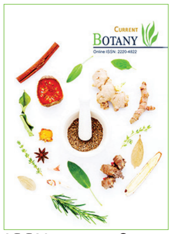
Current Botany 2025, 16: 193-199
doi: 10.25081/cb.2025.v16.9454
https://updatepublishing.com/journal/index.php/cb

Research Article



ISSN: 2220-4822

Evaluation of Vermi-Derma bioformulations against blister blight disease of *Camellia sinensis* (L.) O. Kuntze

Sappanimuthu Parathiraj[1], Ponnusamy Ponmurugan[1]*, Devaraj Mounika[1], Arumugam Anitha[1], Siby Mathew[2]

[1]Department of Botany, Bharathiar University, Coimbatore-641046, Tamil Nadu, India, [2]Research & Development Department, Kanan Devan Hills Plantations Company Private Limited, Munnar-685612, Kerala, India

Received: February 07, 2025
Revised: July 09, 2025
Accepted: July 19, 2025
Published: July 28, 2025

***Corresponding author:**
Ponnusamy Ponmurugan
E-mail: drponmurugan@gmail.com

ABSTRACT

Blister blight disease caused by an obligate fungal pathogen, *Exobasidium vexans* is very common in almost all the tea growing regions in India. Due to this disease, the green leaf yield potential and tea quality parameters are significantly affected. In order to control this disease, several fungicide schedules are made available to tea planters. But the fungicide schedules lead to accumulation of fungicide residues in made tea which ultimately affect the export quality. Keeping in mind, studies were undertaken to evaluate the various concentrations of Vermi-derma bioformulations amended with various native biocontrol agents like *Trichoderma harzianum* (fungi), *Pseudomonas fluorescens* (bacteria) and *Streptomyces sannanensis* (actinomycete) against blister blight disease. The results revealed that there was a significant reduction in blister blight disease in the trail plots after imposing various treatments of Vermi-derma bioformulations. Among the treatments tested, a significant disease protection of 72.42±2.08% was registered with copper oxychloride + Contaf fungicides treatment. On the other hand, the highest green leaf yield of 5401±2.27 kg ha^{-1} made tea was registered with *T. harzianum* amended with Vermi-derma bioformulations (1:20 ratio) treatment. Similarly, biometric analysis, physiological traits and biochemical constituents were also increased in the same treatment. *P. fluorescens* and *S. sannanensis* amended with Vermi-derma bioformulations were found to be on par with each other in terms of disease control and green leaf yield. Increasing all these parameters might be due to the recovery of leaves from *E. vexans* infection by the action of Vermi-derma bioformulations.

KEYWORDS: Tea, *Camellia sinensis*, Blister blight disease, *Exobasidium vexans*, Fungicides, Vermi-Derma, Biocontrol agents

INTRODUCTION

Tea [*Camellia sinensis* (L.) O. Kuntz] is grown as one of the major plantation crops cultivated in more than 40 countries of Asian and African continents. It is being grown extensively as a monoculture in regions with an annual precipitation ranging from 1255 mm to 8500 mm rainfall, ambient temperature between 14 and 35 °C and a day length of 3.4 to 8.5 hrs, and from sea level to 2300 to 3250 m in a wide range of soil types that are acidic (pH) in reaction (Manjukarunambika *et al.*, 2023). The tea growing areas in India covers approximately 4,65,000 hectares, mostly in the states of Assam (55.4%), West Bengal (24.0%), Tamil Nadu (9.13%) and Kerala (8.0%).

Blister blight disease of tea is caused by a biotrophic basidiomycete fungus *Exobasidium vexans* Massee. The life span of *E. vexans* is 9-11 days depending upon the weather conditions. If non-conducive weather conditions are found, the life cycle extends up to 28 days (Ram & Mouli, 1983). This pathogen infects only tender tea shoots due to the availability of larger amounts of nutrients and water. It is vigorous during the monsoon seasons in which many generations of *E. vexans* are completed (Figure 1). Tea industry in southern India has suffered enormous crop losses due to blister blight infection till date because adequate control measures are not available for tea planters (Nisha *et al.*, 2018). The annual loss due to this disease was estimated to be about 18-20 million kg of made tea and teas produced from disease affected leaves are inferior in quality (Ponmurugan *et al.*, 2019).

Recently, a large number of organic fungicides and biocontrol agents have been evaluated against *E. vexans* for organic tea cultivation to avoid fungicide accumulation in tea leaves (Do, 2025). But they are inferior to fungicide schedules due to immediate action against the growth of pathogen. In addition, biocontrol agents found to be poor persistence

