ISSN: 0253-5483

TEA JOURNAL OF BANGLADESH

Volume 51, 2025

BANGLADESH TEA RESEARCH INSTITUTE
SRIMANGAL-3210, MOULVIBAZAR
An organ of
BANGLADESH TEA BOARD
171-172, Baizid Bostami Road
Nasirabad, Chattogram
www.btri.gov.bd

Published by
Bangladesh Tea Research Institute
Srimangal-3210, Moulvibazar
Bangladesh

Published on
21th May 2025 (5th National Tea Day)

Compiled by
Riyadh Arefin, Scientific Officer (Botany), BTRI

Printed by
Obri Printing Artisan
Station Road, Srimangal, Moulvibazar

Rate of subscription
Taka 300.00 per copy (Inland)
US $ 15.00 per copy (Abroad)

A copy of the journal is sent to the planters and managers of all the tea estates in Bangladesh free

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TEA JOURNAL OF BANGLADESH

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Preface

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It is with great pleasure that we present The Tea Journal of Bangladesh (Volume 51), a dedicated platform for advancing research and innovation in the tea industry. This journal serves as a bridge for knowledge exchange among scientists, tea technologists, and industry stakeholders.

This volume features six original research articles and one review, each addressing key challenges and opportunities within the tea sector. Topics include drought tolerance in tea genotypes, the impact of mechanization on pruning practices, and sustainable soil management through vermicompost and organic composite manure. Further studies explore standardized organoleptic grading for green tea, optimal media for seed germination, and the potential integration of solar power into tea estates.

Despite our earnest efforts to ensure accuracy and clarity, we acknowledge that this journal may contain inadvertent mistakes. We respectfully seek the understanding of our esteemed readers for any such oversights and warmly welcome constructive feedback to guide improvements in future editions.

We extend our heartfelt gratitude to the authors, peer reviewers, editorial board members, and contributors whose dedication and expertise have made this volume possible. We hope the insights presented herein will inspire continued research, collaboration, and innovation for the betterment of the tea industry in Bangladesh and beyond.

Maj. Gen. Sheikh Md. Sarwar Hossain, SUP, ndc, psc
Chief Advisor
Tea Journal of Bangladesh

Editorial

The 51th volume of Tea Journal of Bangladesh contains six research papers and one review articles.

The first study offers crucial insights into drought resilience among six tea genotypes in Bangladesh by evaluating 14 morpho-physiological and biochemical traits under water-deficit conditions. The findings highlighted that, B/8/93 as the most drought-tolerant genotype, followed by BT2, using a clustering heatmap to rank overall performance. By identifying key physiological markers such as chlorophyll stability, proline content, and water use efficiency, the research has provided a practical framework for breeding drought-resilient cultivars. These results served as a valuable guide for climate-adaptive tea cultivation and future breeding programs in the region.

The second study presents a timely and comprehensive analysis of how mechanization can transform pruning practices in Bangladesh's tea industry. The research compares manual and mechanized pruning across four major pruning types. The findings highlight that mechanized pruning significantly reduces labour time and enhances efficiency without adversely affecting yield. While economic returns were most favorable for mechanized pruning in labour-intensive operations like Light Prune (LP) and Deep Skiff (DSK), manual pruning remained cost-effective for lighter skiffing methods. The recommendations of this study provide clear guidance for enhancing both the sustainability and profitability of tea cultivation.

The third study evaluates the impact of vermicompost application on tea yield *(Camellia sinensis* L.) with the aim of reducing reliance on inorganic fertilizers. The findings reveal that the application of 6 t/ha of vermicompost combined with 60% of the BTRI-recommended chemical fertilizer dose produced the highest yield of made tea. However, from an economic standpoint, the most profitable treatment was the application of 3 t/ha of vermicompost with 80% of the recommended chemical fertilizer dose, owing to its high gross margin and comparatively lower input costs. This research contributes meaningfully to the promotion of sustainable tea cultivation practices by demonstrating how integrating organic amendments with reduced chemical inputs can enhance both productivity and profitability.

