



RESEARCH ARTICLE

Quality deterioration in made tea due to blister blight disease

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Abstract

Tea, a widely consumed beverage around the world, is vulnerable to blister blight disease caused by *Exobasidium vexans* Masee, which results in substantial crop losses and deterioration in quality. This study aimed to evaluate the impact of blister blight infection on tea quality attributes and biochemical constituents in elite tea cultivars from Southern India. Six cultivars (TRF-1, TRF-4, CR-6017, UPASI-20, TTL-2 and UPASI-9) were assessed for changes in yield, productivity and quality parameters under diseased conditions. Blister blight infection significantly reduced green leaf yield, productivity index and major quality constituents, including theaflavins (TF), thearubigins (TR) and caffeine. Total polyphenol and catechin (C) contents were also markedly decreased in infected leaves, with the highest reduction observed in the CR-6017 clone. Among individual catechins, epigallocatechin gallate (EGCG) was predominant but showed a significant decline due to disease infection. The study demonstrates that blister blight disease adversely affects both tea quality and biochemical composition, highlighting the need for effective disease management and resistant cultivar development to sustain tea productivity and quality.

Keywords: biochemical composition; blister blight; catechins; *Exobasidium vexans*; tea quality

Introduction

Tea is one of the most widely consumed beverages in the world, which ranks first in beverages. Three main species are commonly used in tea processing: *Camellia sinensis* (L.) O. Kuntze, *Camellia assamica* (Masters) Wight and *Camellia assamica* subsp. *lasiocalyx* (Planch ex Watt) Wight. These species exhibit variations in morphology, physiology, biochemistry and molecular characteristics, including differences in susceptibility to pests and diseases (1–3). Tea's widespread popularity is attributed to its refreshing taste, mild stimulating effects and various health benefits (4). Global tea production shows a sustained upward trend, with output projected to increase from about 32.8 million tons in 2024 to over 35.3 million tons by 2028, dominated by major producers such as China, India, Kenya and Sri Lanka. Tea is one of the most economically important agricultural commodities worldwide, particularly in Asia and Africa, where it contributes significantly to foreign exchange earnings, employment and rural development. Millions of smallholder farmers and plantation workers depend on tea cultivation and processing as a primary source of livelihood, underscoring its strong socio-economic importance in producing regions. (5, 6). The global tea industry continues to grow, driven by rising consumer demand and increasing awareness of tea's health-promoting properties, such as its antioxidant and anti-inflammatory effects (7). The quality and market value of tea are largely determined by its biochemical composition particularly polyphenols [18–30 % dry weight (DW)], catechins (C) (3–10 % DW in black tea), theaflavins (TF) (2–6 % DW) and thearubigins (TR) (10–20 % DW), which contribute to its flavour, astringency, colour and

antioxidant properties (8). However, tea cultivation is increasingly threatened by both biotic and abiotic stresses, which not only reduce yields but also degrade tea quality.

Among the various diseases affecting tea, several economically important diseases are commonly observed, including foliar diseases such as blister blight, grey blight, brown blight and red rust, as well as stem and root diseases like dieback and root rot, all of which adversely affect tea yield and quality. Among these, foliar diseases are particularly concerning, as they directly impact the harvestable shoots (two leaves and a bud), leading to significant crop losses of up to 43 % (9). Blister blight, caused by the obligate biotrophic fungus *Exobasidium vexans* Masee, belonging to the class Basidiomycetes, is one of the most destructive foliar diseases, particularly in the humid tea-growing regions of Asia (10). This disease primarily affects young, actively growing leaves and shoots, causing chlorotic blisters, necrotic lesions and tissue deformation, which significantly reduce both tea yield and quality (11–13). The severity of blister blight is exacerbated by its rapid spread under favourable climatic conditions, making it a persistent challenge for tea growers. In addition to the physical damage, blister blight significantly alters the biochemical composition of infected leaves, resulting in a reduction in polyphenol and catechin content, which are crucial for tea's briskness, astringency and overall quality.

This study measured the extent of quality degradation in made tea due to blister blight, focusing on the total polyphenol content, catechin composition and overall tea quality in various tea cultivars, which represent the standard biochemical ranges commonly adopted for marketed black tea quality evaluation as

reported by the Tea Board of India and the United Planters' Association of Southern India (UPASI). By highlighting these changes, the research provided valuable insights into the biochemical effects of blister blight infection and its impact on the sustainability of the tea industry. The findings underscored the urgent need for effective disease management strategies to reduce economic losses and ensure consistent production of high-quality tea.