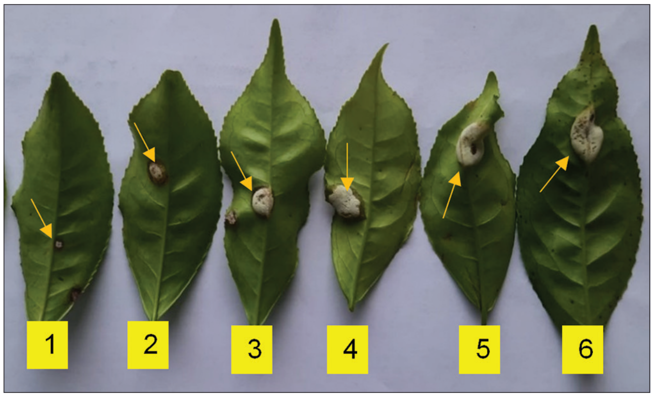


Figure 1: Various stages of blister blight disease caused by *Exobasidium vexans* in tea leaves (Arrows are showing 1. Oil spot, 2. Development of lesion, 3. Matured lesion, 4. Sporulating lesion, 5. Initial necrotised lesion and 6. Matured necrotised lesion)

with high cost and economically not feasible (Gnanamangai *et al.*, 2017). Antagonists like *Trichoderma harzianum*, *Pseudomonas fluorescens*, *Bacillus subtilis* and *Streptomyces sannanensis* were reduced the sporulation of blister blight lesions very markedly and caused lesions to abort (Elango *et al.*, 2015). They also possessed strong eradication action on latent blister lesions which lead stimulatory effect on plant growth and harness its strong antisporulant action. It has been reported that plant diseases were successfully controlled using bacterial, fungal and actinomycete biocontrol agents in various food and forage crops (Chenniappan *et al.*, 2019; Nithya *et al.*, 2020).

Several Plant Pathologists were successfully controlled blister blight disease of tea using bacterial, fungal and actinomycete antagonists (Baby *et al.*, 2004; Elango *et al.*, 2015; Fauziah *et al.*, 2019; Dethoup *et al.*, 2022). Application of various plant growth promoting microorganisms against blister blight disease of tea was reported by Barman *et al.* (2020) and Hazarika *et al.* (2021). But no efforts were made to find out the efficacy of Vermi-Derma bioformulations amended with various antagonists to control blister blight disease and to explore their possibilities in tea plants under field condition.

MATERIALS AND METHODS

Study Site

Experiments were laid out in naturally infected blister blight disease tea fields in Madupatty estate, Munnar, Kerala, India lying at elevation of 1735 m above mean sea level with the latitude of N 10°07.777′ and longitude of E 077°08.453′. The fields were planted with a susceptible tea clone TRI-2025 in 1988 at a spacing of 135x75x75 cm with a population of 13500 plants/ha. Experiments were conducted by following a randomized block design method which consisted of 55 bushes per plot with five replicates. The contact (copper oxychloride) with systemic fungicide (Contaf) and promising biocontrol agents were evaluated for four consecutive disease seasons (2020-2024).

Preparation of Vermi-Derma Bioformulations

Vermi-derma formulations were prepared to test the efficacy of biocontrol activity against blister blight disease of tea plants. The native isolates of *Trichoderma harzianum* (MUN T147), *Pseudomonas fluorescens* (MUN P572) from *Streptomyces sannanensis* (MUN S66) belonging to fungal, bacterial and actinomycete antagonist; respectively were selected for the present study. *T. harzianum* was inoculated on 1.0 L *Trichoderma* selective liquid medium and allowed to grow for 14 days (Elad & Chet, 1983; Chet, 1987). *P. fluorescens* and *S. sannanensis* were grown on 1.0 L nutrient and casein nitrate broths; respectively and allowed to grow for 7 days (Kuster & Williams, 1964). These were kept in a shaking incubator to promote uniform growth of the antagonists. After incubation, the broth containing antagonists were mixed with 5 kg of sterilized vermicompost along with carboxymethyl cellulose (0.5%) as an adhesive agent, salicylic acid (0.2%) and ammonium sulphate (0.2%) as substrates to enhance the growth of antagonists (Ji & Wilson, 2003). These were kept under 5 day's observation for mass multiplication. The spore load in the bioformulations was adjusted to $1x10^6$ colony forming units per gram of sample (Jayarajan *et al.*, 1994).

Field Application of Vermi-Derma Bioformulations

The bioformulations were soaked in 2.0 L vermiwash (liquid taken out from the vermicomposting unit after washing with tap water) in a bucket and allowed to stand overnight to supply organic carbon to promote the maximal growth of antagonists (Suriyakumar, 2009). The various concentrations of Vermi-derma formulation and fungicides were prepared and sprayed using a knapsack sprayer covering one row on either side of the tea bush. The recommended fungicides, copper oxychloride along with Contaf were included in the treatment schedules for comparison. The disease incidence in tea shoots (three leaves and a bud) after imposing various treatments was assessed during every plucking round *i.e.* at 10 days interval. Green leaf yield in the experimental plots was recorded during every plucking round and converted to made tea in kg ha^{-1} using the formula of Ponmurugan and Baby (2007).

Analysis of Biometric Parameters

Recovery of the treated tea bushes after imposing various treatments were assessed in terms of measuring the plucking surface of the bush, number of plucking points containing three leaves and a bud, internodal length, leaf moisture, dry matter, leaf thickness and epicuticular wax contents (Sadasivam & Manickam, 1996; Balasubramanian *et al.*, 2010).

Estimation of Biochemical Constituents

Tea bush mother leaves were collected from the experimental plots and ground with acetone (80%) using a chilled pestle and mortar. The aqueous layer was taken out after filtration using two folds of muslin cloth to estimate total chlorophyll and carotenoid contents as per Harborne (1973) method. Tea shoots containing three leaves and a bud were ground with ethanol (80%) and then filtered to estimate various biochemical constituents such as total sugars (Dubois *et al.*, 1956), nitrogen (AOAC, 1990), proteins (Lowry *et al.*, 1951), amino acids (Moore & Stein, 1948) and polyphenols (Bray & Thorpe, 1954).