The fourth one addresses a vital gap in the growing green tea sector in Bangladesh by introducing a standardized organoleptic grading system based on dry leaf appearance, infused leaf appearance, and liquor characteristics. By establishing a standard sensory benchmark, the proposed system will minimize the errors in quality assessment and promote consistency across tea sector. This structured approach will also enhance transparency and communication among stakeholders, strengthening both domestic credibility and international market competitiveness. Its adoption will make a significant step toward elevating quality assurance and professionalizing green tea tasting practices in Bangladesh.

The fifth study evaluated the impact of a newly developed organic resource-based composite manure, applied through broadcasting methods, on tea yield and soil health, as well as also reducing dependence on inorganic fertilizers. Now a days, the application of organic fertilizer on tea plantation is very important approach to improve not only production but also reduce pollution from excessive chemical fertilizer application. For this reason, making of comparatively cheap and good quality organic manure is the only solution for balanced fertilization. This manure not only improves soil physiochemical properties but also increases soil microbial activity which ultimately effects on soil health. Therefore, it can be concluded that, the most effective dose of composite manure is 1.5 t/ha which can reduce 40% of the use of chemical fertilizers.

The sixth study sheds light on the critical role of germination media in tea seed propagation, revealing that sand and sawdust significantly enhanced seed germination due to their favorable aeration and moisture retention. While early seedling growth did not vary significantly across media, the marked difference in germination rates underscores the importance of selecting appropriate media. The poor performance of polythene sheets highlighted the risks of media that impair gas exchange. These findings offer practical guidance for optimizing tea nursery practices and improving plantation success in Bangladesh.

The last one is a review article, which underscores the pressing need and vast potential for integrating solar power into the country's tea sector. Highlighting Bangladesh's favorable solar radiation, energy challenges, and global examples, the paper makes a compelling case for transitioning away from fossil fuels. It examines the feasibility, benefits, and economic prospects of solar installations in tea estates—particularly in remote regions facing power shortages. Importantly, it aligns solar adoption with national sustainability goals and global climate commitments. The review offers timely insights for policymakers, industry leaders, and researchers aiming to build a greener, more resilient tea industry.

(Dr. Md. Ismail Hossain)
Chief Editor
Tea Journal of Bangladesh

Tea J. Bangladesh 51, 1-15, 2025
https://doi.org/10.5281/zenodo.15684472
ISSN 0253-5483
Available online at http://www.btri.gov.bd

ASSESSMENT OF DROUGHT TOLERANCE ABILITY OF SIX TEA GENOTYPES IN RESPECT OF BANGLADESH

Md. Ismail Hossain[1*], Md. Ashrafuzzaman[2], Md Alamgir Hossain[2], A.K.M. Golam Sarwar[2], Md. Sabibul Haque[2], Md. Abdul Aziz[3], Md. Riyadh Arefin[4]

Abstract

Drought stress significantly limits the growth, physiology, and yield of tea (*Camellia sinensis*), creating the necessity of the identification of drought-tolerant genotypes for sustainable cultivation in Bangladesh. This study evaluated the drought performance of six tea genotypes *i.e.* BT2, BT4, BT10, BT21, BT23 and B/8/93 based on 14 morpho-physiological and biochemical traits to assess their tolerance levels under water-deficit conditions (Maintaining 18% soil moisture content-T_1) with control condition (T_0). Traits analyzed included plant height (PH), base diameter (BD), vertical root length (VRL), root dry weight (RDW), shoot dry weight (SDW), total dry weight (TDW), chlorophyll stability index (CSI), proline content (PRL), relative water content (RWC), stomatal conductance (*gs*), rate of photosynthesis (*A*), transpiration rate (*E*), water use efficiency (WUE) and green leaf per plant (GL) after 30, 60, 90, 120, 150 and 180 days of drought imposition. All the traits significantly affected the growth and development of tea under drought condition. A clustering heatmap based on trait performances grouped the genotypes by tolerance levels, allowing for a ranked sequence from most to least tolerant: B/8/93 > BT2 > BT21 > BT23 > BT4 > BT10. The integration of multiple traits provided a reliable framework for evaluating drought responses and identified key physiological markers for future selection. These findings offer valuable insights for tea breeding programs aimed at developing drought-resilient cultivars to ensure productivity under changing climatic conditions.

