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Review Article

MANAGEMENT OF TEA (*CAMELLIA SINENSIS*) DISEASES WITH APPLICATION OF MICROBES: A REVIEW

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ABSTRACT

Tea (*Camellia* spp.) is one of the most economically important plantation crops and the second-largest non-alcoholic beverage in the world next to water being consumed by people in different forms. It is cultivated mainly in Assam, West Bengal covering the regions such as Darjeeling, Dooars, Terai, and South India in about 6.36 lakh hectares with a production of about 1338 million Kg made teas. Darjeeling tea is world famous for its specific aroma and flavor whereas Assam is known for premier CTC teas. Among various challenges encountered on its bountiful production and desired quality, the occurrence of numerous diseases is one of the major factors. Different fungal and one algal genus are considered as the major phytopathogens to cause leaf, stem, and root diseases. Blight (blister, gray, and brown), dieback, charcoal stem rot, root rot (brown and violet), and black rot are the major threat to tea sustainability. These diseases can be managed through the timely adoption of good agricultural practices. For the past couple of decades, due to the increased awareness about the adverse effects of synthetic fungicides usage, people have been looking for ideal alternative strategies to take care of tea diseases in India under the organic production system. Microbes such as genus *Trichoderma*, *Bacillus*, *Pseudomonas,* and *Actinomycetes* are capable of providing a protective umbrella to this crop against different diseases.

Keywords: Organic tea, diseases, microbes, *Trichoderma*, *Bacillus*, *Pseudomonas*.

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INTRODUCTION

Tea (*Camellia sinensis* [L] O. Kuntze) is a herbaceous, dicotyledonous, and perennial crop belonging to the family *Theaceae*. It occupies the second position next to water as far as consumption of non-alcoholic beverages in the world is concerned. Its commercial cultivation, in India, was initiated around 1835 with the opening of a few gardens under two tea companies of Assam. Its production, as well as area, has increased many folds in the past five decades [1]. China, India, Kenya, Sri Lanka, Vietnam, and Indonesia are the major tea-producing countries around the globe. The total world tea production was estimated at 6150.08 million kg during the year 2019 [2,3]. At present, India covers approximately 6.36 lakh hectares with a production of about 1338 million Kg made tea [2]. Darjeeling tea is world-renowned and branded as the "Champagne of Tea" due to its special aroma and taste. The Darjeeling hills are equally well-known for their stunning landscapes and are heralded by international environmental groups for their numerous biodiversity hotspots [4]. At present, there are about 87 tea gardens in eight valleys, that is, Darjeeling West, Darjeeling East, Kurseong South, Kurseong North, Mirik, Rungbong Valley, Teesta Valley, and Kalimpong. Darjeeling tea cultivation has been converting from inorganic to organic and by now most of its area has converted into organic. The occurrence of numerous diseases is one of the major challenges hindering its production and quality aspects [1,5].

TEA DISEASES

Tea plantations are subjected to attack by hundreds of fungal pathogens [6]. Majority of these infect plant leaf, stem, and root, which ultimately decreases the quantity and quality of made tea. Several diseases are prevalent in the North, North East, and South India [7]. The thorny blight of stem, charcoal stump rot, brown root rot, and blister blight diseases are more prevalent in Darjeeling. Phytopathogens such as *Fusarium solani*, *Cephaleuros* spp., *Corticium* spp., *Poria hypobrunnea*, *Ustulina zonata*, and *Fomes lamaoensis* are important to cause immense losses in terms of yield and quality [8]. A detailed description of tea diseases in various related aspects has been recently documented [5,9].

Fungicides such as copper oxychloride, hexaconazole 5 EC, propiconazole 25 EC mancozeb, carbendazim, and thiophanate methyl are common molecules generally used to handle these diseases. The application of systemic fungicides could successfully control stem diseases. Soil drenching with carbendazim and some other fungicides provides control of primary root diseases too.

Undoubtedly, chemical fungicides are much more effective, however, there are certain problems associated with their frequent use such as environmental pollution, health hazards, phytotoxicity, development of resistance, resurgence, and residues in made tea and hence; such fungicides are not permitted in organic tea crop production. Under such a perspective, usage of certain fungi, bacteria, and viruses could be safer and ideal components of integrated disease management (IDM) for production sustainability. This review focused on the management of major tea diseases through the application of microorganisms.

