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Mini Review

Tea Pest Management: A Microbiological Approach

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ABSTRACT

Tea crop damage is caused by mites and insect pests, and each year a significant amount of crop loss is occurring due to their damage. The efficiency of synthetic pesticides has permitted for their widespread usage as a control tool over several decades. Synthetic pesticides, on the other hand, have resulted in the development of insect pest resistance, pollution, and pesticide residues in the finished product, etc, forcing the planting community to look for the development of an alternate strategy. Microbial pesticides have been employed to counter the mite and insect pest-damaging tendencies while a significant portion of scientific data suggests that their actions are both desirable and environmentally beneficial. The efficiency of entomopathogenic microorganisms against several tea pests was examined and the microbial biopesticides were found to be successful and demonstrated promising effects against tea pests. In this mini-review, we have combined fundamental and integrated pest management information into an easy-to-follow method for control the tea pests.

Keywords: Microbial pesticide; Tea pests; Biopesticides; IPM

INTRODUCTION

Tea, one among the admired non-alcoholic beverages obtained from *Camellia sinensis* (L.) O. Kuntze. *C. sinensis*, a perennial monoculture plantation crop, contributes to the economy of many countries [1] including India. Tea production is threatened by many insects and mite pests worldwide (Table 1). As the tea ecosystem is undergoing rapid changes, from time to time there are outbreaks of newer pests due to change in the global climate [2]. Although, the management of these pests is achieved through adopting cultural and application of chemical practices, however, chemical insecticides have their limitations as they cause several ailing effects as continuous application of synthetic pesticides causes' different health hazard not only to the tea workers but also to the consumers along with environmental pollution [3]. Researchers have been interested in natural insecticides based on botanicals or bio-control agents to treat insect pests of tea plants in recent years [4], and in this regard, entomopathogens are no exception.

Table 1: Different pests of tea crop.

Common name	Scientific name
Major pests of tea	
Tea mosquito bug:	*Helopeltis theivora* Waterhouse (Miridae: Hemiptera)
Thrips	*Scirtothrips dorsalis* Hood (Thripidae: Thysanoptera)
Jassid	*Empoasca flavescens* Fab. (Cicadellidae: Hemiptera)
Aphids	*Toxoptera aurantii* Boyer de Fonscolombe (Aphididae: Hemiptera)
Bunch caterpillar:	*Andraca bipunctata* Walker (Bombycidae: Lepidoptera)
Red spider mite	*Oligonychus coffeae* Nietner (Tetranychidae: Acari)
Tea looper complex	*Buzura suppressaria* Guen (Geometridae: Lepidoptera), *Hyposidra talaca* (Walker), *H. infixaria* (Walker) (Geometridae: Lepidoptera)
Shot hole borer	*Euwallacea fornicates* Eichhoff (Scolytidae: Coleoptera)
Live wood eating termite	*Microcerotermes* sp. (Isoptera:Termitidae)
Scavenging termites	*Odontermes* sp. (Isoptera:Termitidae)
Minor pests of tea	
Flush worm	*Cydia leucostoma* Meyrick (Tortricidae: Lepidoptera)
Pink and Purple mite	*Acaphylla theae* Watt and *Calacarus carinatus* Green (Eriophyidae: Acarina)
Scarlet mite	*Brevipalpus phoenicis* Geijskes (Tenuipalpidae :Acarina)

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Yellow mite	*Polyphagotarsonemus latus* Banks (Tarsonemidae: Acarina)
Leaf roller	*Caloptilia theivora* Walsingham (Gracillariidae: Lepidoptera)
Scales	*Saissetia formicarii* Takahashi, *S. coffeae* Walker, *Eriochiton theae* Green, *Coccus viridis* Green (Coccidae: Hemiptera)
Tea tortrix	*Homona coffearia* Nietner (Tortricide: Lepidoptera)