Estimation of Physiological Variations

According to Manivel and Hussain (1982), the mother leaves of tea plants play an important role to synthesize various biochemical constituents and act as a potent source. Physiological parameters such as net photosynthetic (Pn) rate, transpiration (Tr) rate and stomatal conductance (Sc) were measured in mother leaves using an infrared gas analyzer (ADC LCA-3, UK) attached with an open type of Parkinson leaf chamber (ADC PLC-3). The ratio between net Pn rate and rate of Tr was calculated to arrive the water use efficiency (WUE) (Chandramouli, 1992).

Statistical Analysis

Data on screening of Vermi-derma formulations and fungicides against blister blight disease were subjected to analysis of variance (ANOVA), critical difference (CD) and standard error (SE) using SPSS 14.0 statistical (SPSS, Inc. Chicago, IL) package (Gomez & Gomez, 1984).

RESULTS

Blister Blight Disease Protection

The results of the present study showed that the recommended copper oxychloride + Contaf fungicides provided a significant disease protection to blister blight infected tea plants when compared to biocontrol agents amended with Vermi-derma bioformulations (Table 1). Copper oxychloride + Contaf fungicides schedule protected the plants from infection which accounted for 72.42±2.08% followed by 68.17±2.21% disease protection in *T. harzianum* amended with Vermi-derma bioformulations (1:20 ratio) treatment. The results further showed that various treatments protected the disease to varying degrees and improved the plant health significantly. *P. fluorescens* and *S. sannanensis* amended with Vermi-derma bioformulations were found to be on par with each other in terms of disease control. The biocontrol agents amended with Vermi-derma bioformulations were effective moderately in terms of disease protection but inferior to copper oxychloride + Contaf treatment (Table 1). The disease incidence in the untreated control plots showed the symptoms of defoliating with chlorosis and heavy flowering.

Green Leaf Yield and Biometric Analysis Observation of Treated Plants

The green leaf yield was significantly increased in all the treatments except the untreated control plants (Table 1). Among the treatments tested, the highest green leaf yield of 5401±2.27 kg ha^{-1} made tea was registered with a 1:20 combination of *T. harzianum* amended with Vermi-derma bioformulations treatment followed by 5306±2.15 kg ha^{-1} made tea with a 1:10 combination. The results on biometric analysis of tea bush showed that the plucking surface, plucking points, leaf moisture, internodal length and dry matter contents were significantly improved after imposing various treatments (Table 2). These parameters were found to be highest in *T. harzianum* amended with Vermi-derma bioformulations (1:20 ratio) treatment. These results were coincided with the observation of crop yield. The plucking surface and plucking points were ranged from 6258.3±1.17 to 8639.7±2.15 cm^2 and 141.5±1.54 to 185.0±2.17 per sq ft respectively in the Vermi-derma bioformulations treated plots, whereas these parameters recorded were 5250.5±2.12 cm^2 and 133.3±2.50 per sq ft respectively in the copper oxychloride + Contaf fungicides treated bushes. The leaf moisture, internodal length and dry matter contents registered correspondingly were 73.5±2.31%, 4.84±0.55 cm and 24.26±2.35% in *T. harzianum* amended with Vermi-derma bioformulations (1:20 ratio) treatment. Leaf thickness was 325±3.48 μM and epicuticular wax was 0.027±0.07 g was noticed in the same treatment (Table 2). The

Table 1: Effect of various Vermi-Derma bioformulations amended with various potential biocontrol agents on blister blight disease incidence and green leaf yield of tea plants

S. No.	Treatment details	Disease incidence (%)			Yield (kg ha^{-1} made tea)*
		Pre treatment	Post treatment	Disease protection#	
1	*T. harzianum* with Vermicompost (1:10)	80.87±1.77	28.50±1.68	64.76±1.98	5306±2.15
2	*T. harzianum* with Vermicompost (1:20)	80.27±1.77	25.55±2.58	68.17±2.21	5401±2.27
3	*P. fluorescens* with Vermicompost (1:10)	81.35±2.07	29.11±2.55	64.22±2.11	4697±2.32
4	*P. fluorescens* with Vermicompost (1:20)	82.07±1.58	28.00±2.07	65.88±2.23	4711±2.51
5	*S. sannanensis* with Vermicompost (1:10)	81.85±2.27	31.77±1.54	61.19±2.18	4682±2.71
6	*S. sannanensis* with Vermicompost (1:20)	82.35±1.36	30.55±2.77	62.90±2.08	4812±2.65
7	*T. harzianum* alone (1:20)	81.87±1.95	35.57±2.08	56.55±1.07	3568±1.90
8	*P. fluorescens* alone (1:20)	80.93±2.08	36.55±1.87	54.84±1.10	3014±1.34
9	*S. sannanensis* alone (1:20)	80.08±2.00	37.53±1.87	53.14±1.12	3122±1.23
10	Copper oxychloride+Contaf fungicides	81.13±2.07	22.37±1.63	72.42±2.08	4879±2.61
11	Untreated Control	80.33±1.79	95.00±2.35	-18.26±1.07	1045±0.24
SE ±		0.23	1.14	2.37	22.89
CD at P=0.05		0.47	2.23	3.78	23.89

Data denotes significantly different and vice versa at P<0.05. *Improvements acquired due to various treatments.