Blister blight

Exobasidium vexans Massee is responsible for this disease and it can be classified systematically under Subdivision – Basidiomycotina, Order – Exobasidiales, and Family – Exobasidiaceae. Blister blight (Fig. 1a and b) is one of the most economically important foliar diseases that have emerged as a threat to the tea industry affecting its production and quality in terms of export [10]. It has been known to be a major concern in India since 1855. The occurrence of *Exobasidium* was reported as early as 1895 when blister blight of tea was investigated in upper Assam and the causal organism was identified as *E. vexans* Massee. The outbreak of blister blight on tea in the Darjeeling District occurred in 1908 [11].

Six species of this pathogen, namely, *E. vexans* Massee, *Exobasidium vaccinii* (Fuck.) Wor., *Eoperipatus butleri* Syd., *E. nilagiricum*, *E. celtidis*,

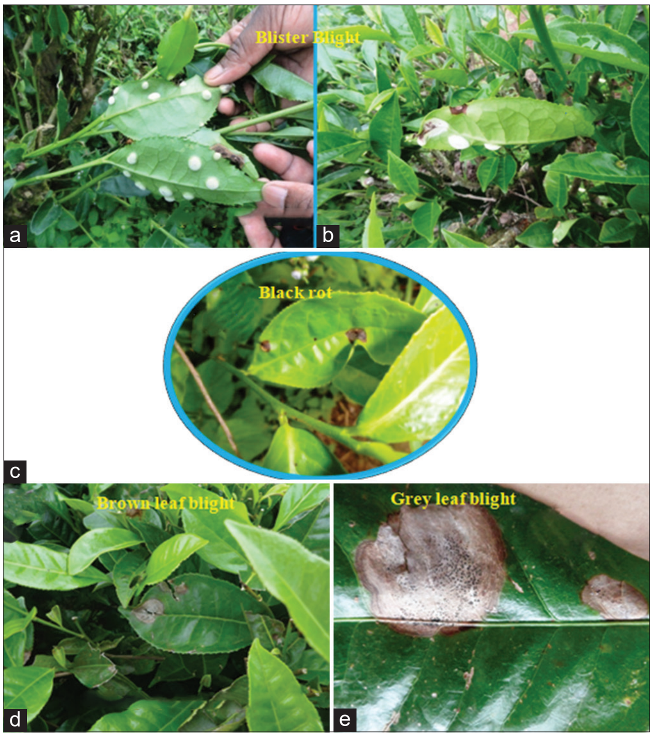

Fig. 1: Tea diseases

and *E. trisepticum,* have been reported in our country, occurring on six host plants. All these have been noticed only in North India, especially in the Himalayan region. Two major epiphytotics occurred in N.E. India [12]. The third outbreak occurred in 1946 in South India and disease spread rapidly over most of the tea growing areas in Central in Travancore, The Anamalais, and The Nilgiris due to exceptionally wet and prolonged rainy weather. Later on, epiphytotics occurred in Ceylon, now Sri Lanka, Sumatra in 1949, and Jawa in 1951 [13]. From 1946, the disease caused crop loss estimating 180 million pounds of tea in South India and was found in all tea districts. Huge crop loss was recorded in Indonesia [13]. In the Darjeeling area, generally, it attacks from July to September and causes huge losses. No scientific literature concerning its initiation, progress, the extent of yield loss, its ETL, disease cycle, the effect of weather factors on it, and local bioagents effective against this disease are available.

Tender tea leaves are the most infected by the phytopathogen resulting in huge crop losses in terms of quantum and its quality aspects [14]. Due to infection, small transparent spots appear on leaves within 3–7 days. Later on, they grow in size with depression on the upper surface. The classic convex-shaped lesions of the blister develop on the lower surface of infected leaves which become necrotic subsequently. Both morphological and physiological changes occur in tea plants due to disease incidence [15]. The pathogen produces certain enzymes to facilitate easy and successful infection [16]. Only tea is its host plant for the successful completion of the life cycle [17].

Beneficial microorganisms such as *Trichoderma harzianum*, *Gliocladium virens*, *Serratia marcescens*, *Pseudomonas fluorescens,* and *Bacillus subtilis* could effectively manage this disease. It has been reported that sprays of vermicompost-based *Trichoderma* could take care of the disease [18]. At low disease pressure, *P. fluorescens* and *B. subtilis* performed in a better way. Native isolates of *Bacillus* spp. were found to be fairly promising bioagents against it under greenhouse as well as field conditions in South India.