Biological Control Agents (BCAs) including *Beauveria*, *Metarhizium*, and other species have been proven to be safe and promising components of IPM techniques employed in several crops, as well as tea [5]. While the existing study of literature on this subject is restricted [6], much of the material on the commercialization of beneficial fungus as microbial pesticides consist of case studies and success stories for the use of tea crop is lacking. Microorganisms are the most vital and active component of various agroecosystems including the tea ecosystem. They are found in soil, air, and phylloplane with different types of known and unknown interactions with plants that ultimately determine crop production to the great extent. These microbes interact with the ecosystem in different ways, resulting in harmful (in the form of development of different diseases of tea crop) and useful manner (help in maintaining the population of certain phytopathogens and insect pests below economic threshold level) (Table 2). These Biological Control Agents (BCAs) play a very important role in managing various insect pests and diseases associated with different agricultural and plantation crops [7]. Seventy-two viral species and roughly 40 fungal and bacterial species that are efficient against insect and mite pests of tea have been found as potential biocontrol agents for tea plants since the 1970s, and since then, several viruses and fungi have been examined to identify others [8]. Table 3 shows a list of mite and insect pest management options, which includes several useful microbial pesticides. Different microbial pesticides with potential efficacy for tea pest management have been discussed in this mini-review.

Table 2: Economic Threshold Level (ETL) of major pests of tea.

Name of the Pest	Economic Threshold Level (ETL)
Tea Mosquito Bug	5% infestation
Aphids	20% infestation
Thrips	3 Thrips per shoot
Jassids	50 nymphs per 100 leaves
Looper caterpillar	4-5 Lopper per plant
Flushworm, Leaf Rollers	5 infested rolls per bush
Red Spider Mites, Pink and Purple Mites	4 mites per leaf
Termites	10% infestation
Nematodes	6 numbers of nematode/10 gm of soil

Table 3: Microbial pesticides used in controlling insect and mite pests of tea plants.

Microbial pesticide	Insect/mite pest	References
E. oblique nuclear polyhedrosisvirus (EcobNPV)	*E. obliqua*	[13]
E.obliqua single nucleocapsid nucleopolyhedro- virus (EcobSNPV)	*E. obliqua*	[14]
P. fluorescens	*O. coffeae*	[15]
Bt	*E. obliqua*	[16]
B. bassiana	*E. onukii*	[17]
V. lecanii, *P. fumosoroseus*,	Termites	Termites
Hirsutella thompsonii,V. lecanii, *P. fumosoroseus* and *H. thompsonii*	*O. coffeae*	[9]
	Termites	Termites
Entomopthora sp. and *Verticillium* sp.	*O. coffeae*	[18]
Metarhizium anisopliae	*O. coffeae*	[19]
Paecilomyces lilacinus	*O. coffeae*	[13]
A. niger and *A. flavus*	*O. coffeae*	[20]
Fusarium, *A. flavus*, *A. niger*, *Cladosporium* sp., *Curvularia* sp., *Acremonium*,and *Trichoderma*	*H. theivora*	[21]
B. bassiana	*H. theivora*	[21]

Beauveria

Shot hole borer beetle (*Euwallacea fornicates*) in tea, *H. antonii* in guava, and *H. theivora* in tea are harmful to *B. bassiana* strains [6,22]. *Pericallia ricini* Fab., a castor hairy caterpillar, has been discovered to have *B. bassiana* as a biological control agent at various larval stages [23]. Kumhar et al. [24] found the highest mortality (77.5%) when crude sugar was combined with *B. bassiana*, which entailed exposing insect populations to tea leaves that had been sprayed with the formulation 5 days before the experiment, and two components of surfactant and humectants were tested as well, the final formulation produced results similar to those of the control. When tea shoots were sprayed on the insects 10 days before the experiment, the mortality rate of the insects was reduced (17.5%-30.0%). Under field circumstances, when Selvasundaram and Muraleedharan mixed *B. bassiana* with two adjuvants, Triton AE and Teepol, their study showed that the mortality of tea plant shot hole borer insects was boosted when the mixture was used [22]. The tea mosquito was better controlled by the designed wettable *B. bassiana* formulation (56.4%-58.4%) than the industrial formulation (38.0%-40.5%). According to Ghatak and Reza [25], *B. bassiana* was shown to be efficient against tea pests under field circumstances at various dosages, and its efficiency was equivalent to that of synthetic chemical pesticides. On onion, *B. bassiana*, and *L. lecanii* were found to be effective against the thrips *T. tabaci* [26].

