyhedrovirus* (BmNPV) and silkworms [70]. Enterohemorrhagic *Escherichia coli* (EHEC), a shiga toxin-producing strain, cause intestinal wall damage and bloody diarrhoea in warm-blooded animals [71]. Using the silkworm model, researchers demonstrated that the lipopolysaccharide O-antigen (LPS-O) of EHEC O157:H7 has lethal effects on animals. The *rfbE* and *waaL* genes played a pivotal role in silkworm mortality through LPS-O production [72]. Furthermore, Matsumoto *et al* [73]. reported that *Cryptococcus neoformans* serotype A exhibits greater virulence than serotype D in both mammals and silkworms. Pathogenesis in mammals has been linked to deletion mutants of genes *gpa1*, *pka1*, and *cna1*. Certain strains of *Bombyx mori* carrying the *Nid-1*, *nsd-1*, *nsd-2*, and *nsd-Z* genes have been found to be resistant to *Bombyx mori densovirus* (BmDV-1 and BmDV-2) [74]. A notable study by Wang *et al* [75]. highlighted the role of autophagy in controlling viral infections. Their findings suggest that BmNPV induces autophagy as an intrinsic innate immune response in infected silkworm cells. Furthermore, autophagy-related genes (*Atg7* and *Atg9*) have been identified as key players in the immune defence mechanism of *Bombyx mori*.

3.2 Management of microbial diseases in the silk industry

The management of silkworm diseases is a crucial aspect of the silk industry. Maintaining a hygienic environment in rearing houses through using proper disinfectants is essential for disease control. The use of appropriate decontaminators is a common practice in the silk industry to eliminate pathogens, while inappropriate disinfectants and unhygienic conditions increase infection rates. Crop loss due to infections can be mitigated by using effective disinfectants. *Asthra* and *Ankush*, two patented disinfectants developed by the Central Sericultural Research and Training Institute (CSRTI), Mysore, India, are highly effective against all silkworm pathogens [76]. Guo-Ping and Xi-Jie[77]. emphasized research on the molecular basis of host-pathogen interactions, the production of disease-resistant silkworm breeds, and disease management protocols. Formalin and bleaching powder are widely used disinfectants in rearing houses. Chlorine dioxide, a stable, non-hazardous, and minimally corrosive disinfectant, has also been employed in sericulture. A disinfectant solution is prepared by mixing chlorine dioxide (500 ppm) in slaked lime. A 0.5% lime solution has been found effective against various pathogens, including Microsporidian (*Nosema bombycis*), *Bacillus thuringiensis*, BmNPV, and *Beauveria bassiana* [78]. (Balavenkatasubbaiah *et al*., 1999). *Serichlor-60* and *Serichlor-20* are popular chlorine dioxide-based disinfectants used in Indian sericulture [79]. Rajagopal *et al* [57]. demonstrated that applying 1.6% *Kavach* (a fungicide) resulted in a 63.10% survival rate for crossbreed silkworm larvae, while bivoltine silkworms had a survival rate of 61.15%. Rasool *et al* [80]. found that the highest silkworm survival rate was achieved using *Vijetha*, followed by a mixture of lime, *Captan*, and walnut hull powder in a ratio of 98.5:1:0.5. According to Anusha *et al* [81]. active lime, hydrated lime, bundh powder, and *Vijetha* are widely used as bed disinfectants in rearing houses. In an *in-vitro* study,