Materials and Methods

Tea leaves, both healthy and those infected with blister blight disease, were collected from the Madupatty tea estate located in Munnar, Kerala, India, at an elevation of 1735 m above sea level. The coordinates for the location are 10° 07.777' N and 077° 08.453' E. Various tea cultivars, including TRF-1, TRF-4, CR-6017, UPASI-20, TTL-2 and UPASI-9, were planted in 1988 with a spacing of 135 × 75 × 75 cm, resulting in a plant population of 13500 per ha. The selected tea clones were managed using standard cultural practices outlined in a previous study (14).

Green leaf yield assessment

Tea shoots, consisting of the top 3 young leaves and a bud, were collected during plucking rounds that took place at 15-day intervals using hand-held shears. The yield and its attributes, including the productivity index, were assessed after each plucking round. The green leaf yield was converted into made tea (kg ha^{-1}) using the formula from a previous experiment (15).

$$\text{Made tea yield (kg ha}^{-1}\text{)} = \text{Green leaf yield (kg ha}^{-1}\text{)} \times 0.22$$

The productivity index in relation to blister blight infection was determined using the formula from a previous study (16).

$$\text{PI} = \text{Yield of the treated plot} / \text{mean yield of the field.}$$

Assessment of blister blight disease

Fifty shoots, each consisting of 3 top leaves and a bud, were collected during the plucking round to assess blister blight incidence (17), the percentage of infection was determined by counting the total number of lesions on the first, second and third leaves and then calculating the average number of lesions for each leaf.

Quality analysis of made teas

Approximately 2.5 kg of both healthy and blister blight-infected tea samples were collected and withered separately at room temperature for 16 hr to reduce the moisture content to 60–65 %. The withered leaves were then processed using crush, tear and curl (CTC) method to produce tea powder (dhoor) after fermentation (oxidation) at 90 % relative humidity, followed by firing at 140–150 °C to achieve a final moisture content of 3 %. Various tea quality parameters, including TR, TF, high polymerised substances (HPS), total liquor colour (TLC), total soluble solids (TSS), crude fibre (CF), flavour index (FI) and dry matter (DM) content, were analysed using standard procedures (17). All experiments were conducted in triplicate and the process was repeated three times (18–20). The estimation of total polyphenols, catechins and caffeine was determined (21–23).

Estimation of free total polyphenol and catechin fractions

The total polyphenolic content in tea was determined using the Folin-Ciocalteu phenol reagent method (24); tea extracts were reacted with Folin-Ciocalteu reagent followed by sodium carbonate (Na_2CO_3) and the resulting blue colour intensity was measured

spectrophotometrically at 765 nm and expressed as gallic acid (GA) equivalents. The total polyphenol content was calculated using a calibration curve prepared with GA. The various catechin fractions in white tea were quantified following the method outlined in ISO 14502-2005 using high performance liquid chromatography (HPLC) (25). The content of individual catechins, including (-) epigallocatechin gallate (EGCG), (-) epigallocatechin (EC), (-) epicatechin gallate (ECG), (-) epicatechin (EC) and (+) catechin hydrate (22).

Statistical analysis

All the data were statistically evaluated using one way analysis of variance (ANOVA) and critical difference at various levels of significance (SPSS 14.0 statistical package, Inc. Chicago, IL).

Results

The results of present study showed that blister blight infection was the highest with UPASI-20 (44.5 ± 1.7 %) followed by UPASI-9 (42.7 ± 1.5 %) tea cultivars and it was found to be least with CR-6017 (32.7 ± 1.5 %). The green leaf yield was higher with TRF-4 clone which accounted 4255 ± 32.8 kg ha^{-1} made tea followed by TRF-1 (4078 ± 25.7 kg ha^{-1} made tea) cultivars. These results were reflected with productivity index which recorded 2.85 ± 0.5 % and 2.34 ± 0.7 % respectively (Table 1). Due to blister blight infection, green leaf yield and productivity index were significantly reduced. The heavily affected blister blight infected tea bushes showed the symptoms of defoliating with chlorosis and heavy flowering (Fig. 1).

