Review Article

Indian Journal of Agricultural Sciences **92** (1): 03–09, January 2022/Review Article
https://doi.org/10.56093/ijas.v92i1.120819

Revisiting non-chemical modes of diseases and pests management in tea (*Camellia sinensis*): A review

POPY BORA[1]* and L C BORA[1]

Assam Agricultural University, Jorhat, Assam 785 013, India

Received: 12 April 2021; Accepted: 12 August 2021

ABSTRACT

Tea [*Camellia sinensis* (L) O. Kuntze] like any other perennial plantation crop is subjected to loss in biomass yield and functional quality, once exposed to beyond economic thresholds of diseases and pests load. A battery of diseases and pests are reported to badly affect the tea industry of India. Microbial antagonists and botanicals emerged as two most vibrant via-media of addressing tea diseases and pests amongst non-chemical modes, in a manner, closest to residue free production system. Authors revisited the use of microbial antagonists and botanicals through comprehensive updated analysis of breakthroughs recorded in the success of microbial antagonists-and botanicals mediated diseases and pests management in tea. Our efforts also portrays the futuristic viewpoints in terms of developments of commercial formulations of botanicals using their bioactive compounds, consortium of bioagents and fortification of botanicals with bioagents through area wide field response studies in the back drop of growing demand of organic tea, the most pressing developmental issue of tea industry.

Keywords: Botanicals, Diseases, Microbial antagonists, Organic tea, Pests, Tea

Tea, the world's most preferred beverage consumed by two thirds of the population has multiple health benefits attributed to different phyto-constituents in tea [*Camellia sinensis* (L) O. Kuntze] leaves with antioxidant property. The tea crop is grown in as many as 58 countries (Area and production of 4.12 million ha and 5.36 million tonnes, respectively) representing all the five continents with Asia sharing the largest area followed by Africa (Tea Board of India 2019). India measuring an area of 5.66 lakh ha with annual production of 1.39 million tonnes, is the second largest producer of tea after China. Assam state is the single largest contiguous tea growing belt of the world, occupying an area of 3.38 lakh ha area with a production of 715.79 million kg, representing nearly 51% of total tea production of India (Tea Board of India 2019). Tea plantations resembling to "single species forest", with stable microclimate favours the attack of as many 380 fungal pathogens and 250 insect pest species (Hazarika *et al.* 2009) , out of which 190 fungi and 167 pests have been detected in northeast India alone, causing both primary and secondary production losses to tea industry (Barthakur 2011, Bora *et al.* 2021, Saikia *et al.* 2020, 2021). Among different diseases, grey blight, blister blight, stem canker etc. and insect pests like tea mosquito bug, red spider mite, tea looper caterpillar etc are reported adversely affecting the growth of Indian tea industry (Saha *et al.* 2012). The diseases and pests are reported to cause 11-55% yield loss on an average, with annual production loss of tea to the tune of 85 million kg worth ₹ 425 crores in northeast India alone (Tea Board of India 2020).

Growing demand for organic tea or pesticide residue free tea in the international market due to higher technical efficiency and functional quality of organic tea compared to conventional tea (Deb *et al*. 2017) has always been a daunting challenge. The ecofriendly and health friendly alternatives are the need of the hour wherein plant beneficial microbes and botanicals can be the key players. A voluminous literature ably demonstrates the efficacy of these alternatives (Bora and Bora 2021). However cataloguing the bioagents and botanicals and a suitable delivery mechanism in terms of formulations need a thorough revisit. The plant growth promoting microbes, viz. fluorescent pseudomonads, *Trichoderma* spp., *Bacillus subtilis* etc. are regarded as dominant root colonizers with ability to enhance plant health and serve as efficient biocontrol agents against variety of pathogens (Bora *et al.* 2019, 2020, Bora *et al.* 2020) , besides activating the accumulation of defense-related phytochemicals in plants against bacterial, fungal and viral pathogens (Sarma *et al.* 2015). Many entomopathogenic fungi like *Beauveria bassiana*, *Verticillium lecanii* and *Metarhizium anisopliae* have been extensively used for biological management of

Present address: [1]Assam Agricultural University, Jorhat, Assam. *Corresponding author e-mail: pbora.sonitpur10@gmail.com.

tea mosquito bugs, loopers, aphids, stem borer, thrips, mites, etc. (Hazarika *et al.* 2009). Use of botanicals against insect pests of tea has also been quite popular and equally effective, and reported to induce defense response in plants similar to microbial bioagents (Pretali *et al.* 2016). The drawbacks with conventional management practices of diseases and pests management have shifted our guards towards environmentally benign methods of tea growing. Such approaches involving intervention of microbial antagonists and botanicals, though well known, but recent developments warrant a thorough revisit and evolve a better strategy against diseases and pests for commercial tea cultivation (Bora and Bora 2020, Bora *et al*. 2021) .