The study conducted by Gatarayiha et al. found a 60.0 to 85.7 percent mortality rate of spotted spider mites utilizing the bacterium *B. bassiana* (4.2×10^6 conidia per ml) in combination with Break-thru (polyether-polymethylsiloxane-copolymer, a silicone surfactant) [27]. This fungus is effective in killing adult mites when combined with oil emulsion, with results ranging from 39.4 to 61.3 percent. Sileshi et al. analyzed the in vitro bioefficacy of two isolates of *B. bassiana* against termites by spraying various dosages ranging from 1×10^5 to 1×10^9 conidia per milliliter [28]. They observed that, at varying concentrations, *B. bassiana* caused 25%-95% termite mortality.

Earlier, the effectiveness of different isolates of *B. bassiana* was reported against tea mosquito bug [29], and other insect pests of tea plants such as tea weevils [4], and termites [30]. Field application of *B. bassiana* (10^7 and 10^8 spores/ml) against shot hole borer beetles damaging tea plants revealed that the higher doses were more effective in reducing insect populations than the lower doses [22]. Recently, Ekka et al. reported that the formulation (BPA/B7) of *B. bassiana* (1.68×10^6 spores/ml) was found to reduce the shoots damage of tea plants up to 50% at a concentration of 21.87 ml/l in Assam India [29]. The efficacy of *B. bassiana* both in the laboratory, and in-field conditions may be due to the production of several toxins such as beauvericin, enniatins, oosporein, and bassianolide during the infection that has a major role in the pathogenic activity of *B. bassiana* against tea mosquito bug [31].

As far as the impact of entomopathogens on the natural enemies is concerned, Thungrabeab and Tonga found that *B. bassiana* (1×10^8 conidia/ml) was nonpathogenic on the non-target insects such as *Chrysoperla carnea*, *Coccinella septempunctata*, and *Dicyphus tamaninii* as well as *Heteromurus nitidus*, a beneficial soil insect [32]. Similar findings were reported by observations of earlier investigators who reported that some entomopathogens such as, *B. bassiana, Hirsutella* spp., and M. anisopliae did not affect the population of natural enemies [33,34]. This suggests that entomopathogenic fungi may be highly selective, infecting only a specific type of host.

Previously, researchers reported that the formulations of *B. bassiana* were more effective than the synthetic insecticides against *H. antonii* damaging cashew [35], hairy caterpillar, *Pericallia ricini* damaging castor crop [23], and other insect pests of tea plants [25]. Besides, some investigators reported that *B. bassiana* was compatible with synthetic insecticides such as imidacloprid [36], and Bifenthrin [37]. Therefore, due to the eco-friendly nature of entomopathogens, this will be compatible with the other insect management components in the integrated pest management program.

In contrast, phytotoxicity on tea leaves and insecticide residue level above the EU approved limits has been reported for various insecticides in harvestable tea shoots [38], which showed that natural bio-pesticides could be a substitute to decrease the pesticide load in tea plantations. In particular, the compatible use of insecticides with entomopathogens can help to reduce pesticide residues in the harvestable shoots of tea plants [37].

Metarhizium

This entomopathogen, *Metarhizium anisopliae sensulato* (s.l.), is a sordariomycetes fungus of the order hypocreales that has demonstrated potential efficacy against a wide range of insect pests in several crops, including the tea crop [39,40]. Under field conditions, the formulations of *M. anisopliae* isolates have shown efficacy against a wide spectrum of tea crop pests in Kenya [4]. According to Kumhar et al. the formulation of *M. anisopliae* could result in 46.3% to 63.85% mortality of tea red spider mite [24]. Under the laboratory conditions, mortality was found to be concentration-dependent and the highest at a concentration containing 2×10^8 conidia/ml and lowest at a concentration containing 1×10^8 conidia/ml.