Spraying the tea crop with *Bacillus* as well as *Pseudomonas* at weekly intervals could effectively control the disease in the fields and enhanced the tea production significantly continuously for two consecutive seasons [19]. Application of *P. fluorescens* increased production of certain defense enzymes such as peroxidase, polyphenol oxidase, phenylalanine ammonia-lyase, chitinase, β-1,3-glucanase, and phenolics required for the induction of systemic resistance in plants against the disease. Root colonizing bacteria enhanced plant growth, the emergence of seed and yield [20]. Application of plant growth-promoting rhizobacteria resulted in improved seed germination, drought tolerance, the weight of shoots and roots, vegetative plant growth, as well as crop yield [21].

Pseudomonas increased indole acetic acid production that helped in the development of a good root system [22]. This bacterium produces antibiotics, siderophores, and hydrogen cyanide playing role in biocontrol activities. *T. viride*, *T. harzianum*, *B. subtilis*, and actinomycetes are reported as potential microbes for the control of blister blight under field conditions in North East India. *B. subtilis* is a successful microbial candidate for the management of certain tea diseases. Antagonist *Trichoderma* is efficient in controlling certain stem as well as soil-borne root diseases. The isolates of actinomycetes showed an encouraging response toward the control of tea plantation diseases. The spray of *Ochrobactrum anthropi* strain BMO-111 controlled the blister blight and improved the chlorophyll, polyphenols, and catechins content in the pluckable tea shoots [23].

Black rot

It is caused by fungal phytopathogen *Corticium theae* and *Corticium invisum.* The pathogens infect the older foliage (Fig. 1c) leading to the steady tea bush health wear and tear which ultimately results in crop yield loss. The sclerotia of fungus germinate in March and April and infect the plantation from May to July. The active stage of the phytopathogenic fungus may last up to September in the field. The overwintering of fungal sclerotia takes place in the stem of tea bushes generally in its cracks and crevices during unfavorable conditions. Such sclerotia again germinate with the advent of favorable environmental conditions and start the fresh infection on the tea bushes. Its seasonal incidence and disease progress occur under the existing weather factors of Darjeeling. Application of *B. subtilis* was effective against this pathogen during both active and dormant phases. Its repetitive application at fortnightly intervals provided better disease control. The hand plucking of tea leaves helps in reducing the disease incidence [24].

Leaf blight

Leaf blight of tea is yet another important disease that is classified into two types, namely, brown and gray blight (Fig. 1d and e). *Pestalotiopsis theae*, causing gray blight, is a fungal phytopathogen of global occurrence in tea cultivating areas [24] which has endophytic behavior [25] and is responsible for huge crop losses around the globe [25,26]. There are five species reported so far; however, two species, namely, *P. longiseta* (Speg.) H.T. Sun and R.B. Cao as well as *P. theae,* are of more significance as far as disease status is concerned [27]. *Trichoderma* isolates reduced the growth of *Glomerella cingulata* significantly, and therefore, it is suitable to include in the IDM strategies for controlling brown blight disease [29].

T. viride (KBN-24) and *T. harzianum (*KBN-29 – accession number: ITCC-7764) were also found efficient in controlling *P. theae* in a laboratory study [30]. Eleven local *Trichoderma* isolates identified from the tea plantations of West Bengal were evaluated against *P. theae*, under *in vitro* conditions. Results revealed that the isolates were found efficient in suppressing the growth of *P. theae* in the range of 49.3–65.8%; however out of isolates, three *Trichoderma* isolates, namely, KBN-1/14, KBN-2/14, and KBN-29, showed a good response [31].

Stem diseases

Branch canker (Fig. 2a) caused by *P. hypobrunnea* as well as thorny blight incited by *Tunstallia aculeata* is also of economic significance, infecting the tea bushes in plain and hilly regions of tea growing Indian states. Both pathogens enter through cuts that occurred on the bushes due to the commencement of heavy pruning operations and infect the plant. Therefore, to protect from disease, proper care of fresh pruning cuts is