Trivedy *et al* [82]. demonstrated that a 2% bleaching powder solution and a 0.3% slaked lime solution, followed by a 2% formalin solution, effectively controlled fungal diseases in silkworms. Antibiotics are crucial for managing bacterial infections in silkworms. Their use reduces larval and pupal mortality while increasing cocoon weight, shell weight, and shell ratio. Shah *et al* [83]. reported that among antibiotics, amoxicillin was the most effective, followed by oxytetracycline and doxycycline. Mahmoud *et al* [84]. found that gentamicin is widely used to treat bacterial flacherie in *Bombyx mori* in Egypt. Biological disease control offers an alternative to chemical disinfectants. *Burkholderia cepacia* Lu10-1, a mulberry endophytic bacterium, has shown antagonistic activity against *Bacillus bombyseptieus*, a septicemic pathogen in silkworms [85]. Eco-friendly plant powders have also been explored as disinfectants. Soumya[86]. reported that green dusts were highly effective against *Beauveria bassiana*. Eucalyptus plant extracts exhibited the highest fungal growth inhibition, followed by *Acacia auriculiformis*, *Moringa oleifera*, *Murraya koenigii*, and *Syzygium cumini* under *in-vitro* conditions. Botanical applications significantly improved silk production. Somu *et al* [87]. found that *Phyllanthus amarus* extract exhibited antiviral activity against BmNPV, while herbal extracts effectively controlled bacterial pathogens. Karthikairaj *et al* [88]. extracted antimicrobial compounds from *Ocimum sanctum*, *Acalypha indica*, and *Leucas aspera*, which inhibited *Staphylococcus aureus* growth. Gore *et al* [89]. demonstrated that *Phyllanthus emblica* (Amla) leaf extract prevented *Bacillus subtilis* multiplication in silkworms, enhancing silk production when applied at 10%. Isaiarasu *et al* [12]. found that extracts from *Tridax procumbens*, *Acalypha indica*, and *Ocimum sanctum* controlled microbial infections such as muscardine and flacherie. In muga silkworms (*Antheraea assama*), plant extracts have been effective in controlling flacherie. Unni and Neog[90]. demonstrated that the fruit extract of *Terminalia chebula*, known as *Muga Heal*, effectively inhibited *Pseudomonas aeruginosa* AC-3, a significant flacherie pathogen. The gallic acid compound in Muga Heal improved feeding behaviour, increased cocoon quality, and reduced pathogenic infections. The National Research and Development Corporation (NRDC), India, has developed an eco-friendly botanical-based powder, *Amruth*, for managing grasserie and flacherie diseases. A solution of this herbal powder (2.0g/100 ml) is sprayed on mulberry leaves (70.0 ml/kg) before feeding silkworms, with air-dried leaves ensuring effective application [91]. Nanobiotechnology has also been explored for silkworm disease management. Prabhu *et al* [92]. reported that silver nanoparticles (AgNPs) exhibited promising antibacterial activity against silk pathogens. Feeding silkworms with AgNP-treated mulberry leaves significantly reduced gut bacterial populations compared to untreated leaves. AgNPs demonstrated bactericidal effects against both Gram-negative and Gram-positive pathogenic strains in *Bombyx mori* and mulberry plants. Li *et al* [93]. found that cytoplasmic polyhedral viruses (CPVs) were degraded by "Sumerian Silver." Xu *et al* [94]. demonstrated that titanium dioxide nanoparticles (TiO_2NPs) enhanced *Bombyx mori*'s resistance by preventing BmNPV multiplication. Jayaraman[95]. reported that transgenic silkworms could combat viral infections, while Kiran Kumar and Naik[96]. found that BmNPV-tolerant hybrids (polyvoltine × bivoltine) were highly effective in disease control. Sharma *et al* [97]. demonstrated that CA2×NB4D2 bivoltine silkworm races exhibited the lowest disease susceptibility during monsoon seasons in Uttar Pradesh, India. Some *et al* [98]. reported that biosynthesized nanosilver (10µg/ml) improved mulberry silkworm survivability, larval and pupal body weight, cocoon weight, and shell weight by increasing feed efficiency. The same AgNP dose increased cocoon length by 13.9% compared to the control. These studies highlight diverse experimental approaches to controlling silkworm diseases, ranging from chemical disinfectants and antibiotics to biological control, plant-based remedies, and nanobiotechnology.

4. Conclusion

This agro-cottage-based industry plays a crucial role in the economic development of society. Sericulture and even Moriculture provide significant social and economic benefits, particularly to rural communities. However, silkworm diseases pose a major challenge, often exacerbated by unfavorable weather conditions and unhealthy rearing environments, which facilitate the spread of pathogens. The improper and unscientific use of disinfectants in rearing houses fails to effectively control infections. Moreover, relying solely on disinfectants cannot eliminate all disease-related issues. Antibiotic use must be approached with caution, as overuse can lead to bacterial resistance. Among various preventive measures, biological control has emerged as the most eco-friendly and non-harmful approach. Additionally, the administration of plant extracts has been found to enhance cocoon quality and improve resistance to infections. Maintaining proper feeding habits is also essential, as it ensures optimal metabolic and immunogenic standards in silkworms. Advances in transgenesis and molecular biology now allow for the development of disease-resistant transgenic silkworms, both bivoltine and multivoltine. These strategies must be carefully applied based on specific needs to effectively manage infections. Furthermore, the application of nanobiotechnology in designing novel drugs could provide a promising solution for combating microbial pathogens. The introduction of nano-based drugs in the silk industry is expected to reduce infection and mortality rates while improving the cost-benefit ratio. This article examines various microbial infections affecting mulberry silkworms, their impacts, and potential management strategies to enhance sericulture productivity and sustainability.