Table 2: Effect of various Vermi-Derma bioformulations amended with various potential biocontrol agents on biometric analysis of tea bush with respect to blister blight disease incidence*

S. No.	Treatment details	Plucking surface (cm^2)	Plucking points (per sq. ft)	Leaf moisture (%)	Internodal length (cm)	Dry matter content (%)	Leaf Thickness (μM)	Epicuticular wax (g)
1	*T. harzianum* with Vermicompost (1:10)	7576.3±2.11	155.5±2.32	70.3±2.11	4.05±0.44	24.14±2.18	298±3.27	0.016±0.05
2	*T. harzianum* with Vermicompost (1:20)	8639.7±2.15	185.0±2.17	73.5±2.31	4.84±0.55	24.26±2.35	325±3.48	0.027±0.07
3	*P. fluorescens* with Vermicompost (1:10)	7339.0±2.47	157.5±2.44	72.5±2.62	3.81±0.39	23.63±2.65	251±3.28	0.014±0.05
4	*P. fluorescens* with Vermicompost (1:20)	7363.3±2.21	163.5±2.32	71.5±1.70	3.18±0.62	23.30±2.94	266±3.25	0.022±0.06
5	*S. sannanensis* with Vermicompost (1:10)	7157.5±1.15	167.7±1.75	72.3±1.53	3.54±0.56	23.19±2.65	274±3.11	0.012±0.04
6	*S. sannanensis* with Vermicompost (1:20)	7247.5±1.14	170.0±2.81	70.5±2.08	3.60±1.21	22.23±2.82	284±3.28	0.023±0.03
7	*T. harzianum* alone (1:20)	6358.0±2.10	150.3±1.48	68.8±1.24	2.33±1.15	20.74±1.37	247±3.18	0.014±0.03
8	*P. fluorescens* alone (1:20)	6258.3±1.17	143.5±1.55	64.3±1.34	2.34±1.37	18.26±1.28	241±3.10	0.013±0.04
9	*S. sannanensis* with Vermicompost (1:20)	6359.3±1.15	141.5±1.54	65.2±1.33	2.33±1.35	18.26±1.28	240±3.07	0.013±0.04
10	Copper oxychloride+Contaf fungicides	5250.5±2.12	133.3±2.50	53.5±1.22	3.06±1.64	20.25±2.47	215±2.66	0.012±0.02
11.	Untreated Control	1345.5±0.15	102.7±0.14	33.3±1.41	1.06±1.04	08.28±0.90	107±2.53	0.007±0.01
SE ±		15.57	5.57	1.33	1.02	3.22	6.78	0.03
CD at P=0.05		8.17	7.14	3.24	2.11	5.41	9.07	0.12

Data denotes significantly different and vice versa at $P<0.05$. *Improvements acquired due to various treatments

harvestable shoots collected from Vermi-derma bioformulations treated experimental plots showed fairly dark green, slightly more pubescent, slender and reasonably easy to harvest.

Physiological and Biochemical Response of Treated Plants

Physiological traits such as Pn rate, Tr rate, WUE and SC and biochemical constituents like total chlorophyll, carotenoid, sugars, nitrogen, proteins, amino acids and polyphenols were also increased in *T. harzianum* amended with Vermi-derma bioformulations (1:20 combination) treatment (Tables 3 & 4). All these physiological parameters were reflected in the estimation of biochemical parameters in treated and untreated plants. The enzyme activities *viz*., cellulase, peroxidase and polyphenol oxidase were recorded the maximum in the same treatment similar to that of biometric, physiological and biochemical analysis (Figure 2). Pn and Tr rates recorded were 9.88±0.06 per mol min^{-2} m^{-2} and 4.38±0.63 mol s^{-2} m^{-2} respectively and WUE and SC recorded were 3.82±0.56 and 0.47±0.02 mol s^{-2} m^{-2} respectively in the same treatment. The results on the estimation of chlorophyll and carotenoid contents indicated that these were found to be highest in *T. harzianum* amended with Vermi-derma bioformulations treated bushes which were estimated as 2.78±0.29 and 0.58±0.09% by mass. The same trend was observed in estimating total sugars (5.13±0.18%), nitrogen (4.33±0.21%), proteins (3.87±0.79%), amino acids (0.88±0.03%) and polyphenols (23.65±3.46%). It was noticed that there was a reduction in physiological and biochemical estimations in fungicides treated and untreated control bushes (Tables 3 & 4).

Among the two different kinds of Vermi-derma combinations such as 1:10 and 1:20 ratios evaluated, 1:20 combinations were performed better in terms of enhancing green leaf yield, biometric, physiological and biochemical activities in the leaves than fungicides treated bushes due to growth promoting effect. Among the different biocontrol agents tested, *T. harzianum* belongs to the bacterial community was found to be significantly better than fungal and actinomycete antagonists in protecting tea plants and enhancing all the plant metabolic parameters.

DISCUSSION

In southern India, tea estates resort to chemical control measures against blister blight disease with the onset of monsoon and continue till the end of the season. With the escalating cost for blister blight disease management, efforts could be taken to reduce the number of fungicide applications with long residual action and high efficacy and also by avoiding unwarranted spray applications (Han *et al.*, 2024). To keep in mind, attempts were made to evaluate biocontrol agents amended with Vermi-derma bioformulations at different combinations to achieve better control of blister blight disease with long residual action which in turn enhanced the green leaf yield. Intensified use of contact and systemic fungicides to enhance crop production, has resulted in environmental and groundwater pollution, pathogen resurgence and resistance breakdown and evolution of fungicide tolerant (Sanjay *et al.*, 2008). In order to meet these challenges, viable alternatives to control blister blight disease are being sought and the use of antagonistic microbes is one of the promising approaches (Sreenivasaprasad & Manibushanarao, 1990).