Both total polyphenol and catechin contents were higher in the healthy shoots of CR-6017 followed by TTL-2 and UPASI-9 tea clones (Fig. 2). The results indicated that total polyphenols content recorded in these tea clones were 17.4, 16.62 and 16.06 % respectively. Similar to that of total polyphenols content, total catechin registered were 27.58, 26.48 and 26.21 %. Both these two contents were reduced significantly in tea shoots infected with blister blight disease. The CR-6017 clone exhibited the highest reduction in total polyphenol and catechin contents, with decreases of 12.55 and 20.36 %, respectively. In contrast, the TRF-1 clone showed the lowest reductions in these two contents, with decreases of 12.2 and 18.88 %, respectively (Fig. 2).

The results revealed that the quality of made tea produced from blister blight-infected shoots, particularly in terms of TF, TR and caffeine content, showed a significant decrease. Among the tested tea cultivars, the TTL-2 clone exhibited a notable reduction in TF, TR and caffeine levels, with decreases of 1.29, 6.04 and 1.38 %, respectively (Table 2). Other quality parameters, such as HPS, TSS, TLC, FI and water-soluble solids, were also significantly reduced in blister blight-infected tea leaves. The extent of these reductions varied across the diseased tea leaves from the elite cultivars.

Table 1. Blister blight disease incidence and green leaf yield potential in different tea cultivars of Southern India

Tea cultivars	Blister blight infection (%)	Green leaf yield (kg ha^{-1} made tea)	Productivity index (%)
TRF-1	35.5 ± 1.6	4078 ± 25.7	2.34 ± 0.7
TRF-4	38.7 ± 1.8	4255 ± 32.8	2.85 ± 0.5
CR-6017	32.7 ± 1.5	3567 ± 26.6	1.55 ± 0.5
UPASI-20	44.5 ± 1.7	3289 ± 23.5	1.17 ± 0.6
TTL-2	40.3 ± 1.5	3831 ± 26.7	2.02 ± 0.7
UPASI-9	42.7 ± 1.5	3254 ± 27.4	1.05 ± 0.4
SEm ($\pm$)	1.12	47.56	0.11
CD at $p = 0.05$	3.45	123.72	0.47



Fig. 1. Blister blight-induced morphological and physiological symptoms in tea plants. A: typical disease lesions; B: mild chlorosis with defoliation; C: excessive flowering under disease stress.