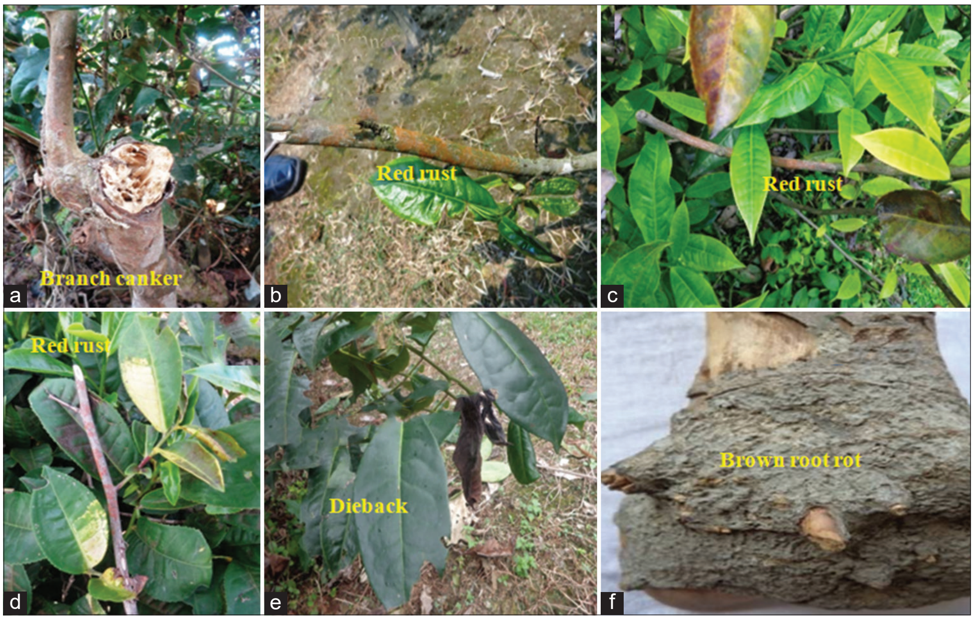

Fig. 2: Tea diseases

of primary significance, it may be achieved through the application of suitable microbes.

Immediately after pruning operation, the application of *Trichoderma* on the pruned cuts is quite effective in managing both diseases. In the case of rejuvenation and medium pruning, its higher concentration is helpful while in the case of light pruning, its lower concentration is applicable [7]. It was noted that the application of the paste of talc-based *Trichoderma* formulation on pruned cuts and its soil application at 1 kg/bush was found effective in managing stem diseases [32]. *T. harzianum* and *G. virens* were used against collar canker of tea.

B. amyloliquefaciens, *T. harzianum*, *G. virens,* and *Beauveria bassiana* were tested on pruned tea which was naturally infected with branch canker caused by *Macrophoma theicola* at UPASI Tea Research Institute, Valparai, Tamil Nadu, India, and it was noted that *B. amyloliquefaciens* protected better followed by *G. virens* and *B. bassiana* [33]. *P. fluorescens* showed growth promotional activity in tea plants and controlled several fungal pathogens under *in vitro* conditions. This bacterial strain contains various antifungal metabolites which inhibit the growth of fungal pathogens and is suitable for soil application. Bioeffectiveness of *Bacillus* spp., *T. viride*, *T. harzianum*, and *Pseudomonas* spp. was assessed under field conditions to manage the branch canker (*Macrophoma* spp.) and it was found that *Bacillus* spp. protected tea plants superiorly [34].

Red rust

Alga, *Cephaleuros parasiticus,* is the primary causative agent of red rust. In general, the disease infects the young stems of tea bushes. Eventually, the symptoms of the disease appear on leaves. It is comparatively more harmful to young tea plants. The pathogen destroys the stem tissues in patches which ultimately turn into dieback. The appearance of variegation with yellow patches on the leaves of the infected branches is the characteristic feature of this disease. Symptoms of the disease appear as small translucent water soaking spots on leaves.

On the upper surface, the spot becomes purple-red, then black with a purple margin. On the under surface, it is purple-red becoming gray-brown with the advancement of time (Fig. 2b-d). If it attacks the petiole at its junction with the stem, the leaf falls and its sporangia are spread by wind or rain. Species of *Azotobacter*, *Azospirillum*, *Bacillus*, *Pseudomonas*, *Streptomyces*, *Trichoderma*, etc., protected the tea plantation from red rust under field conditions [8].

Dieback of primaries and seed decay

F. solani is the pathogen of this disease. A few TV (Tocklai Vegetative) clones and some biclonal seed stocks are more susceptible. The humid and temperate climate is favorable for the fungal phytopathogen.

The leaf petioles turn black due to infection. Later, the infection spreads to the nodes and internodes resulting in wilting of the primary branches (Fig. 2e). The white cottony mycelial growth of the pathogenic fungus can be observed on the dead tissues, and then, the fungal mycelia turn brown colored in the advanced stage. When the pathogen infects the seeds, the fruit carp turns black colored and results in untimely or pre-mature cracking and dropping of seeds. The affected seeds turn light pinkish along with powdery mass on their surface. *G. virens* could inhibit the pathogen's growth successfully when it was dually cultured with dieback causing fungus [36]. A few *Trichoderma* isolates of the West Bengal tea ecosystem were *in vitro* evaluated against the dieback disease pathogen, which resulted in promising suppression of growth of the phytopathogen to the tune of 54.3–77.1%, however, isolates, namely, KBN-1/14, KBN-2/14, and KBN-29, performed satisfactorily in controlling the pathogen in the laboratory as well as under field conditions [30,35,36]. An indigenous isolate of *Trichoderma* showed very good control of *F. solani* the cause of the dieback disease of tea [38]. The effectiveness of *T. viride* was established for the management of dieback disease of this crop [35].