5. Acknowledgements

SS and JM are highly grateful to the Department of School Education, Government of West Bengal, India for encouragement.

6. Source of funding agency

None.

7. Author's contribution

SS designed the concept. AM and JM contributed to preparing the initial draft and figures of the manuscript (MS). SS wrote the final version of the MS with the help of other authors.

8. Conflict of interest

The authors declare that they have no conflict of interest.

9. References

1. Jiang L, Xia Q. The progress and future of enhancing antiviral capacity by transgenic technology in the

silkworm *Bombyx mori*. Insect Biochem Mol Biol. 2014;48:1–7.
2. Jaiswal KK, Banerjee I, Mayookha VP. Recent trends in the development and diversification of sericulture natural products for innovative and sustainable applications. Bioresour Technol. 2021;13:100614.
3. Takeda S. Sericulture. In: Resh VH, Cardé RT, editors. *Encyclopaedia of Insects*. 2nd ed. San Diego: Academic Press; 2009. p. 912–4.
4. Kumari SS, Subbarao SV, Misra S, Murty US. Screening strains of the mulberry silkworm, *Bombyx mori*, for thermo tolerance. J Insect Sci. 2011;11:116.
5. Shah AI. Flacherie – A threat to the socio-economic fabric of India: A review. Int J Adv Res. 2016;4(9):692-5.
6. Dong HL, Zhang SX, Tao H, Chen ZH, Li X, Qiu JF, *et al*. Metabolomics differences between silkworms (*Bombyx mori*) reared on fresh mulberry (*Morus*) leaves or artificial diets. Sci Rep. 2017;7(1):10972.
7. Patil BR, Singh KK, Pawar SE, Maarse L, Otte JM. Sericulture: An Alternative Source of Income to Enhance the Livelihoods of Small-scale Farmers and Tribal Communities. 2009. Available from: https://api.semanticscholar.org/CorpusID:140115285. Accessed on 29 Jan 2025.
8. Omar AS, Fathy MD. Evaluation of controlling silkworm bacterial disease using propolis extract and cinnamon oil. J Agril Chem Biotechnol. 2016;7(7):213-8.
9. Bhat IA, Buhroo ZI, Bhat MA. Microsporidiosis in silkworms with particular reference to mulberry silkworm (*Bombyx mori* L.). Int J Entomol Res. 2017;2(1):1-9.
10. Jansi Rani L, Venkatesh B, Kumaran T. Sensitivity and antibiogram studies on pathogenic microbes isolated from the silkworm *Bombyx mori* L. Pharma Innov. 2015;4(6):101-3.
11. Tayal MK, Chauhan TPS. Silkworm diseases and pests. In: Omkar, editors. *Industrial Entomology*. 1st ed. Singapore: Springer; 2017. p. 265-89.
12. Isaiarasu L, Sakthivel N, Ravikumar J, Samuthiravelu P. Effect of herbal extracts on the microbial pathogens causing flacherie and muscardine diseases in the mulberry silkworm, *Bombyx mori* L. J Biopestic. 2011;4(2):150-5.
13. Berche P. Louis Pasteur, from crystals of life to vaccination. Clin Microbiol Infect. 2012;18(5):1-6.
14. Sakthivel S, Angaleswari C, Mahalingam PU. Isolation and identification of bacteria responsible for Flacherie in silkworms. Adv Appl Sci Res. 2012;3(6):4066-8.
15. Vootla SK, Lu XM, Kari N, Gadwala M, Lu Q. Rapid detection of infectious Flacherie virus of the silkworm, *Bombyx mori*, using RT-PCR and nested PCR. J Insect Sci. 2013;13(120):1-9.
16. Chitra C, Bhandarkar A, Karanth NGK, Vasantharajan VN. Studies on "Sappe" disease of the silkworm *Bombyx mori* L. Curr Sci. 1973;42(11):373-6.
17. Patil CS. Grasserie - Nuclear polyhedrosis virus (NPV) disease of silkworm, *Bombyx mori* L. Indian J Seric. 2005;44(1):1-12.