Sileshi et al. tested the bioefficacy of two *M. anisopliae* isolates against termites in vitro by spraying concentrations of 1×10^5 to 1×10^9 conidia per milliliter, and found that at different concentrations, *M. anisopliae* could cause 60-100% mortality [28]. A native entomopathogen, *M. anisopliae*, was tested in the field against a live tea wood-eating termite in Cachar [41]. There was a significant reduction in termite infestation due to the application of *M. anisopliae* over a conventional termiticide. Earlier, the effectiveness of *M. anisopliae* s.l. was reported against mite pests of many crops, including tea such as tea red spider mite [42], termite *Microtermes obesi* Holmgren [43], carmine spider mite [44], two-spotted spider mite infesting horticultural crops [45], and green pepper [46]. Addisu et al. while studying the bio-efficacy of four isolates of *M. anisopliae* against termite reported that 1×10^5 to 1×10^9 conidia per ml concentrations of *M. anisopliae* may cause 60-100 percent mortality [47]. Field application of *M. anisopliae* (10^7 and 109 spores/ml) against termite damaging tea plants revealed that the higher doses were more effective in reducing the insect populations than the lower doses [48]. In 2017, Baruah and Deka reported that the formulation of *M. anisopliae* s.l. (1×10^9 spores/ml) reduced mite populations in tea gardens up to 50% in Assam, India [19].

As far as the impact of entomopathogens on the natural enemies is concerned, Thungrabeab and Tongma found that *M. anisopliae* (1×10^8 conidia/ml) was nonpathogenic on the non-target insects such as *C. carnea, C. septempunctata*, and *D. tamaninii* as well as *H. nitidus*, a beneficial soil insect [32]. Previously, researchers reported that the formulations of *M. anisopliae* were more effective than the synthetic insecticides against *Aphis craccivora* Koach (Hemiptera: Aphididae) damaging cowpea crop [49], larvae of the cotton leafworm, *Spodoptera littoralis* Boisd (Lepidoptera: Noctuidae) [50], legume flower thrips, *Megalurothrips sjostedti* Trybom (Thysanoptera: Thripidae), tea mosquito bug, *H. theivora*, the western flower thrips, *Frankliniella occidentalis* Pergande (Thysanoptera: Thripidae) and the onion thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae) [51].

Baculoviruses as insect pathogens

Baculovirus-based biopesticides are suitable for use in integrated pest control programs [52]. Baculoviruses are considered to be entirely harmless to humans, livestock, bees, predatory insects, and parasitoids are examples of beneficial insects because they are extremely specific [53]. Baculoviruses have been found in more than 600 different insect species [54]. Baculoviruses are a diverse group of viruses with circular, supercoiled DNA genomes that range in size from about 80 to over 180 kb and encode between 90 and 180 genes [52]. The existence of occlusion bodies called polyhedra for NPVs and granules or capsules for GVs distinguishes *Baculoviridae* members. A crystalline matrix consisting of polyhedrin (in NPVs) and granulin makes up the occlusion body (in GVs). A popular feature is the arrangement of nucleocapsids within polyhedra into single or multiple aggregates of nucleocapsids within an envelope [55].

NPV

Since the late 1970s, researchers have been researching insect viruses linked to tea pests. Insect-Specific Viruses (ISV) is very successful in controlling tea caterpillar pests naturally. ISV may be interesting candidates that might serve as biocontrol agents [56]. Out of the 82 viral species revealed that are associated with tea insects, more than 95% of species are reported from China [8]. In tea farming in China, *Buzura suppressaria* NPV (BusuNPV), *Eucalyptus obliqua* NPV (EcobNPV), *Euproctis pesudoconspersa* NPV (EupeNPV), *Andraca bipunctata* GV (AnbiGV), and *Adoxophyes orana* GV (AdorGV) all have been successfully implemented as large-scale biocontrol agents. The first and second generations of *B. suppressaria* perished in greater than 90% of instances within ten days of spraying polyhedral suspensions containing BusuNPV at 3 × 1012 PIB/ha [57]. Granulo Viruses (GVs), Entomo Pox Viruses (EPVs), and the Nuclear Polyhedrosis Virus (NPV) have all been used to successfully manage tea pests in Japan, notably *Adoxophyes* *honmai* and *Homona magnanima* (Tortricidae: Lepidoptera) [58]. Mukhopadhyay et al. reported about the symptoms of NPV infection in *B. suppressaria* and the virulence of NPV against *B. suppressaria* under in-vitro conditions was established [59]. The identification of NPVs, GVs, and EPVs in the lepidopteran pests of diverse tea-growing locales, as well as their lethal efficiency with an emphasis on cross infectivity, offers up new pathways for turning this viral disease into a biopesticide.