Major diseases and pests of tea

The majority of tea pathogens are of fungal origin and more than 300 species of fungi are reported to affect different parts of tea plant. The diseases such as blister blight (*Exobasidium vexans* Massee), algal rust (*Cephaleurus parasiticus* Karst and *C. virescens* Kunze), stem canker (*Macrophoma theicola* Petch), thorny stem blight (*Tunstallia aculeate* Petch) and *Fusarium* die-back (*Fusarium solani* Mart. Sacc.) are considered having serious implications along the tea belts of northeast India (Gurusubramanian and Barthakur 2005). Amongst foliar diseases of tea, the grey blight has been widely reported from all tea-growing countries of the world (Bora *et al*. 2021). The causal agent of the disease is a fungus known as *Pestalotiopsis theae*, which enters through injured leaves and stems (Naglot *et al*. 2015). Several studies revealed that foliar diseases such as blister blight, brown blight, grey blight, bird's eye spot and red rust adversely affected the physiological functions of tea plant as well as important quality parameters due to reduced photosynthesis and transpiration rate of tea leaves (Deb *et al*. 2017, Bora *et al*. 2021).

Tea plants suffer from more than 300 recognized pests, of which 25-30 insect pests occur regularly in poorly managed tea gardens, and some of them are major ones causing significant crop losses (Shrestha and Thapa 2015). The arthropods (insects and mite pests) are reported to cause an average of 5–55% yield losses, which may go up to 100%, if left unchecked (Hazarika *et al.* 2009). The important pests affecting the tea crop are listed as: tea mosquito bug (*Helopeltis theivora* Waterhouse), thrips (*Scirtothrips dorsalis* Hood), jassid (*Empoasca flavescens* Fabricius), aphid (*Toxoptera aurentii* Boyer), red spider mite (*Oligonychus coffeae* Nietner) and tea looper complex (*Buzura suppressaria* Guenée, *Hyposidra talaca* Walker, *H.*

Table 1 Response of microbial antagonists against diseases and pests in tea plantation

Treatment	Biotic stress	Responses
Microbial anatgonists in diseases management		
P. fluorescens and *B. subtilis*	Grey blight (*Pestalotiopsis theae*)	Increased cell wall lytic enzymes
P. fluorescens and *Orchrobactrum anthropi*	Blister blight (*Exobasidium vexans)*	Reduced spore germination and increased siderophore production and, lytic enzymes.
Aspergillus flavus, *Aspergillus niger*, *Trichoderma atroviride* and *T. citrinoviride*	Black rot disease (*Corticium theae*)	Reduction in pathogen inhibition, percent symptoms, and salinity index
Bacillus subtilis , *Pseudomonas fluorescens, Trichoderma atroviride, T. harzianum* and *Streptomyces sannanensis*	Birds eye spot disease (*Cercospora theae*)	Increase in green leaf yield, biochemical parameters ,and quality parameters
Serratia narcescens strain	Root rot diseases (*Curvularia eragrostidis, Pestalotiopsis theae, Colletotrichum camelliae, Lasiodiplodia theombromae,* and *Rhizoctonia solani*)	Increased hydolytic enzymes and plant growth promoting metabolites
Microbial antagonists in pests management		
Metarhizium anisopliae	Termites (*Microcerotermes beesoni* and *Microtermes obesi*)	3.0 kg bio-terminator + 300 kg cow dung + 2.0 kg molasses controlled nearly 855 termites infestation up to 9 months in field
Beauveria bassiana along with Tween 20 and crude sugar	Tea mosquito bug (*Helopeltis theivora*)	Control of 2nd instar nymphs by 53%
Metarhizium anisopliae	Red spider mite (*Oligonychus coffeae*)	Reduction in pest population by 84%
Beauveria bassiana and *Metarhizium anisopliae*	Tea mosquito bug (*Helopeltis theivora* and red spider mite (*Oligonychus coffeae*)	5% AS of *B. bassiana* and *M. anisopliae,* respectively, controlled 51.89–71.82% and 53.80–72.66% population in field

Pallavi *et al*. (2012); 2. Sowndha- rarajan *et al.* (2012); 3. Thoudam and Dutta (2012); 4. Gnanamangai and Ponmurugan (2012); 5. Purkayastha *et al*. (2018); 6. Hoque *et al*. (2016); 7&8. Kumhar *et al*. (2020); 9. Babu (2020).

infixaria Walker) affecting the yield and tea quality according to Mamun *et al*. (2020). Of these pests, tea mosquito bug has assumed the status of a major insect pest in several tea growing areas in West Bengal and Assam (Somchoudhury *et al*. 1993).