18. Joshi RP, Ahmad RI. Seasonal incidence of pathogenic disease grasserie in silkworm *Bombyx mori* in Vidarbha region (Maharashtra). Indian J Appl Pure Biol. 2017;32(2):111-6.
19. Rajitha K, Savithri G. Studies on symptomological and economic parameters of silk cocoons of *Bombyx mori* inoculated with *Beauveria bassiana* (Bals.) Vuill. Int J Curr Microbiol Appl Sci. 2015;4(2):44-54.
20. Gupta SK, Hossain Z, Nanu MM, Mondal K. Impact of microsporidian infection on growth and development of silkworm *Bombyx mori* L. (Lepidoptera: Bombycidae). Agr Nat Resour. 2016;50(5):388-95.
21. Sahaf KA. Incidence of protozoan disease (Pebrine) of silkworm, *Bombyx mori* L. in Jammu and Kashmir. J Entomol Res. 2002;26:305-7.
22. Some S, Sarkar B, Biswas K, Jana TK, Bhattacharjya D, Dam P, *et al*. Bio-molecule functionalized rapid one-pot green synthesis of silver nanoparticles and their efficacy towards the multi-drug resistant (MDR) gut bacteria of silkworms (*Bombyx mori*). RSC Adv. 2020;10:22742–57.
23. Sericulture Information Linkages and Knowledge System (SILKS), India. Diseases and pests of mulberry silkworm. 2025. Available from: http://silks.csb.gov.in/gajapati/diseases-and-pests-of-silkworms. Accessed on 31 Jan 2025.
24. Balavenkatasubbaiah M, Sivaprasad V. Flacherie disease and its management in silkworm rearing. 2025. Available from: www.csrtimys.res.in/sites/default/files/menufiles/forewarning-kn-flacherie.pdf. Accessed on 25 Jan 2025.
25. Selvakumar T. Prevalence of flacherie disease and pathogenicity of isolated pathogens in silkworm *Bombyx mori* (L.) under different environmental conditions. Agric Sci Dig. 2013;33(4):253–8.
26. Cappellozza S, Saviane A, Tettamanti G, Squadrin M, Vendramin E, Paolucci P, *et al*. Identification of *Enterococcus mundtii* as a pathogenic agent involved in the "Flacherie" disease in *Bombyx mori* L. larvae reared on artificial diet. J Invertebr Pathol. 2011;106(3):386-93.
27. Ayoade F, Oyejide NE, Fayemi SO. Isolation, identification, antibiogram and characterization of bacterial pathogens of the silkworm, *Bombyx mori* in South-West Nigeria. J Biol Sci. 2014;14(6):425-30.
28. Swathi HC. Isolation and molecular characterization of bacteria associated with Flacherie disease of silkworm *Bombyx mori* L. [Ph. D. Thesis]. University of Agricultural Sciences, Bengaluru, India; 2015. Available from: http://krishikosh.egranth.ac.in/handle/1/5810028694. Accessed on 15 Jun 2018.
29. Gurgulova KI, Orozova PS, Panayotov MV, Zhelyazkova IZ, Takova SB, Guncheva RP. Isolation and identification of some Gram-positive bacteria causing infections in silkworm *Bombyx mori* L. (Lepidoptera). Acta Zool Bulg. 2017;8:139-44.
30. Martínez-Zubiaur Y, Abreu MP, Hernández M del CP, Sihler W, Falcão R, Ribeiro BM, *et al*. First record of a Bombyx mori nucleopolyhedrovirus (BmNPV) isolate from Cuba. Int J Curr Res. 2016;8(8):35766-70.
31. Selvakumar T, Sharma SD, Shashidhara M. Effect of temperature on incidence of Grasserie disease in silkworm, *Bombyx Mori* L. Indian J Seric. 2013;52(2):163-6.
32. Deb S. Studies on Nuclear Polyhedrosis (Grasserie disease) of silkworm, *Bombyx mori* L. in West Bengal and its management [Ph. D. Thesis]. The University of Burdwan, West Bengal, India; 2013.
33. Torquato EFB, Neto MH de M, Brancalhão RMC. Nucleopolyhedrovirus infected central nervous system