Among all baculoviruses, NPV, which belongs to the family *Baculoviridae*, is found to be very active in infecting tea loopers (*Hyposidra talaca*) under field conditions [52,60]. HytaNPV is a group II alphabaculovirus with a 139,089-bp circular DNA genome and 39.6% GC content [52]. The polyhedron gene of HytaNPV contains a high conserved region with 527 bp and shows a sequence identity of 98% with the NPV of *H. infixaria* and *B. suppressaria* [61]. Dasgupta et al., reported the pathogenicity of HytaNPV against *H. talaca* was around 4.6-7.5 × 10^5 POBs/ml within 4-6 days [61].

Lecanicillium

Lecanicillium lecanii (Zimm.) (Hypocreales: Cordycipitaceae), a synonym of *Verticillium lecanii* (Zimm.) (Hypocreales: Cordycipitaceae), causes mycosis in insects (Hypocreales: Cordycipitaceae). *L. lecanii* is a species that develops cylindrical conidia of white colonies in awl-shaped phialides and is widely isolated. It refers to a collection of extremely tiny species [62]. Despite being a facultative parasite, it is not a mammalian pathogen [63]. To successfully initiate infection, the fungus requires temperatures between 15°C and 25°C and humidity levels of at least 85 percent for ten to twelve hours a day [64]. It may spread by invading the hosts before they are ready, most frequently through non-natural orifices [63].

In laboratory bioassays against *S. bispinosus*, the nymphs exhibited evidence of *L. lecanii* mycelial growth within 3-4 days of treatment [65]. Annamalai et al. reported similar results when *Thrips tabaci* L. (Thysanoptera: Thripidae) was treated with isolates of *L. lecanii* [26]. The direct spray of *L. lecanii* (1 × 10^8 conidia/ml) produced a significant difference in mortality in *S. bispinosus* 2nd instar nymphs after 96 hours of exposure. Low conidial concentrations (1 × 10^5 conidia/ml) resulted in a low death rate during the leaf exposure phase. In various concentration bioassays, increasing the concentration of *L. lecanii* against *S. bispinosus* resulted in increased thrips mortality [65]. Subramaniam et al., observed that employing the *L. lecanii* may significantly lower the thrips population while performing a large-scale field investigation [65].

The efficiency of EPF against insect pests, as well as its low virulence against non-target insects, is both critical for its usefulness as biological control agents. *L. lecanii* sprayed on predators present in the tea environment, such as *O. pygmaea, S. gilvifrons, M. boninensis*, and *N. longispinosus*, and had no harmful impact on these natural enemies [65]. According to Derakhshan et al., [66] *L. lecanii* is not pathogenic to coccinellids and has no significant negative impact on its biological characteristics. *C. carnea* exhibited no harmful effects from *L. lecanii* spore suspensions [66]. Mamun et al. tested the efficiency of *L. lecanii* WP (1 × 10^8 conidia/g) against *O. coffeae* on tea plants at a rate of 4 kg/ha and found that the fungus dramatically decreased mite populations by 83 percent one week after treatment [67]. Citrus Black Aphid, *Toxoptera aurantii* (Hemiptera: Aphididae), and Woolly Whitefly (*Aleurothrixus floccosus*), two minor tea pests, were both controlled by *L. lecanii* [68]. Babu et al., investigated the antagonistic effect of *L. lecanii* against tea thrips [69]. In tea plantations, there have been reports of entomopathogenic fungi such as *Cladosporium* sp., *Acremonium* sp., *Aspergillus flavus, Trichoderma* sp. *Aspergillus niger, Curvularia* sp., and *Fusarium* sp. infecting *H. theivora* in N.E. India, causing significant losses [70].