Root diseases

Primary root diseases

Charcoal stump rot, brown root rot (Fig. 2f), and black root rot are major diseases causing severe damage to tea plantations. The first two diseases are commonly infecting tea plantations in North Eastern plains whereas the third one is a major challenge in Darjeeling. The main sources of disease dissemination are diseased plant material, contact from diseased to healthy plants, air, and rain. No clear-cut disease symptom appears on the above-ground plant parts for early detection. The infected plants died within a period of 6 months–4 years. The infected bushes, after their death, can easily infect the immediate neighboring bushes. Adoption of proper cultural practices helps in reducing the incidence of root diseases.

Genus *Trichoderma* has been found effective in controlling such diseases. Treatment of planting pits and excavated soil with this bioagent has been reported to be useful. In the collar region of young tea plants, the application of *Trichoderma* is proved to be very good in suppressing diseases. Several

T. viride isolates were studied under laboratory conditions for antagonism against pathogenic *Rhizoctonia solani*, *Sclerotium rolfsii*, *Macrophomina phaseolina*, *Alternaria alternata*, *F. solani,* and *Colletotrichum capsici* and proven to be very good antagonists [39].

Bioagents, namely, *T. harzianum*, *G. virens*, *B. subtilis,* and *P. fluorescens,* showed effective control of charcoal stump rot of tea caused by *U. zonata* [40]. Out of *Streptomyces griseus*, *Streptomyces lydicus*, *B. subtilis*, and *T. harzianum* evaluated in the field for bioefficacy in managing the red root rot disease caused by *Poria hypolateritia* revealed that *S. griseus* and *T. harzianum* reduced the disease and enhanced green leaf yield as well as improved quality in terms of higher theaflavin and thearubigin contents evident from liquor characteristics [41]. Antagonistic fungal genera were found efficient in managing various tea diseases [42].

Application of an aqueous suspension of *O. anthropi* TRS-2 into the rhizosphere of seedlings of TV-18, T-17, HV-39, S-449, and UP-3 varieties enhanced plant growth in terms of height, the number of shoots and leaves in addition to decreasing brown root rot disease incited by *Phellinus noxius* [43]. Copper and silica nanoparticles of *P. fluorescens*, *T. viride*, and *S. griseus* reduced the incidence of red root rot due to *P. hypolateritia* and canker disease incited by *Phomopsis theae* in South Indian tea plantations [44]. Under field conditions, soil application of copper nanoparticles synthesized using *S. griseus* exhibited promising management of *P. hypolateritia*, a pathogen of red root rot disease of tea plantation [45].

S. marcescens strain ETR17, an isolate of tea rhizosphere, found promising in controlling several foliar as well as root rot pathogens of tea under laboratory and greenhouse conditions, in addition, it had plant growth promotion characteristics [46].

Species of *Azotobacter, Azospirillum, Bacillus, Pseudomonas, Streptomyces, Trichoderma*, etc., protected the tea plantation from black rot, red rust, and dieback under field conditions [8].

Secondary root diseases

Violet root rot, *Spherostilbe repens*, and Diplodia root rot, *Diplodia* spp., are the main diseases under this category. In general, these pathogens infect the weaker tea plants. Clayey soil with water logging is conducive for the spread of these diseases. Proper water drainage can handle this problem. There is a great loss of reserve starch in infected plants.

CONCLUSION AND RECOMMENDATIONS

Tea is one of the most commonly consumed non-alcoholic beverages in the world after water. Its cultivation encounters the challenges of various diseases. Although these diseases could be controlled by various fungicides, from the health point of view, usage of chemical fungicides is not advisable in tea crop production. Under such circumstances, the IDM approach is the best way to have healthy tea production. Disease resistant or tolerant genotypes, the use of beneficial microbes for the management of diseases, are the components of IDM, which is a vital, economic, eco-friendly viable, and long-lasting successful strategy. To find out resistant/tolerant tea genotypes, the development of a "disease screening nursery" is of prime need for its sustainability. For the biological control of diseases, local strains of beneficial microbes should be explored followed by their evaluation and commercialization. Disease progress depending on weather factors should be undertaken to realize the role of these factors in the initiation and development of economically important diseases.

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