Management of tea diseases and pests: Non-chemical options

Biointensive approach for disease and pest management holds the top most priority in recent times, where use of host resistance, cultural practices including site selection, field sanitation, soil amendments, mechanical and physical methods and use of biocomponents like botanical and microbial biopesticides are key players facilitating minimal dependence on chemicals (Hazarika *et al.* 2009). Out of these options, an heightened necessity warranted exploring microbial bioagents (Table 1) as well as plant based biopesticides (Table 2) as a holistic strategy against tea diseases and pests.

Microbial bioagents and suppression of tea diseases

Microbial biocontrol agents have long been used for plant disease management in organic production of tea. Both rhizospheric and endophytic microbes have displayed an unprecedented success in the past for plant health management (Bora *et al.* 2019, Bora and Bora 2021). A large number of *Trichoderma* spp. (*T. viride, T. harzianum, T. koningii, T. hamatum, T. polysporum* and *T. longibrachiatum*) have been reported to exhibit biocontrol efficacy against many soil borne diseases, employing an array of mechanisms, viz. hyperparasitism, competition for nutrients, antibiosis and induction of defense in host plant (Bora *et al.* 2016a, 2019). Another breakthrough emerged when Ponmurugan (2017) evaluated the suppressive activity of nanoparticles produced by an indigenous isolate, *T. atroviride* against *Phomopsis theae*.

Dutta and Thakur (2020) screened a total of 150 rhizobacterial isolates for antagonistic activity against *Pestalotiopsis theae*, *Curvularia eragostidis*, *F. oxysporum*,

Table 2 Response of botanicals in suppression of diseases and pests in tea plantation

Treatment	Biotic stress	Responses
Botanicals against major diseases		
Ethanol and aqueous extract of *Allium sativum*, *Datura metel*, *Dryopteris fillix, Zingiber officinale, Smilax zeylanica*, *Azadirachta indica* and *Curcuma longa*	Grey blight (*Pestalotiopsis theae*, *Colletotrichum camelliae*, *Curvularia eragrostidis* and *Botryodiplodia theobromae)*	100% inhibition in spore germination with 10% extract
Aqueous leaf extract of *Lippia javanicum, Urtica massaica, Satureia biflora* and *Warburgiaungadensis*	Stem canker (*Phomopsis theae)*	Reduced the mycelial growth and pycnidial production
Pongamia pinnata, *Syzigium aromaticum*, *Acorus calamus rhizome*, *Parthenium hysterophorus*, *Ageratum conyzoides, Allium sativum* and *Abutilon indicum*	Brown blight (*Glomerella cingulata*)	10% aqueous extract reduced the growth of pathogen
Aquous extract of *Acrous calamus, Curcuma longa* and *Hibiscus rosasinensis* (10%), *Psidium guajava* and *Allamanda cathartica*	Stem canker (*Macrophoma theicola*)	15% extract increased the yield of green leaf and quality parameters
Curcuma longa, *Hibiscus rosasinensis, Psidium guajava*, *Allamanda cathartica*, *Murraya koenigii, Azadirachta indica* and *Artemisia nilagirica*	Branch canker (*Macrophoma theicola*)	Aqueous extract of 15% reduced the pathogen spore germination
Botanicals suppressing major pests		
Azadirachta indica, 2% aqueous extract	Aphid (*Toxoptera aurantii*)	Suppression in 80% population of aphid
Sapindus mukorossi L. , *Nyctanthes arbortristis* L. and *Phlogacanthus thyrsiformis* Nees	Red spider mite (*Oligonychus coffeae*)	5-10% aqueous solution suppressed the field population by 62-74%
Wild sage (*Allamanda catharica* L.) and horse weed (*Conyza bonariensis* L.)	Red spider mite (*Oligonychus coffeae)*	5% aqueous extract suppressed the adult mortality *in vitro* by 80-100%
Sweet flag (*Acorus calamus*), clerodendron (*Clerodendron infortunatum*), bur weed (*Xanthium strumarium*) and smart weed (*Polygonum hydropiper*)	Red spider mite (*Oligonychus coffeae)*	10% aqueous extract reduced 46.9-81.8% pest population
undi (*Calophyllum*) and karanj (*Pongamia pinnata*)	Tea mosquito bug (*Helopeltis antonii* Signoret)	5% aqueous extract showed 65.0-68.3% nymphs mortality after 10 days of application

Sohail *et al.* (2012); 2. Linner *et al.* (2017); 3. Handique *et al*. (2017); 4. Sarmah *et al.* (2009); 5.Navik *et al.* (2015); 6. Saha *et al.* (2005); 7. Kuberan *et al.* (2012); 8. Barman *et al.* (2015); 9&10. Mareeswaran *et al*. (2015).