Bacillus thuringiensis

Bacillus thuringiensis (Berliner) is a sporogenous gram-positive bacteria distributed around the world. It can have up to 50 serotypes or 63 serovars [71]. Several studies have been published on the effectiveness of entomopathogenic bacteria and viruses against tea caterpillar pests [72-75]. Muraleedharan and Radhakrishnan reported on the effectiveness of *B. thuringiensis* against tea insect pests [76]. The potential of *B. thuringiensis* as an entomopathogenic bacterium is documented in the majority of reviews on the most common diseases of tea pests [8, 77-80]. *B. thuringiensis* is mostly used in China to treat tea pests, and it has been demonstrated to be 95% efficient against lepidopterous larvae [8]. In Japan, two types of *B. thuringiensis* preparations have been approved for use in tea plantations. The live spore crystal mixture preparation (called BACILEXR) and the spore-dead *B. thuringiensis* preparation (called TOAROW-CTR) are two of them [81]. In NorthEast India, *B. thuringiensis* var. Kurstaki was shown to be effective in eradicating *S. dorsalis, B. suppressaria*, and *Adalia bipunctata* (up to 45-95 percent for each) [82]. However, due to its negative impact on the silkworm industry, the use of *B. thuringiensis*-based insecticides for pest management in countries like India and Japan is prohibited [81, 82]. *Heterotermes indicola* was killed by the bacteria *Bifiditermes beesoni*, which was isolated from naturally infected nymphs of the termite B. beesoni [84]. On the fifth day of observation, Singha et al. [85] found that bacterial concentrations of 1 × 10^5 and 1 × 10^6 cells/ml caused 100 percent death of *M. beesoni* workers with the strain of *B. thuringiensis subsp. Israelensis*, whereas *B. thuringiensis* caused only 81-90 percent of death. The worker castes of *M. obesi* were shown to be significantly affected by both *B. thuringiensis* strains. Bt sub-species have been isolated from a wide range of dead or dying insects, mostly from the Lepidoptera, Diptera, and Coleoptera orders, but also from leaf surfaces, soil, and other environments [86]. Several Bt strains have been described for use in the management of tea pests [8,77-81,87]. The target insect responded well to Bt-treated leaves being fed to it, and the pest population was kept well beneath the economic threshold [77,88]. Different Bt strains were identified from insect cadavers in the Terai tea plantation in the sub-Himalayan Himalayas and proven to be effective in the field [89]. These strains were also shown to be non-infectious to the multivoltine silkworm (*B. mori*), which is extensively grown in the Terai and Dooars areas in India [90]. The pathogenicity of Bt was examined against two species of tea termites, *M. syriacus* and *M. beesoni*, and both termite species demonstrated over 80% death [85]. *Bt subsp. Israelensis* proved more virulent against termites than Bt var. Kurstaki [85].

The use of Bt had no detrimental consequences for non-targeted insects [91-93]. When adults of *Trichogramma cacoeciae* (chalcid wasps) were fed suspensions of a commercial Btk product, there was no detrimental effect [94]. Silkworms are very poisonous to practically all Bt (commercial product) strains, according to research [95]. As a result, sericulture nations like Japan and India, particularly Assam, have had difficulty employing *B. thuringiensis* -based pesticides for pest management in tea because of the harm they do to silkworms [83]. This problem has been partially handled by developing less toxic Bt strains for silkworms, either through genetic manipulation or seclusion from the natural environment. Tea pests such as stem and root borers, sucking pests, and leaf rollers are all common; however, topical Bt treatments have minimal impact.