cells of *Bombyx mori* L. (Lepidoptera: Bombycidae). Neotrop Entomol. 2006;35(1):70-4.
34. Etebari K, Matindoost L, Mirhoseini SZ, Turnbull MW. The effect of BmNPV infection on protein metabolism in silkworm (*Bombyx mori*) larva. Invertebrate Surviv J. 2007;4(1):13-7.
35. Singaravelu G, Deepa K, Prabu P, Sakila M. Biochemical action of BmNPV Infection on certain tissues of silkworm *Bombyx mori* L. Asian J Microbiol Biotechnol Environ Sci. 2004;6(4):675-9.
36. Reddy KB, Rao KVJ. Seasonal occurrence of control of silkworm diseases, grassery, flacherie, muscardine, and insect fly uzi fly in Andhra Pradesh, India. Int J Ind Entomol. 2009;18(2):57-61.
37. Banerjee S, Pal S, Mukherjee S, Podder D, Mukherjee A, Nandi A, *et al*. Cellular abnormalities induced by *Trichoderma* spp. during *in vitro* interaction and control of white muscardine (*Beauveria bassiana*) and green muscardine (*Metarhizium anisopliae*) disease of silkworm *Bombyx mori*. J Biopestic. 2016;5:1-6.
38. Chandrasekharan K, Nataraju B. Studies on white muscardine disease of mulberry silkworm *Bombyx mori* L. in India - A review. Indian J Seric. 2008;47(2):136-54.
39. Wang JJ, Yang L, Qiu X, Liu YG, Zhou W, Wan YJ. Diversity analysis of *Beauveria bassiana* isolated from infected silkworm in South West China based on molecular data and morphological features of colony. World J Microbiol Biotechnol. 2013;29:1263-9.
40. Shanmugam V, Seethapathy P. Isolation and characterization of white muscardine fungi *Beauveria bassiana* (Bals.) Vuill. - A causative of mulberry silkworm. J Entomol Zool Stud. 2017;5(3):512-5.
41. Krutmuang P. Laboratory studies on green muscardine fungus, *Metarhizium anisopliae* for control of termites (Isoptera). 1996. Available from: [suspicious link removed]. Accessed on 20 Jun 2018.
42. Kumar V, Singh GP, Babu AM, Ahsan MM, Datta RK. Germination, penetration, and invasion of *Beauveria bassiana* on silkworm, *Bombyx mori* causing white muscardine. Italian J Zool. 1999;66(1):39-43.
43. Santoro PH, Zorzetti J, Constanski K, Neves PMOJ. Conidial production, virulence, and stress tolerance of *Beauveria bassiana* conidia after successive *in vitro* sub culturing. Rev Colomb Entomol. 2014;40(1):85-90.
44. Tamil Nadu Agricultural University (TNAU), India. Disease management: mulberry silkworm. 2014. Available from: http://agritech.tnau.ac.in/sericulture/disese%20mgt_silkworm.html. Accessed on 19 Jul 2018.
45. Hukuhara T. The epizootiology of pebrine, one of the great scourges of sericulture. J Biochem Biotechnol. 2017;1(1):1-3.
46. Tekin OK, Sezer D, Soganci K, Tunca RI. Molecular and microscopic detection of *Microsporidia* in some silkworm (*Bombyx mori* L.) populations in Turkey. Turk Tarim Doga Bilim Derg. 2014;1(4):450–3.
47. Nayaka ARN, Sharma SD. Paradigm of vertical transmission of newly isolated microsporidian NIK-5hm in popular multivoltine and bivoltine breeds of silkworm *Bombyx mori* L. J Entomol Zool Stud. 2014;2(1):73-5.
48. Patil CS, Jyothi NB, Dass CMS. Role of Nosema bombycis infected male silk moths in the venereal transmission of Pebrine disease in *Bombyx mori* (Lep., Bombycidae). J Appl Entomol. 2002;126(10):563-6.