Glomerella cingulata and *Rhizoctonia solani*. Among these, *P. fluorescens* and *Bacillus* spp. were reported displaying antagonistic effect against the pathogens and plant growth promotion (Borkotoki *et al.* 2016).The bioagents not only reduced the disease load, but also enhanced the green leaf yield and improved the biochemical parameters like polyphenol, caffeine etc. in tea leaves (Deb *et al.* 2017). Ruan and Wu (2000) observed that balanced plant nutrition in tea reduced the fungal diseases such as anthracnose (*Gleosporium theaesinensis*), brown blight (*Guignardia camelliae*) and grey blight (*P. theae*) via elevated accumulation in polyphenol content, indicating hand-in-gloves relationship between plant nutrition and disease suppression.

Botanicals and suppression of tea diseases

The development of botanical pesticides has aroused great interest among researchers throughout the world in recent times due to their easy biodegradability and non-toxic residual effect. Globally, over 2500 plant species belonging to 235 families have been reported to have biological properties against different pests (Yang and Zhang 2019). In northeast India, known as the biodiversity hub, around 1400 plant species are known to have medicinal or pesticidal property (Swagata *et al.* 2021), and some of these native botanicals have long been used against major tea diseases. In a survey carried out by Saikia *et al.* (2006) on use of botanicals for insect pests management among 100 small tea growers of Assam revealed efficacy of popular botanicals such *Clerodendrum viscosum*, *Pongamia pinnata*, *Adhatora vasica*, *Psidium guajava*, *Xanthium strumarium*. The use of botanicals such as *Lantena camera, P. pinnata*, *X. strumarium*, *Aegle marmelos, Azadirachta indica, M. azadirachta* etc. as conventional management options by tea growers have also been practised in Bangladesh according to Mamun *et al.* (2015) .

Saha *et al.* (2012) reported about the effect of *X. strumarium* extract on different tea pathogens, displaying maximum efficacy against *P. theae* and *Colletotrichum camelliae*. Mareeswaran (2016) evaluated different botanical extracts against tea branach canker pathogen, *Macrophoma theicola* which showed maximum inhibition with 10% aqueous extract of *Acorus calamus* followed by *Psidium guajava* and *A. indica* with 15% and 10% concentration, respectively. Substantial nutrient value of botanicals such as *P. pinnata* and *X. strumarium* supply an additional metabolically active nutrients impart tea plants with required physiological preparedness (Kamboj and Saluja 2010) to fight against diseases. Studies on these lines in tea are, however, are very limited.

Microbial bioagents against tea pests

Microbial diversity has also been extensively explored for insect pest management, besides disease management. The microbes with ability to cause disease in insect pests popularly known as entomopathogens have distinct advantage due to their higher efficacy, easy mass production, conserve biodiversity, and serve as strong alternative to chemical insecticides under varied conditions (Baverstock *et al.* 2009). The potentiality of utilizing *Verticillium lecanii*, *Beauveria bassiana*, *Metarhizium anisopleae* and *Entomophthora* sp. against tea insect pests were earlier reported by Hazarika *et al.* (2009). Kaushik and Dutta (2016) recorded less infestation of aphid, tea mosquito bug, red spider mite in *M. anisopleae* treated plants over untreated plants. The entomopathogenic fungi, *Paecilomyces fumosoroseus* from south India (Selvasundaram and Muraleedharan 2003) and *Hirsutella thompsonii* (Debnath 2004) have been observed effective against red spider mite of tea in northeast India. However, the microbial agents when applied in combination have shown greater efficacy against tea pests than using as a single bioagent (Bora *et al.* 2021). Deb *et al.* (2017) observed much higher reduction in tea mosquito bug (87%) and red spider mite (84%) with application of formulation comprising entomopathogens, viz. *B. bassiana, M. anisopleae* and *B. thuringiensis* than single microbe.

Botanicals and management of tea pests

Unlike conventional insecticides based on a single active ingredient, botanical insecticides comprise different chemical compounds which act collectively and, thereby, reduce any possible chance of resistance development. Bhuyan *et al*. (2017) highlighted the use of variety of plants for developing the locally made pesticides in small tea gardens of Assam for control insect pests of tea like red spider mite, tea mosquito bug and looper caterpillar . These included aerial parts of *P. pinnata* leaves, *Polygonum hydropiper*, leaves and seeds of *A. indica*, leaves of *Clerodendrum viscosum*, *Capsicum annuum* fruits, dried leaves of *Nicotianna tabacum*, *Aegle marmelos* and *Melia azedarach*. An acaricidal activity of leaf extract of *Lantana* (Azad *et al.* 2020), *X. strumarium* (Mamun *et al.* 2013) and *Acorus calamus*, *Polygonum hydropiper, Clerodendron infortunatum* and *X. strumarium* (Sarmah *et al.* 2009), have been reported against red spider mite, tea mosquito bug, looper caterpillar and tea thrip. Despite these breakthroughs, unfortunately only a few botanicals like neem and chrysanthemum have been thoroughly investigated, and bioactive compounds are developed into commercial formulation.