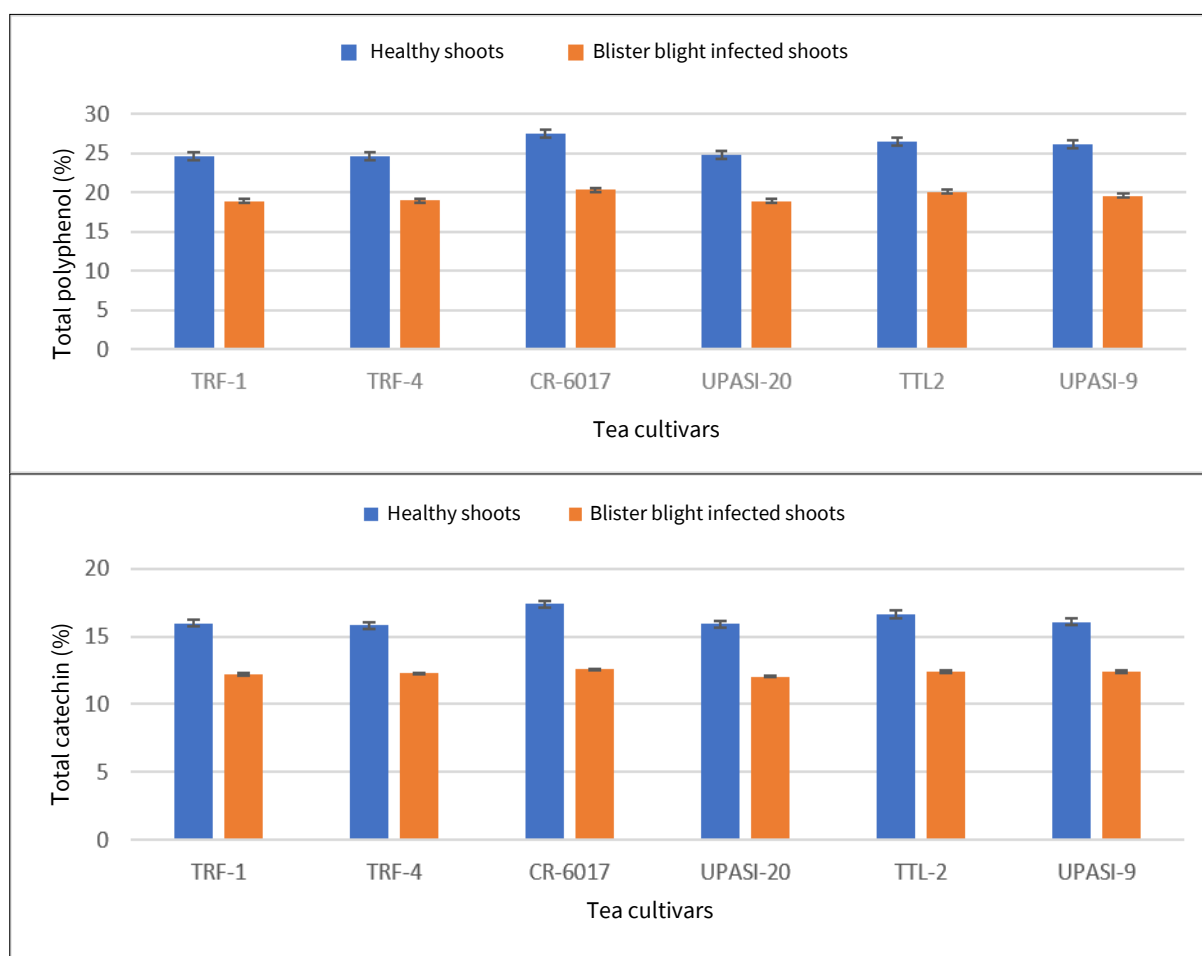


Fig. 2. Estimation of total polyphenols and catechins between healthy and blister blight-infected tea shoots of different tea cultivars.

The different catechins present in the made tea from various cultivars are shown in Table 3. Among the catechins, EGCG was identified as the dominant catechin in made tea, followed by ECG, EGC, C and EC fractions. The study revealed that the CR-6017 clone had the highest total catechins content (19.01 %), followed by TTL-2 (18.69 %), UPASI-9 (17.93 %), UPASI-20 (14.74 %) and TRI-2043 (12.55 %). The individual catechins varied significantly across the tea cultivars, with EGCG, ECG and EGC showing the highest levels, while catechin hydrate and EC were less abundant. The EGCG content was highest in the TTL-2 clone (12.7 %), followed by UPASI-9 (11.65 %), CR-6017 (11.41 %), UPASI-20 (9.28 %) and TRI-2043 (7.56 %). The TRI-2043 clone had the lowest EGCG content and the black tea produced by conventional methods showed only 6.36 %.

Discussion

Polyphenols and catechins are essential components of secondary metabolism in plants, playing a key role in their defence mechanisms. These compounds are produced in response to various stress factors such as pathogens, herbivores and environmental stressors (26, 27). The present study clearly demonstrated that blister blight infection significantly influences the biochemical quality of tea shoots, particularly total polyphenol and catechin contents. Healthy shoots of CR-6017, TTL-2 and UPASI-9 clones recorded comparatively higher levels of total polyphenols and catechins, indicating their superior biochemical potential and suitability for quality tea production. The observed reduction in both polyphenol and catechin contents in blister blight-infected shoots may be attributed to pathogen-induced metabolic alterations, including enhanced

Table 2. Effect of blister blight disease of different tea cultivars on the quality of processed tea (%)

Constituents	Different tea cultivars infected with blister blight disease												SEm (±)	CD at <i>p</i> = 0.05
	TRF-1		TRF-4		CR-6017		UPASI-20		TTL-2		UPASI-9			
	H	I	H	I	H	I	H	I	H	I	H	I		
Theaflavin	1.88	1.35	1.80	1.42	1.70	1.36	1.65	1.39	1.81	1.29	1.67	1.34	0.03	0.13
Thearubigin	9.17	6.55	9.00	6.57	8.12	6.42	9.00	6.33	9.23	6.04	8.31	6.57	0.13	1.03
Caffeine	4.89	2.17	4.95	1.88	4.90	1.67	4.95	1.57	4.07	1.38	4.63	1.74	0.53	1.89
Highly polymerised substances	7.24	9.27	7.27	9.87	6.89	9.21	7.45	9.00	7.34	9.43	6.37	9.23	0.34	1.22
Total soluble solids	38.24	33.05	38.89	32.00	37.94	31.14	38.92	32.41	39.09	32.23	39.20	33.07	0.21	1.27
Total liquor colour	4.97	4.08	4.88	3.88	4.57	3.14	4.66	3.44	4.64	3.87	4.61	3.17	0.06	0.49
Flavour Index	1.93	0.67	1.89	0.50	1.79	0.62	1.79	0.55	1.78	0.55	1.57	0.60	0.03	0.17
Water soluble solids	44.65	40.89	45.15	39.58	44.00	39.00	43.65	38.45	45.23	38.23	41.61	39.85	1.20	3.22