49. Joshi RP, Raja IA. Polymerase chain reaction based detection of grasserie virus, BmNPV in silkworm, *Bombyx mori*. Biosci Biotechnol Res Commun. 2016;10(1):121-4.
50. Khyade VB, Tyagi BK. Detection of Grasserie virus, BmNPV in the fifth instar larvae of silkworm, *Bombyx mori* (L) (Race: PM x CSR2) through Polymerase Chain Reaction. Int J Curr Microbiol Appl Sci. 2017;6(3):13-23.
51. Tang F, Zhang Y, Shao Y, Zhu F, Huang P, Bai X. Isolation and identification of a new *Bombyx mori* Nucleopolyhedrovirus strain isolated from Yunnan, China. Sci Asia. 2017;43(1):26-32.
52. Roy G, Mandal K, Ravikumar G. PCR-based detection of microsporidia in silkworms using non-conventional RNA polymerase primers. Biosci Biotechnol Res Commun. 2017;10(4):676-9.
53. Abou El-Ela AA, Abdelaleim YF, Kariman MM. Isolation and identification of some bacteria causing infections in silkworm (*Bombyx mori* L.). Int J Curr Res Biosci Plant Biol. 2015;2(12):69-74.
54. Mohanta MK, Saha AK, Saleh DKMA, Islam MS, Mannan KSB, Fakruddin M. Characterization of *Klebsiella granulomatis* pathogenic to silkworm, *Bombyx mori* L. 3 Biotech. 2015;5(4):577–83.
55. Tao HP, Shen ZY, Zhu F, Xu XF, Tang XD, Xu L. Isolation and identification of a pathogen of silkworm *Bombyx mori*. Curr Microbiol. 2011;62:876-83.
56. Priyadharshini P, Mahalingam CA, Shashidhar KR. Identification and characterization of bacterial pathogens in silkworm, *Bombyx mori* L. Curr Biotica. 2008;2(2):181-92.
57. Rajagopal V, Ramesh HL, Yogananda Murthy VN, Ninge Gowda KN. Efficacy of fungicide 'Kavach' against *Beauveria bassiana* L. in silkworm *Bombyx mori* L. J Appl Nat Sci. 2014;6(1):31-7.
58. Castillo-Henríquez L, Brenes-Acuña M, Castro-Rojas A, Cordero-Salmerón R, Lopretti-Correa M, Vega-Baudrit JR. Biosensors for the Detection of Bacterial and Viral Clinical Pathogens. Sensors. 2020;20(23):6926.
59. Cesewski E, Johnson BN. Electrochemical biosensors for pathogen detection. Biosens Bioelectron. 2020;159:112214.
60. Wang Q, Song Y, Chai Y, Pan G, Li T, Yuan Y, *et al*. Electrochemical immunosensor for detecting the spore wall protein of *Nosema bombycis* based on the amplification of hemin/G-quadruplex DNAzyme concatamers functionalized Pt@Pd nanowires. Biosens Bioelectron. 2014;60:118-23.
61. Wang Q, Song Y, Xie H, Chai Y, Yuan Y, Yuan R. L-cysteine induced hemin/G-quadruplex concatemers electrocatalytic amplification with Pt-Pd supported on fullerene as a nanocarrier for sensing the spore wall protein of *Nosema bombycis*. Chem Commun. 2015;51(7):1255-8.
62. Zafar B, Shabir AW, Malik MA, Ganai MA. A Review: disease resistance in mulberry silk worm *Bombyx mori* L. Asian J Sci Technol. 2013;4(11):157-66.
63. Xu M, Zhu F, Chen K. Silkworm: a promising model organism in Life Science. J Insect Sci. 2017;17(5):97.
64. Reddy HA, Venkatappa B. Effects of *Staphylococcus aureus* infection on biochemical and antioxidant activities of fifth instar silkworm larvae (*Bombyx mori* L.). J Bacteriol Parasitol. 2016;7(4):1000286.