Induction of plant defense vis-à-vis bioagents and botanicals

The plant secondary metabolites such as phenolics, flanonoids and plant defensive proteins contribute significantly in tea defense against pathogens and herbivores (Sharma *et al.* 2020). The plant beneficial microbes offer priming effect to the host plant through induced systemic resistance (ISR) regulated through salicylic acid-dependent mechanisms (Ryals *et al*. 1994). However, antagonists triggering salicyclic acid-dependent type of ISR resembling pathogen- induced SAR have also been reported. Resistance offered by bioagents result in an increased concentration of metabolites and enzymes-related to defense mechanisms, such as phenylalanine ammonia lyase, polyphenol oxidase and chalcone synthase according to Viterbo *et al.* (2007), which provide defense to the hosts against pathogens and herbivores including insects. However, only a few studies suggested that botanicals also induce same kind of defense response in tea plants.

Futuristic overview

Bioprospecting tea rhizosphere health and plant health (shift from microbe to micorbiome) in tandem exploiting metagenomics is the current trend of next generation research for ensuring the prolonged health of tea plantation. Developing consortium (exploiting the cross talk between microbial players restraining pathogen colonization) of microbial antagonists derived either from rhizosphere or endosphere of tea is seen as most guarded strategy to decode the consortium-regulated tea defense responses of tea as a comprehensive disease management protocol. Microbial communities from rhiosphere and endosphere have shown some promise in pest and disease management. Rhizosphere specific AMF-based microbial consortium could add a new dimension in enhancing the tea immune system fight against pathogens and pests. The recent exploitation of tailor-made core microbiome transfer therapy foresee a much greater application in managing diverse plant diseases of economic importance. Detailed evaluation of microbial pathogenicity based on physiological, biological and genetic studies, mass production, field application, microbial interactions with other natural enemies, and bio-safety issues must be carried out for developing effective antagonists-based bioformulations. Authors made some valiant efforts in developing number of effective bioformulations and evaluated them in field in number of other crops (Bora and Bora 2008a, Bora *et al*. 2013, Bora *et al.* 2016a, 2016b, 2019, 2020, Khan *et al.* 2018), need further replicated field validation studies in tea.

The majority of the plant-based products used in tea diseases and pests management are in the form of crude extracts prepared *in-situ* and locally without standard dose, as commercially standardized formulations are not available for most of the plant products (Hazarika *et al.* 2001). An in depth study to screen newer and bioactive molecules with antimicrobial and pesticidal property are another interesting area of research for future green pesticide design. While addressing tea diseases, botanicals are comparatively less effective than microbial antagonists. Fortification of botanicals with microbial antagonists is another novel area of future research to have better in-field performance for disease management across geographical regions. Development of biofungicides and nano-technology aided microbial bioformulations as next generation green approach is another cutting edge research to fit into chemical free options of diseases and pests management. These futuristic views are anticipated to lay a solid foundation in developing chemical residue free modern day tea industry catering to current challenges of export oriented international trade.

REFERENCES

Ahmed S and Stepp J R. 2016. Beyond yields: climate change effects on specialty crop quality and agroecological management. *Elementa: Science of the Anthropocene*. **4**:000092. doi: 10.12952/journal.elementa.000092.

Babu A. 2020. Role of Microorganisms in sustainable tea cultivation in northeast India: Recent advances and current scenario. *Journal of Applied Microbiology* **6**: 170.

Barman H, Roy A and Das S K, 2015. Evaluation of plant products and antagonistic microbes against grey blight (*Pestalotiopsis theae*), a devastating pathogen of tea. *African Journal of Microbiology Research* **9**(18): 1263–67.

Barthakur B K. 2011. Recent approach of Tocklai to plant protection in tea in northeast India. *Science and Culture* **77**: 361–84.

Baverstock J, Roy H E and Pell J K. 2009. Entomopathogenic fungi and insect behaviour: from unsuspecting hosts to targeted vectors. (In) *The Ecology of Fungal Entomopathogens*. Springer, Dordrecht, pp 89–102.

Bhuyan K K, Saikia G K, Deka M K, Phukan B and Barua S C. 2017. Traditional tea pest management practices adopted by small tea growers of Assam. *Journal of Entomological and Zoological Studies* **7**(2): 1338–44.

Bora L C, Bora Popy and Gogoi M. 2020. Potential of *Trichoderma* spp. for Pest Management and Plant Growth Promotion in NE India. Trichoderma. 2020:205. Sharma A, and Sharma P (Eds). *Trichoderma. Rhizosphere Biology*. Springer, Singapore. https://doi.org/10.1007/978-981-15-3321-1_11

Bora Popy, Saikia K and Ahmed S S. 2020. Pathogenic fungi associated with storage rot of *Colocasia esculanta* and evaluation of bioagents against the pathogen. *Pest Management in Horticultural Ecosystem* **26**(1): 123–30.