Actinomycetes

The Actinomycetes, comprise a group of gram-positive bacteria belonging to the order Actinomycetales, are abundant in nature, and are well known to have antimicrobial properties against different diseases causing bacteria and phytopathogenic fungi [96]. They exhibit antimicrobial activities by secreting secondary metabolites and enzymes that act upon pathogens in many different ways [97]. The biocontrol efficiency of certain Actinomycetes obtained was examined from several South Indian tea-growing soils. In vitro tests were performed on ten probable one of the eight different Actinomycetes isolates from the Anamallais (AAS2, AAS5, AAS6, AAS7, AAS15, APSA1, APSA4, APSA5, and APSA6) and one additional Actinomycete isolate (CAS4) were obtained from the Nilgiris for the study's antagonistic potential to tackle tea pathogens, as well as activity against red spider mites. The most effective inhibitors of foliar pathogens, such as *Pestalotiopsis theae*, were CAS4 (100 percent) and APSA1 (82.1 percent). APSA1 cell-free culture filtrate demonstrated the strongest inhibitory impact (85.3%) on *Glomerella cingulata*, followed by CAS4 (65.4%) on *Cylindrocladium* sp. To stem infections like *Hypoxylon serpens* and *Macrophoma* sp., APSA1 and CAS4 exhibited the best responses (80.3 percent and 80.3 percent, respectively). Root pathogen *Xylaria* sp. was fully reduced by the fungicide AAS7 and the soil bactericide APSA4. In tea red spider mites, three Actinomycetes isolate inhibited a greater death rate, with APSA1 recording 100% overall mortality, followed by AAS7 (94.0%) and APSA6 (92.0%) [98].

Aspergillus

Aspergillus is a fungal genus that includes species that have adapted to a wide variety of environmental conditions. It was first described in 1729. *Aspergillus* species contain a wide range of mycotoxins that can contaminate a variety of agricultural products and cause a variety of human and animal diseases. Mycotoxins can damage insects and nematodes, causing insecticidal effects as well as developmental delays [99]. *A. niger* was much more effective against red spider mites than *A. flavus* [20]. It was found that various workers had earlier reported the efficacy of *A. flavus* against different insect pests [100]. Efficacy of *A. niger* and *A. flavus* against *Helopeltis* sp. in tea plantations was previously assessed and was found to be accurate, with mortality rates of 80 percent and 90 percent for *A. niger* and *A. flavus*, respectively [70].

Paecilomyces sp.

In 1907 *Paecilomyces* was initially described as a genus closely related to *Penicillium*, with just one species, *P. variotii* Bainier [101]. *Paecilomyces* is a genus of pathogenic and saprophytic bacteria found in several settings, including insects [102-105] worms [106,107]. Even though many biological regulatory mechanisms are still unknown, metagenomics has shed light on the plant–pathogen–antagonist interaction [108,109]. In the genus *Paecilomyces*, direct and indirect microbial strategies for pest and disease control include parasitism, competition, and antibiosis, as well as plant defense via Induced Systemic Resistance (ISR) mechanisms [110-112]. The fungus *Paecilomyces fumosoroseus* Apopka (strain Pfr116) was employed to suppress tea green leafhoppers. Spraying an oil-based emulsifiable formulation with 2×10^7 conidia/ml of imidacloprid 10% WP at a rate of 3% of the recommended rate resulted in 71 percent leafhopper control [17]. When population growth is minimal, spraying *P. fumosoroseus* (5%) and *L. lecanii* in alternate rounds help keep populations below the threshold level. Red spider mites are also controlled to some extent by *Trichothecium roseum* and *Hirsutella thompsonii* [113]. Root knot nematode species can also be managed by the fungus *Paecilomyces lilacinus* [114,115]. The fungus *Paecilomyces tenuipes* (Peck) Samson was accessed from a tea psychid pest in Darjeeling, India, and discovered to be infectious to the flushworm *Cydia leucostoma* Meyr [116].

CONCLUSION

Pest control alternatives to traditional chemical pesticides that are environmentally friendly and minimize pesticide residues in made tea are becoming increasingly common in sustainable tea cultivation. The successful application of microbial biocontrol agents is the result of decades of intensive research. Microbial protection activities have increased in many tea-growing locations, under integrated pest control programs, which provide an environmentally friendly pesticide-free alternative to conventional pesticide use. To use this method, native entomopathogens must be isolated, identified, and exploited in tea ecosystems. Entomopathogens can be used as an alternative to broad-spectrum chemical insecticides which can provide efficient control while still conserving biodiversity. Entomopathogens (fungi, bacteria, and viruses) are thought to be suitable candidates for integration into integrated pest control programs because of their insect specificity. Their effects on other natural enemies are thought to be negligible.

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