65. Kaito C, Akimitsu N, Watanabe H, Sekimizu K. Silkworm larvae as an animal model of bacterial infection pathogenic to humans. Microb Pathog. 2002;32(4):183-90.
66. Tezuka M, Oura T, Kajiwara S. A silkworm model of fungal infections for antifungal screening. *Abstract Volume of 17th International Society for Human and Animal Mycology*. 2009. Available from: https://www.aspergillus.org.uk/content/silkworm-model-fungal-infections-antifungal-screening. Accessed on 15 Jun 2018.
67. Kaito C, Kurokawa K, Matsumoto Y, Terao Y, Kawabata S, Hamada S, *et al*. Silkworm pathogenic bacteria infection model for identification of novel virulence genes. Mol Microbiol. 2005;56(4):934-44.
68. Iiyama K, Chieda Y, Lee JM, Kusakabe T, Yasunaga-Aoki C, Shimizu S. Effect of superoxide dismutase gene inactivation on virulence of *Pseudomonas aeruginosa* PAO1 toward the silkworm, *Bombyx mori*. Appl Environ Microbiol. 2007;73(5):1569-75.
69. Chieda Y, Iiyama K, Lee JM, Kusakabe T, Yasunaga-Aoki C, Shimizu S. Virulence of an exotoxin A-deficient strain of *Pseudomonas aeruginosa* toward the silkworm, *Bombyx mori*. Microb Pathog. 2011;51(6):407-14.
70. Xue J, Qiao N, Zhang W, Cheng R-Lin, Zhang X-Qin, Bao Y-Yuan, *et al*. Dynamic interactions between *Bombyx mori* Nucleopolyhedrovirus and its host cells revealed by transcriptome analysis. J Virol. 2012;86(13):7345-59.
71. Nguyen Y, Sperandio V. Enterohemorrhagic *Escherichia coli* (EHEC) pathogenesis. Front Cell Infect Microbiol. 2012;2:90.
72. Miyashita A, Iyoda S, Ishii K, Hamamoto H, Sekimizu K, Kaito C. Lipopolysaccharide O-antigen of enterohemorrhagic *Escherichia coli* O157:H7 is required for killing both insects and mammals. FEMS Microbiol Lett. 2012;333(1):59-68.
73. Matsumoto Y, Miyazaki S, Fukunaga DH, Shimizu K, Kawamoto S, Sekimizu K. Quantitative evaluation of cryptococcal pathogenesis and antifungal drugs using a silkworm infection model with *Cryptococcus neoformans*. J Appl Microbiol. 2016;112(1):138-46.
74. Gupta T, Okuda KK, Ito K, Trivedy K, Ponnuvel KM. Densovirus infection in silkworm *Bombyx mori* and genes associated with disease resistance. Invertebrate Surviv J. 2015;12(1):118-28.
75. Wang L, Xiao Q, Zhou XL, Zhu Y, Dong ZQ, Chen P, *et al*. *Bombyx mori* Nuclear Polyhedrosis Virus (BmNPV) induces host cell autophagy to benefit infection. Viruses. 2018;10(1):14.
76. Balavenkatasubbaiah M, Chandrasekharan K, Sharma SD, Nayaka AR, Bindroo BB. Disinfection and hygiene technology using Asthra and Ankush for the management of silkworm diseases. Int J Pl Anim Environm Sci. 2014;4:100-6.
77. Guo-Ping K, Xi-Jie G. Overview of silkworm pathology in China. African J Biotechnol. 2011;10(79):18046-56.
78. Balavenkatasubbaiah M, Ananthalakshmi KVV, Selvakumar T, Nataraju B, Datta RK. Chlorine dioxide, a new disinfectant in sericulture. Indian J Seric. 1999;38(2):125-30.
79. Balavenkatasubbaiah M, Nataraju B, Sharma SD, Selvakumar T, Chandrasekharan K, Rao PS. Serichlor: a new disinfectant in Indian Sericulture. Int J Indust Entomol. 2006;12:7-14.
80. Rasool S, Ganie NA, Wani YM, Dar KA, Khan IL, Mehraj S. Evaluation of a suitable silkworm bed disinfectant against silkworm diseases and survivability under temperate conditions of Kashmir. Int J Chem Stud. 2018;6(1):1571-4.
81. Anusha HG, Bhaskar RN, Doreswamy C, Naika R. Effect of bed disinfectants and seasonal incidence of silkworm diseases in different types of rearing houses. Environ Ecol. 2013;31:1935-8.
82. Trivedy K, Kumar SN, Vinutha N, Qadri SMH. In-vitro testing of common disinfectants used in sericulture to control the growth of fungi in rearing houses. Res J Microbiol. 2011;6(5):439-65.
83. Shah HAM, Rokonuzzaman Md, Uddin Md A, Ahsan Md K. The effects of amoxicillin, oxytetracyclin and doxycycline on the growth and development of silkworm, *Bombyx mori* L. J Entomol Zool Stud. 2017;5(6):1316-21.
84. Mahmoud SM, Taha RH, Saad IAI. Antibiotic (Gentamicin) impact on bacterial flacherrie disease of silkworm, *Bombyx mori* L. Egypt Acad J Biol Sci. 2012;5(2):55-63.
85. Dong FB, Mu ZM, Yu Q, Zhao K, Liu ZY, Wang YW, *et al*. Control effect and bacteriostasis of mulberry endophytic bacterium *Burkholderia cepacia* Lu10-1 on silkworm septicemia. Chinese J Appl Ecol. 2012;23(11):3109-15.
86. Soumya BR. Use of botanicals as bed disinfectant against white muscardine disease of silkworm *Bombyx mori* L. [M. Sc. Thesis]. University of Agricultural Sciences, Bengaluru, India; 2011. Available from: http://krishikosh.egranth.ac.in/handle/1/94282. Accessed on 15 Jun 2018.
87. Somu C, Paulchamy R, Moorthy SM, Sundaram J. Antiviral activity of selected medicinal plants and marine seaweeds on the grasserie infected larvae of silkworm, *Bombyx mori*. Arch Phytopathol Plant Prot. 2017;50(17-18):850-67.
88. Karthikairaj K, Isaiarasu L, Sakthivel N. Herbal extracts for *Bombyx mori*. J Biopestic. 2014;7:89-93.
89. Gore D, Rai M, Shinde G. Effect of Amla extract on bacterial infection in the silkworm, *Bombyx mori* L. J Pharmacy Res. 2014;8(5):679-80.
90. Unni BG, Neog K. Current trend of biotechnological and molecular research in Muga silkworm, *Antheraea assamensis*, helfer and future prospects. Abstract volume of National Seminar on Recent Trends in Research & Development in Muga Culture – Ideas to Action. Guwahati, India; 2012. p. 12-20.
91. National Research and Development Corporation (NRDC), India. Amruth – A botanical product for controlling grasserie and flacherie in silkworm. Available from: https://www.nrdcindia.com/english/index.php/.05./sericulture/305-seri-tech-7. Accessed on 15 Jun 2018.
92. Prabhu PG, Selvisabhanayakam, Mathivanan V. Antibacterial activity of silver nanoparticles against bacterial pathogens from gut of silkworm, *Bombyx mori* (L.) (Lepidoptera: Bombycidae). Int J Res Pure Appl Microbiol. 2013;3(3):89-93.
93. Li W, Volodymyr K, Wang Y, Volodymyr D. The bactericidal spectrum and virucidal effects of silver nanoparticles against the pathogens in sericulture. Open J