A significant disease protection was observed upon foliar spray of copper oxychloride+Contaf fungicides (72.42±2.08%) not only due to the disease control mechanism but also due to their phytotonic effect (Table 1). Kalim *et al.* (2000) reported that systemic fungicides like Contaf is well known for direct action on the pathogen in terms of inhibiting the spindle formation during mitosis. The highest green yield was observed in the trial plots treated with biocontrol agents amended with Vermi-derma bioformulations which accounted in the range of 3014±1.34 - 5401±2.27 kg ha^{-1} made tea (Table 1). Vermi-derma bioformulations (1:20) containing *T. harzianum* registered the highest crop yield about 5401±2.27 kg ha^{-1} made tea followed by *S. sannanensis* (4812±2.65) and *P. fluorescens* (4711±2.51). Amendments of biocontrol agents in Vermi-derma bioformulations resulted in increasing the overall plant metabolism. According to Papavizas (1985) and Windham *et al.* (1986), *Trichoderma* spp. is known to produce a wide spectrum of antibiotics to suppress the development of the pathogen *in situ*

Table 3: Effect of various Vermi-Derma bioformulations amended with various potential biocontrol agents on physiological variations in the mother leaves with respect to blister blight disease incidence*

S. No.	Treatment details	Pn rate	Tr rate	WUE	SC
1	*T. harzianum* with Vermicompost (1:10)	9.03±0.78	3.51±0.55	3.13±0.36	0.36±0.02
2	*T. harzianum* with Vermicompost (1:20)	9.88±0.06	4.38±0.63	3.82±0.56	0.47±0.02
3	*P. fluorescens* with Vermicompost (1:10)	7.72±0.19	3.90±0.42	3.14±0.37	0.31±0.01
4	*P. fluorescens* with Vermicompost (1:20)	8.28±0.45	3.77±0.37	2.87±0.32	0.28±0.02
5	*S. sannanensis* with Vermicompost (1:10)	7.08±0.41	3.68±0.80	2.88±0.45	0.32±0.02
6	*S. sannanensis* with Vermicompost (1:20)	8.08±0.51	3.63±0.74	2.63±0.62	0.33±0.01
7	*T. harzianum* alone (1:20)	6.47±0.32	3.55±0.61	2.55±0.41	0.28±0.01
8	*P. fluorescens* alone (1:20)	5.64±0.65	2.23±0.54	2.05±0.41	0.21±0.01
9	*S. sannanensis* alone (1:20)	5.77±0.66	2.24±0.53	2.04±0.42	0.22±0.02
10	Copper oxychloride+Contaf fungicides	5.11±0.50	2.08±0.32	3.63±0.67	0.31±0.02
11	Untreated Control	3.23±0.13	1.12±0.20	1.15±0.14	0.10±0.01
SE ±		1.52	0.44	1.45	0.15
CD at P=0.05		2.23	1.32	2.87	1.12

Pn rate - Photosynthetic rate (per mol.min^{-2} m^{-2}); Tr rate - Transpiration rate (mol s^{-2}m^{-2}); WUE - Water use efficiency (Ratio of Pn/Tr rate); SC - Stomatal conductance (mol s^{-2} m^{-2}). Data denotes significantly different and vice versa at $P<0.05$. *Improvements acquired due to various treatments

Table 4: Effect of various Vermi-Derma bioformulations amended with various potential biocontrol agents on biochemical variations in the mother leaves with respect to blister blight disease incidence*

S. No.	Treatment details	Chlorophyll	Carotenoid	Sugars	Nitrogen	Proteins	Amino acids	Polyphenols
1	*T. harzianum* with Vermicompost (1:10)	2.70±0.27	0.55±0.08	5.06±0.15	4.88±0.14	3.24±0.16	0.81±0.03	22.11±3.18
2	*T. harzianum* with Vermicompost (1:20)	2.78±0.29	0.58±0.09	5.13±0.18	4.33±0.21	3.87±0.79	0.88±0.03	23.65±3.46
3	*P. fluorescens* with Vermicompost (1:10)	2.72±0.17	0.48±0.07	4.60±0.17	4.28±0.11	4.87±0.13	0.84±0.02	21.37±4.04
4	*P. fluorescens* with Vermicompost (1:20)	2.73±0.18	0.50±0.05	4.70±0.16	4.28±0.13	4.07±0.13	0.77±0.02	21.94±4.33
5	*S. sannanensis* with Vermicompost (1:10)	2.72±0.17	0.52±0.05	4.27±0.08	4.17±0.11	4.89±0.10	0.72±0.02	21.84±4.62
6	*S. sannanensis* with Vermicompost (1:20)	2.60±0.17	0.41±0.06	4.23±0.09	3.38±0.10	2.87±0.09	0.68±0.02	20.66±0.87
7	*T. harzianum* alone (1:20)	1.83±0.15	0.32±0.04	3.66±0.07	3.25±0.08	2.54±0.07	0.65±0.01	20.82±1.15
8	*P. fluorescens* alone (1:20)	1.64±0.16	0.30±0.03	3.28±0.08	2.13±0.07	2.23±0.08	0.62±0.02	19.43±1.44
9	*S. sannanensis* alone (1:20)	1.69±0.17	0.29±0.03	3.23±0.07	2.13±0.09	2.0340.05	0.64±0.02	19.75±1.44
10	Copper oxychloride+Contaf fungicides	1.58±0.23	0.27±0.07	2.05±0.07	3.55±0.05	2.17±0.06	0.54±0.03	16.47±1.73
11	Untreated Control	0.52±0.01	0.14±0.02	1.80±0.05	1.14±0.04	1.24±0.04	0.28±0.01	12.34±4.91
SE ±		1.06	0.07	1.17	1.22	1.32	1.10	2.05
CD at P=0.05		2.17	0.13	2.53	2.63	2.55	2.24	3.87