Bora L C and Bora Popy. 2008. Vemicompost based bioformulation for management of bacterial wilt of tomato in poly house. *Journal of Mycology and Plant Pathology* **38**(3): 527–30.

Bora Popy and Bora L C. 2020. Disease management in horticulture crops through microbial interventions: An overview. *Indian Journal of Agricultural Sciences* **90**(8): 1389–96

Bora Popy and Bora L C. 2021. Microbial antagonists and botanicals mediated disease management in tea, *Camellia sinensis* (L) O. Kuntz: An overview. *Crop Protection* **148**(1): 105711.

Bora Popy, Bora L C and Begum M. 2013. Ecofriendly management of bacterial wilt disease in brinjal through application of antagonistic microbial population. *Journal of Biological Control* **27**(1): 29–34.

Bora Popy, Bora L C and Bhuyan R P. 2021. Evaluation of botanicals and microbial bioformulations for management of grey blight disease of tea under organic production system. *Indian Journal of Agricultural Sciences* **91**(1): 54–57

Bora Popy, Bora L C and Deka P C. 2016a. Efficacy of substrate based bioformulation of microbial antagonists in the management of bacterial diseases of some solanaceous vegetables in Assam. *Journal of Biological Control* **30**(1): 49–54.

Bora Popy, Deka P C and Sarmah A K. 2016b. Efficacy of *Pseudomonas fluorescens* and *Trichoderma viride* based bioformulation for management of bacterial wilt disease of ginger. *International Journal of Plant Science* **11** : 34–39.

Bora Popy, Saikia K, Hazarika H and Ragesh G. 2019. Exploring potential of bacterial endophydes in disease management of horticultural crops. *Current Horticulture* **7**: 32–37.

Chakraborty U, Chakraborty B N and Basnet M. 2006. Plant growth promotion and induction of resistance in *Camellia sinensis* by *Bacillus megaterium*. *Journal of Basic Microbiology* **46**: 186–95.

Deb R, Bora L C and Das P. 2017. Microbial bioformulations for suppression of major insect pests and diseases and enhanced biochemical properties of tea crop. *International Journal of Current Microbiology and Applied Science* **6**(5): 1872–79.

Deb S, Dutta A, Phukan B C, Manivasagam T, Justin-Thenmozhi A, Bhattacharya P and Borah A. 2019. Neuroprotective attributes of theanine, a bioactive amino acid of tea, and its potential role in Parkinson's disease therapeutics. *Neurochemistry International*, p 129. 104478, 10.1016/j.neuint.2019.104478.

Debnath S. 2004. Natural occurrence of entomopathogenic fungus, *Hirsutella thompsonii* on red spider mite, *Oligonychus coffeae* (Nietner) infesting tea plants *Camellia sinensis* (L.) O. Kuntze in North East India. (*In*) *Proceedings of the international conference of tea culture and science*, ICOS-2004, November 4- 6, 2004, Shizuoka, Japan. pp 1204–06.

Dutta J and Thakur D. 2020. Evaluation of antagonistic and plant growth promoting potential of *Streptomyces* sp. TT3 isolated from tea (*Camellia sinensis*) rhizosphere soil. *Current Microbiology.* https://doi.org/10.1007/ s00284-020-02002-6.

Gnanamangai B M and Ponmurugan P. 2012. Evaluation of various fungicides and microbial based biocontrol agents against bird's eye disease of tea plants. *Crop Protection* **32**: 111–18.

Gurusubramanian G and Barthakur B K. 2005. Tocklai Experimental Station, TRA Jorhat Assam Printing Works Private Limited, Jorhat Assam, India, p 81–91.

Gurusubramanian G, Rahman A, Sarmah M, Roy S and Bora S. 2008. Pesticide usage pattern in tea ecosystem, their retrospects and alternative measures. *Journal of Environmental Biology* **29**: 813–26.

Hazarika L K, Bhuyan M and Hazarika B N. 2009. Insect pests of tea and their management. *Annual Review Entomology* **54**: 267–84.

Hazarika L K, Puzari K C and Wahab S. 2001. Biological control of tea pests. (*In*) *Biocontrol Potential and its Exploitation in Sustainable Agriculture: Insect Pests.* Upadhyay R K, Mukerji K G and Chamola B P (Eds). Kluwer Academic, New York, **2**: 159–80.

Hoque A K M R, Aslam A F M, Ahmed M, Mamun M S A and Howlader A J. 2016. Laboratory and field evaluation of an entomopathogenic fungus formulation-bioterminator (*Metarhizium anisopleae* Metchnikoff) against termite infesting tea. *Journal of Tea Science and Research* **6**(9): 1–6.