Table 3. Estimation of total catechin fractions between healthy and blister blight infected tea shoots of different tea cultivars

Clones used	Tea cultivars											
	TRF-1		TRF-4		CR-6017		UPASI-20		TTL-2		UPASI-9	
	H	I	H	I	H	I	H	I	H	I	H	I
Gallic acid	1.02	0.75	0.92	0.64	1.09	0.79	0.81	0.59	0.98	0.69	0.66	0.49
(-) Epigallocatechin	1.85	1.41	1.54	1.11	1.73	1.25	1.64	1.01	1.99	1.49	1.58	0.92
(+) Catechin hydrate	0.44	0.35	0.84	0.71	0.99	0.82	1.04	0.61	1.15	0.86	1.06	0.52
(-) Epicatechin	0.35	0.29	0.77	0.53	1.21	0.73	0.54	0.41	1.12	0.84	0.87	0.65
(-) Epigallocatechin gallate	7.12	5.12	6.56	4.98	7.85	5.39	6.41	4.81	7.06	5.29	5.89	4.82
(-) Epicatechin gallate	1.52	1.14	1.79	1.18	1.84	1.38	1.06	0.79	1.59	1.19	1.49	1.12
Total Catechins	11.28	8.31	11.50	8.51	13.62	9.57	10.69	7.63	12.91	9.68	10.89	8.03

oxidative stress and the diversion of phenolic compounds towards plant defence responses. The pronounced reduction in CR-6017 suggests a higher sensitivity of this clone to blister blight-mediated biochemical degradation, despite its inherently high phenolic content under healthy conditions (28). In contrast, the relatively lower reduction observed in TRF-1 indicates a greater tolerance to blister blight infection, possibly due to more efficient antioxidant defence mechanisms or reduced pathogen colonisation. Since polyphenols and catechins are key determinants of tea quality, contributing to briskness, astringency and antioxidant capacity, their significant depletion in infected shoots is likely to adversely affect the quality and market value of made tea (29–31).

Black tea, made from young healthy shoots containing 3 leaves and a bud, shows high levels of EGCG and ECG fractions (Table 3). However, these contents are significantly reduced in shoots infected with blister blight disease. This finding is consistent with a previous study (32). The present results corroborate with a previous study (33), reported that foliar diseases significantly reduce biochemical constituents critical for black tea quality. In this study, made tea from blister blight-infected shoots showed a significant decline in TF, TR and caffeine contents, with the TTL-2 clone exhibiting pronounced reductions of 1.29 %, 6.04 % and 1.38 %, respectively. Other quality attributes, including HPS, TSS, TLC, FI and water-soluble solids, were also significantly reduced in infected samples. These reductions can be attributed to disease-induced disruption of phenolic and flavonoid metabolism in harvestable shoots, thereby limiting precursor availability for the formation of key quality compounds during processing.

The reduction in quality components observed in elite tea cultivars may be due to the severity of the disease caused by the *E. vexans* pathogen in the leaves (34). These findings contrast with the quality estimation of made tea from crop shoots treated with ergosterol biosynthesis inhibitors (EBIs). The variations in tea quality attributes among the elite cultivars could be attributed to the inherent characteristics and genetic makeup of each cultivar.

Conclusion

The study offers valuable insights into the total polyphenolic content, total catechins and individual catechin fractions in tea produced from select elite cultivars of Southern India affected by blister blight disease. Tea quality parameters such as theaflavin (TF), thearubigin (TR) and caffeine demonstrated a significant decrease in the leaves impacted by blister blight, with variations observed among different tea clones. The decline in quality can be attributed not only to the inherent traits and genetic makeup of the tea cultivars but also to alterations in plant metabolism and the tea ecosystem. These biochemical changes have direct economic implications, as reductions in polyphenols, catechins, TF and TR lower the market value of made tea, affecting both tea prices in the commercial market and the profitability of tea production.

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Authors' contributions

PS carried out the biochemical and physiological analyses, participated in data interpretation and drafted the manuscript. KM participated in the biochemical assays, data compilation and sequence alignment. PP conceived the study, participated in its design and coordination and critically revised the manuscript. SM performed statistical analyses and contributed to manuscript editing. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

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