Data denotes significantly different and vice versa at $P<0.05$; *Improvements acquired due to various treatments and results were expressed by % by mass

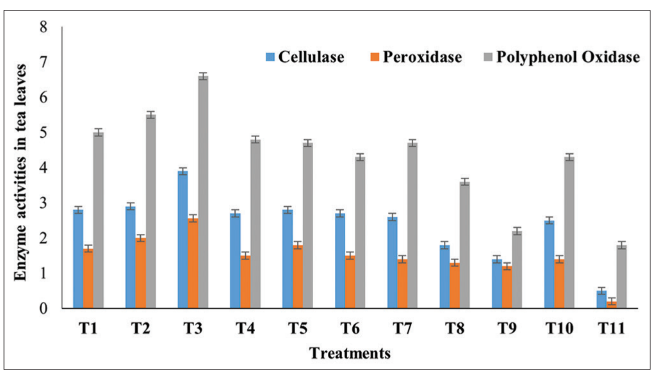


Figure 2: Effect of various biocontrol agents amended with Vermi-Derma bioformulations on enzyme activities of blister blight disease infected tea leaves (Values were mean with standard deviations of triplicates [T1 - *T. harzianum* with Vermicompost (1:10); T2 - *T. harzianum* with Vermicompost (1:20), T3 - *P. fluorescens* with Vermicompost (1:10); T4 - *P. fluorescens* with Vermicompost (1:20); T5 - *S. sannanensis* with Vermicompost (1:10); T6 - *S. sannanensis* with Vermicompost (1:20); T7 - *T. harzianum* alone (1:20), T8 - *P. fluorescens* alone (1:20); T9 - *S. sannanensis* alone (1:20, T10 Copper oxychloride + Contaf fungicides; T11 - Untreated Control]

and plant growth promoting substances like auxins, cytokinins and gibberellins to enhance the plant metabolism.

The results presented in Tables 2 to 4 showed that all the biometric, physiological and biochemical parameters were increased significantly after imposing various treatments. However, all these parameters were highest in treatments where different combinations of Vermi-derma bioformulations were sprayed. Increasing all these parameters might be due to the recovery of plants from *E. vexans* infection and biocontrol treated plants are physiologically more active compared to that of the fungicides treated and untreated control plants. As per the statement of Gnanamangai *et al.* (2017), when the plants are physiologically active, biochemical constituents and enzyme are synthesized in more quantity (Table 4 & Figure 2) which resulted a significant improvement in crop yield (Table 1) and their attributes (Table 2).

Trichoderma bioformulations have proved to be successful in controlling some of the primary as well as secondary root diseases (Borthakur & Dutta, 1992), *Phomopsis* canker (Ponmurugan &

Baby, 2007), grey blight (Sanjay *et al.*, 2008), red rust (Ramya *et al.*, 2013) and bird's eye spot (Gnanamangai *et al.*, 2017) diseases of tea plants. Anusuya and Jayarajan (1998) reported the solubilization of insoluble phosphates into soluble form in the vermicompost formulations amended with *Trichoderma* spp. Since vermicompost formulations had more number of phosphates, *Trichoderma* spp. were solubilized phosphates effectively due to acid and alkaline phosphatase enzymes and secreting phytohormones along with organic acids which in turn were useful to enhance the plant growth (Bagyalakshmi *et al.*, 2017).

CONCLUSION

It is concluded that the control of blister blight disease of tea through Vermi-Derma bioformulations was found to be very effective in reducing the disease severity and also improving the plant growth metabolism simultaneously. The present study might be useful for a considerable foreign exchange through tea powder export based on the quality attributes and free from chemical residues in tea.

AUTHORS' CONTRIBUTIONS

All authors contribute equally to performing the whole work, experimentation, investigation, methodology, analysis and interpretation of results. All authors read and approved of the final manuscript.

ACKNOWLEDGEMENTS

The authors would like to acknowledge National Tea Research Foundation, Kolkata, India for financial support to carry out the study. The authors are much indebted to thank Dr. T. Parimelazhagan, Professor and Head, Department of Botany, Bharathiar University, Coimbatore, Tamil Nadu, India for his critical comments and constant encouragement.

REFERENCES

Anusuya, D., & Jayarajan, R. (1998). Solubilization of phosphorus by *Trichoderma viride*. *Current Science, 74*(5), 464-466.