Anim Sci. 2013;3(3):169-73.
94. Xu K, Li F, Ma L, Wang B, Zhang H, Ni M, *et al*. Mechanism of enhanced *Bombyx mori* Nucleopolyhedrovirus - resistance by Titanium Dioxide Nanoparticles in silkworm. PLoS One. 2015;10(2):e0118222.
95. Jayaraman KS. Engineered silkworms resist virus infection. Nature India. 2012. https://doi.org/10.1038/nindia.2012.175.
96. Kiran Kumar KP, Naik SS. Development of Polyvoltine x Bivoltine hybrids of mulberry silkworm, *Bombyx mori* L. tolerant to BmNPV. Int J Zool Res. 2011;7(4):300-9.
97. Sharma R, Ganie NA, Rufaie ZH, Khan IL, Parkash J. Screening of various bivoltine hybrids of silkworm *Bombyx mori* L. for disease susceptibility during monsoon seasons in Uttar Pradesh. Int J Adv Biol Res. 2014;4(3):352-6.
98. Some S, Bulut O, Biswas K, Kumar A, Roy A, Sen IK, *et al*. Effect of feed supplementation with biosynthesized silver nanoparticles using leaf extract of *Morus indica* L. V1 on *Bombyx mori* L. (Lepidoptera: Bombycidae). Sci Rep. 2019;9(1):14839.