Kamboj A and Saluja A. 2010. Phytopharmacological review of *Xanthium strumarium* L. (Cocklebur). *International Journal of Green Pharmacy* **4**: 129–29.

Kaushik H and Dutta P. 2016. Establishment of *Metarhizium anisopleae*, an entomopathogen as endophyte for biological control in tea. *Field Crop Research* **17**(2): 385–87.

Khan P, Bora LC, Bora Popy, Talukdar K and Kataky L. 2018. Efficacy of microbial consortia against bacterial wilt caused by *Ralstonia solanacearum* in hydroponically grown lettuce plant. *International Journal of Current Microbiology and Applied Sciences* **7**(06): 3046–55.

Kuberan T, Balamurugan A, Vidhyapallavi R, Nepolean P, Jayanthi R, Beulah T and Premkumar R. 2012. *In-vitro* evaluation of certain plant ectracts against *Glomerella cingulata* causing brown blight diseases of tea. *World Journal of Agriculture Science* **8**(5): 464–67.

Kumhar K C, Babu A, Arulmarianathan J P, Deka B, Bordoloi M, Rajbongshi H and Dey P. 2020. Role of beneficial fungi in managing diseases and insects pests of tea plantation. *Egyptian Journal of Biological Pest Control* **30**: 78–84.

Linner C S, Birgen J K and Maingi J. 2017. *In-vitro* response of *Phomosis theae* to the products of *Azadirachta indica* and extracts of *Warbugia ugandensis. Biotechnology* **14**: 37–46.

Mamun M A A, Asim M M H, Sahin M A Z and Al-Bari M A A. 2020. Flavonoids compounds from *Tridax procumbens* inhibit osteoclast differentiation by down-regulating c-Fos activation. *Journal of Cellular Molecular Medicine* **24**: 2542–51.

Mamun M S A, Ahmed M, Paul S K and Chowdhury R S. 2013. Evaluation of some indigenous plant extracts against tea mosquito bug, *Helopeltis theivora* Waterhouse (Hemiptera: Miridae) infesting tea. *Tea Journal of Bangladesh* **42**: 10–20.

Mamun M S A, Hoque M M and Ahmed M. 2015. Evaluation of some plant origin commercial biopesticides against red spider mite, *Oligonychus coffeae* Nietner (Acarina: Tetranychydae) in tea. *Journal of Tea Science Research* **8**: 1–7.

Mareeswaran J, Nepolean P, Jayanthi R, Samuel P, Asir R and Radhakrishnan B. 2015. *In-vitro* studies on branch canker pathogen (*Macrophoma* sp.) infecting tea. *Journal of Plant Pathology and Microbiology* **6**(7): doi:10.4172/2157-7471.1000284.

Mareeswaran J. 2016. Evaluation of botanical extract for the management of branch canker disease (*Macrophoma* sp.) in tea. *Journal of Indian Botanical Society* **95**(3): 218–24.

Naglot A, Goswami S, Rahman I, Shrimali D D, Yadav K K, Gupta V K, Rabha A J, Gogoi, H K and Veer V. 2015. Antagonistic potential of native *Trichoderma viride* strain against potent tea fungal pathogens in north east India. *Plant Pathology Journal* **31**(3): 278–89.

Navik O, Godase S K, Turkhade P D and Alnaraglar. 2015. Evaluations of entomopathogenic fungi and botanicals against tea mosquito bug *Helopeltis antonii* Signoret. *Current Advances in Agricultural Sciences (An International Journal)* **7**(2): 203.

Pallavi R V, Nepolean P, Balamurugan A, Jayanthi R, Beulah T and Premkumar R. 2012. *In-vitro* studies of biocontrol agents and fungicide tolerance against grey blight disease in tea. *Asian Journal of Tropical biomedicine* **2**(1): 5435–38.

Ponmurugan P. 2017. Biosynthesis of silver and gold nanoparticles using *Trichoderma atroviride* for the biological control of *Phomopsis* canker disease in tea plants. *IET Nanobiotechnology* **11**(3): 261–67.

Pretali C, Bernardo L, Butterfield T S, Trevisan M and Lucini M. 2016. Botanical and biological pesticides elicit a similar Induced Systemic Response in tomato (*Solanum lycopersicum*) secondary metabolism. *Phytochemistry* **130**: 56–63.

Purkayastha G A, Mangar P, Saha A and Saha D. 2018. Evaluation of the biocontrol efficacy of a *Serratia marcescens* strain indigenous to tea rhizosphere for the management of root rot disease in tea. *PLoS ONE* **13**(2):e0191761.

Ruan J and Wu X. 2000. Balanced plant nutrition may help reduce pesticide use by improving tea plants resistance to fungal diseases. *UNEP Industry and Environment* **1**: 89–90.