AOAC. (1990). Estimation of various biochemical parameters. In K. Helrich (Ed.), *Official Methods of Analysis of the Association of Official Analytical Chemists* (15th ed., pp. 1552-1555). AOAC International: Gaithersburg, USA.

Baby, U. I., Balasubramanian, S., Ajay, D., & Premkumar, R. (2004). Effect of ergosterol biosynthesis inhibitors on blister blight disease, the tea plant and the quality of made tea. *Crop Protection, 23*(9), 795-800. https://doi.org/10.1016/j.cropro.2004.01.001

Bagyalakshmi, B., Ponmurugan, P., & Balamurugan, A. (2017). Potassium solubilization, plant growth promoting substances by potassium solubilizing bacteria (KSB) from southern Indian Tea plantation soil. *Biocatalysis and Agricultural Biotechnology, 12*, 116-124. https://doi.org/10.1016/j.bcab.2017.09.011

Balasubramanian, S., Netto, L. A., & Parathiraj, S. (2010). Unique graft combination of tea, Cr-6017/UPASI-9. *Current Science, 98*(11), 1508-1517.

Barman, A., Nath, A., & Thakur, D. (2020). Identification and characterization of fungi associated with blister blight lesions of tea (*Camellia sinensis* L. Kuntze) isolated from Meghalaya, India. *Microbiological Research, 240*, 126561. https://doi.org/10.1016/j.micres.2020.126561

Borthakur, B. K., & Dutta, P. K. (1992). Prospects of biocontrol of tea diseases in North East India. Proceedings of the 31st Tea Conference, Assam, India (pp. 163-168).

Bray, H. C., & Thorpe, W. V. (1954). Analysis of phenolic compounds of interest in metabolism. In D. Glick (Ed.), *Methods of Biochemical Analysis* (Vol. 1, pp. 27-52) New York, US: John Wiley & Sons. https://doi.org/10.1002/9780470110171.ch2

Chandramouli, B. (1992). Plant pathology. *Annual Report of UPASI Scientific Department, 66*, 93-114.

Chenniappan, C., Narayanasamy, M., Daniel, G. M., Ramaraj, G. B., Ponnusamy, P., Sekar, J., & Ramalingam, P. V. (2019). Biocontrol efficiency of native plant growth promoting rhizobacteria against rhizome rot disease of turmeric. *Biological Control, 129*, 55-64. https://doi.org/10.1016/j.biocontrol.2018.07.002

Chet, I. (1987). *Trichoderma* application, mode of action and potential as a biocontrol agent of soilborne plant pathogenic fungi. In I. Chet (Ed.), *Innovative approaches to plant disease control* (pp. 137-160). New York, US: John Wiley & Sons.

Dethoup, T., Klaram, R., Pankaew, T., & Jantasorn, A. (2022). Impact of fungicides and plant extracts on biocontrol agents and side-effects of *Trichoderma* spp. on rice growth. *European Journal of Plant Pathology, 164*, 567-582. https://doi.org/10.1007/s10658-022-02581-z

Do, Q. T. (2025). The endophytic bacterium *Bacillus subtilis* R8 as a prospective biocontrol agent for managing tea blister blight and enhancing tea yield. *Biocontrol, 70*, 379-390. https://doi.org/10.1007/s10526-025-10303-7

Dubois, M., Gills, K. A., Hamilton, J. K., Rebers, P. A., & Smith, F. (1956). Sugar estimation by phenol-sulphuric acid method. *Analytical Chemistry, 26*, 350.

Elad, Y., & Chet, I. (1983). Improved selective medium for isolation of *Trichoderma* or *Fusarium* spp. *Phytoparasitica, 11*, 55-58. https://doi.org/10.1007/BF02980712

Elango, V., Manjukarunambika, K., Ponmurugan, P., & Marimuthu, S. (2015). Evaluation of *Streptomyces* spp. for effective management of *Poria hypolateritia* causing red root-rot disease in tea plants. *Biological Control, 89*, 75-83. https://doi.org/10.1016/j.biocontrol.2015.05.003

Fauziah, F., Setiawati, M. R., Pranoto, E., Susilowati, D. N., & Rachmiati. Y. (2019). Effect of indigenous microbes on growth and blister blight disease of tea plant. *Journal of Plant Protection Research, 59*(4), 529-534. https://doi.org/10.24425/jppr.2019.131264

Gnanamangai, B. M., Ponmurugan, P., Jeeva, S. E., Manjukarunambika, K., Elango, V., Hemalatha, K., Kakati, J. P., Mohanraj, R., & Prathap, S. (2017). Biosynthesised silver and copper nanoformulation as foliar spray to control bird's eye spot disease in tea plantations. *IET Nanobiotechnology, 11*(8), 917-928. https://doi.org/10.1049/iet-nbt.2017.0023

Gomez, K. A., & Gomez, A. A. (1984*). Statistical procedure for agricultural research* (2nd ed.). New York, US: John Wiley & Sons.

Han, Y., Deng, X., Tong, H., & Chen, Y. (2024). Effect of blister blight disease caused by *Exobasidium* on tea quality. *Food Chemistry, 21*, 101077. https://doi.org/10.1016/j.fochx.2023.101077

Harborne, J. B. (1973). Phytochemical Methods: *A guide to modern techniques of plant analysis*. (3rd ed.). UK, London: Chapman and Hall.