Ruksana Nasreen, Bora Popy and Medhi K K. 2020. Citrus canker: Developments down the lane. *Annals of Plant and Soil Research* **22**(4): 396–404.

Ryals J, Uknes S and Ward E. 1994. Systemic acquired resistance. *Plant Physiology* **104**: 1109–12.

Saha D, Dasgupta S and Saha A. 2005. Antifungal activity of some plant extracts against fungal pathogens of tea (*Camellia* *sinensis*). *Journal of Pharmaceutical Biology* **43**(1): doi. org./10.1080/13880200590903426.

Saha D, Kumar R, Ghosh S, Kumari M and Saha A. 2012. Control of foliar diseases of tea with *Xanthium strumarium* leaf extract. *Industrial Crops and Products* **37**(1): 376–82.

Saikia A, Mbata T I and Lu D. 2006. Antibacterial activity of the crude extract of Chinese green tea (*Camellia sinensis*) on *Listeria monocytogene*. *International Journal of Microbiology* **3**: 2.

Saikia K, Bora L C, Popy Bora and Hazarika H. 2020. Management of bacterial blight of rice through combined application of endophytes and rhizospheric streptomyces. *Indian Journal of Agricultural Sciences* **90**(12): 2323–327.

Sarma B K, Yadav S K, Singh S and Singh H B. 2015. Microbial consortium mediated plant defense against phytopathogens: re-addressing for enhancing efficacy. *Soil Biology and Biochemistry* **87**: 25–33.

Sarmah M, Rahman A, Phukan A K and Gurusubramanian G. 2009. Effect of aqueous plant extracts on tea red spider mite, *Oligonychus coffeae* Nietner (Tetranychidae: Acarina) and *Stethorus gilvifrons* Mulsant. *African Journal of Biotechnology* **8**(3): 417–23.

Sarmah S R, Dutta P, Begum R, Tanti A J, Phukan I, Debnath S and Barthakur B K. 2005. Microbial bioagents for controlling diseases of tea. (In) International Symposium on Innovation in Tea Science and Sustainable Development in Tea Industry, Proc. China Tea Science.

Selvasundaram R and Muraleedharan N. 2003. Red spider mite-biology and control. *Hand Book of Tea Culture*. UPASI Tea Research Foundation, Valparai, p 4.

Sharma P, Bora L C, Acharjee S, Bora Popy and Jagdale B R. 2020. Zinc enriched *Pseudomonas fluorescens* triggered defense response in rice against bacterial leaf blight. *Indian Journal of Agricultural Sciences* **90**(3): 593–96.

Shrestha G and Thapa R B. 2015. Tea pests and pesticide problems and integrated management. *Journal of Agriculture and Environment* **16**: 188–200.

Sohail A S,Hamid F S, Waheed A and Ahend N. 2012. Efficacy of different botanical materials against APHID *Toxoptera aurantii* on tea (*Camellia sinensis* L.) cuttings under high shade nursery. *Journal of Materials and Environmental Science* **3**(6): 1065–70.

Somchoudhury A K, Samanta A K and Dhar P P. 1993. Approaches to integrated control of tea mosquito bug. Proceedings of International Symposium, Calcutta, pp 330–38.

Sowndhararajan K, Marimuthu S and Manjan S. 2012. Biocontrol potential of phylloplane bacterium *Ochrobactrum anthropi* BMO-111 against blister blight disease of tea. *Journal of Applied Microbiology* **114**: 209–18.

Sudhkaran R. 2000. Studies in the Tea Experimental Station, Tea Research Association, mosquito bug, *Helopeltis theivora* Waterhouse Jorhat, Assam, India, p 169–73. (Hemiptera: Miridae) infesting tea in Southern'.

Das S C, 1984. Resurgence of tea mosquito bug India. Ph D thesis, Bharathiar University India.

Swagata S, Popy Bora and Bora L C. 2021. Microbial bioformulations-mediated canker management in Assam lemon. *Indian Journal of Agricultural Sciences* **91**: 198–201.

Tea Board of India. 2019. https://teaboard.gov.in/ statistics/world production.

Tea Board of India. 2020. http://www.teaboard.gov.in/ TEABOARDCSM/NDQ

Thoudam R and Dutta B K. 2012. Control of black rot disease of tea, *Camellia sinensis* (L.) O. Kuntze with mycoflora isolated from tea environment and phyllosphere. *Journal of Biological Control* **26**(4): 341–46.

Viterbo A, Wiest A, Brotman Y, Chet I and Kenerley C. 2007. The 18mer peptaibols from *Trichoderma virens* elicit plant defence responses. *Molecular Plant Pathology* **8**: 737–46.

Yang Y and Zhang T. 2019. Antimicrobial activities of tea polyphenol on phytopathogens: A review. *Molecules (Basel, Switzerland)* **24**(4): 816.