Hazarika, S. N., Saikia, K., Borah, A., & Thakur, D. (2021). Prospecting endophytic bacteria endowed with plant growth promoting potential isolated from *Camellia sinensis*. *Frontiers in Microbiology, 12*, 738058. https://doi.org/10.3389/fmicb.2021.738058

Jayarajan, R., Ramakrishnan, G., Diwakaran, D., & Sridhar, R. (1994). *Biotechnology in India* (pp. 25-36). Valparai, Tamil Nadu, India: UPASI Tea Research Institute.

Ji, P., & Wilson, M. (2003). Enhancement of population size of a biological control agent and efficacy in control of bacterial speck of tomato through salicylate and ammonium sulfate amendments. *Applied Environmental Microbiology, 69*(2), 1290-1294. https://doi.org/10.1128/AEM.69.2.1290-1294.2003

Kalim, S., Luthra, Y. P., & Gandhi, S. K. (2000). Influence of Bavistin seed treatment on morphological and biochemical parameters of cow pea roots susceptible to *Rhizoctonia* species. *Journal of Mycology and Plant Pathology, 30*(3), 375-379.

Kuster, E., & Williams, S. T. (1964). Selection of media for isolation of *Streptomyces*. *Nature, 202*, 928-929. https://doi.org/0.1038/202928a0

Lowry, O. H., Rosebrough, N. J., Farr, L., & Randall, R. J. (1951). Protein measurement with the folin phenol reagent. *Journal of Biological Chemistry, 193*(1), 265-275.

Manivel, L., & Hussain, S. (1982). Photosynthesis in tea II: Direction of movement of photosynthates. *Two Bud, 29*, 49-52.

Manjukarunambika, K., Mandal, A. K. A., Balasubramanian, M. G., & Ponnusamy, P. (2023). Multifaceted plant growth-promoting traits of indigenous rhizospheric microbes against *Phomopsis theae*, a causal agent of stem canker in tea plants. *World Journal of Microbiology and Biotechnology, 39*(9), 237-242. https://doi.org/10.1007/s11274-023-03688-z

Moore, S., & Stein, W. H. (1948). Photometric ninhydrin method for use in the chromatography of amino acids. *The Journal of biological chemistry, 176*(1), 367-388. https://doi.org/10.1016/S0021-9258(18)51034-6

Nisha, S. N., Prabu, G., & Mandal, A. K. A. (2018). Biochemical and molecular studies on the resistance mechanisms in tea [*Camellia sinensis* (L.) O. Kuntze] against blister blight disease. *Physiology and Molecular Biology of Plants, 24*, 867-880.

Nithya, M., Ponmurugan, P., Gnanamangai, B. M., Robinson, J. P., Mathivanan, N., & Senthilkumar, J. (2020). Evaluation of different native *Streptomyces* spp. for effective management of rhizome rot of turmeric. *Journal of Applied Botany and Food Quality, 93*, 225-233.

Papavizas, G. C. (1985). *Trichoderma* and *Gliocladium*: biology, ecology and potential for biocontrol. *Annual Review of Phytopathology, 23*, 23-54. https://doi.org/10.1146/annurev.py.23.090185.000323

Ponmurugan, P., & Baby, U. I. (2007). Evaluation of fungicides and biocontrol agents against Phomopsis canker of tea under field condition. *Australasian Journal of Plant Pathology, 36,* 68-72. https://doi.org/10.1071/AP06084

Ponmurugan, P., Gnanamangai, M. B., & Manjukarunambika, K. (2019). Architectural effect of different tea clones on the development of blister blight disease. *Journal of Applied Botany and Food Quality, 92*, 7-14. https://doi.org/10.5073/JABFQ.2019.092.002

Ram, C. S. V., & Mouli, B. C. (1983). Interaction of dosage, spray interval and fungicide action in blister blight disease control in tea. *Crop Protection, 2*(1), 27-36. https://doi.org/10.1016/0261-2194(83)90023-6

Ramya, M., Ponmurugan, P., & Saravanan, D. (2013). Management of *Cephaleuros parasiticus* Karst (Trentepohliales: Trentepohliaceae), an algal pathogen of tea plant, *Camellia sinensis* (L) (O. Kuntze). *Crop Protection, 44*, 68-74. https://doi.org/10.1016/j.cropro.2012.10.023

Sadasivam, S., & Manickam, A. (1996). *Biochemical methods.* (2nd ed.). New Delhi, India: New age international Publishers.

Sanjay, R., Ponmurugan, P., & Baby, U.I. (2008). Evaluation of fungicides and biocontrol agents against grey blight disease of tea in the field. *Crop Protection, 27*(3-5), 689-694. https://doi.org/10.1016/j.cropro.2007.09.014

Sreenivasaprasad, S., & Manibhushanrao, K. (1990). Antagonistic potential of *Gliocladium virens* and *Trichoderma longibrachiatum* to phytopathogenic fungi. *Mycopathologia, 109*, 19-26. https://doi.org/10.1007/BF00437002

Suriyakumar, C. R. (2009). Vermicompost: technology, evaluation and enterprising. In P. Ponmurugan & B. Nithya (Eds.), *Guidelines for Entrepreneurship development programme to Biotechnology graduates* (pp. 31-38) New Delhi, India: Excel India Publishers.

Windham, M. T., Eland, Y., & Baker, R. (1986). A mechanism for increased plant growth induced by *Trichoderma* spp. *Phytopathology, 76*(5), 518-521.