Keywords: Tea, Drought, Genotypes, Morphological, Biochemical Traits, Heatmap

[1]Director (in-charge), Bangladesh Tea Research Institute, Srimangal-3210, Moulvibazar
[2]Professor, Department of Crop Botany, Bangladesh Agricultural University, Mymensingh-2202
[3]Chief Scientific Officer (Botany Division), Bangladesh Tea Research Institute, Srimangal-3210, Moulvibazar
[4]Scientific Officer (Botany Division), Bangladesh Tea Research Institute, Srimangal-3210, Moulvibazar

*Corresponding author's email: directorbtri@gmail.com (Md. Ismail Hossain)

Introduction

Tea (*Camellia sinensis* (L.) O. Kuntze) is one of the most widely consumed beverages in the world, with significant economic, cultural, and social importance (Hossain et al., 2012). Bangladesh is a notable tea-producing country, ranking among the top ten global producers, with tea cultivation playing a crucial role in its agricultural economy (Islam, 2024). The tea industry in Bangladesh contributes substantially to employment, export earnings, and rural livelihoods, with the majority of production concentrated in the northeastern regions, particularly Sylhet, Moulvibazar, Habiganj, Chittagong and Northern region (Arefin et al., 2024).

However, tea production in Bangladesh faces numerous challenges, including climate change-induced abiotic stresses, among which drought is one of the most detrimental (Islam et al., 2021). Drought stress affects tea (Langaroudi et al., 2023) and other plants (Baroi et al., 2024) at multiple physiological and biochemical levels, disrupting water balance, reducing photosynthetic efficiency, inducing oxidative stress, and impairing growth and development. The consequences are often reflected in reduced shoot biomass, leaf yield, and quality parameters such as polyphenol and caffeine content in tea (Li et al., 2024). Given the increasing frequency and intensity of drought events due to climate variability, identifying drought-tolerant tea genotypes is critical for sustaining tea production in Bangladesh.

Several physiological and biochemical markers have been used to assess drought stress responses in tea (Samarina et al., 2020) and other crops (Mohi-Ud-Din et al., 2022). These include relative water content, photosynthesis, stomatal conductance, chlorophyll stability index, proline accumulation, root-shoot dry matter, etc (Hossain, 2019). Studies have shown that genotypic variation exists in the ability of tea plants to adapt to drought through mechanisms such as osmotic adjustment, enhanced root development, and increased antioxidative capacity (Zhou et al., 2024). The identification of such traits in drought-tolerant genotypes can aid in the selection and breeding of resilient cultivars. In Bangladesh, limited research has been conducted to comprehensively evaluate the drought performance of tea genotypes using such parameters, creating a knowledge gap that this study seeks to address.

This research aims to evaluate the drought performance of six selected tea genotypes such as BT2, BT4, BT10, BT21, BT23 and B/8/93, among which some are commonly cultivated (BT2, BT4, BT10, BT21, BT23) and one is under consideration for commercial release (B/8/93) in Bangladesh. These genotypes exhibit distinct morphological, physiological, and yield characteristics under normal conditions. However, their comparative performance under drought stress remains largely unexplored. The present study seeks to fill this gap by subjecting the genotypes to controlled drought conditions and assessing their responses across a range of physiological, biochemical, and agronomic parameters. The ultimate objective is to identify genotypes that demonstrate superior drought tolerance and are thus suitable for cultivation in drought-prone areas of Bangladesh.

Materials and Methods

The experiment was conducted in BTRI experimental farm from 2022-2023. A total of six tea genotypes BT2, BT4, BT10, BT21, BT23 and B/8/93 were used to evaluate the drought performance. Two treatments viz. T_0 (well irrigated control condition) and T_1 (Maintaining 18% soil moisture content) were used for assessing drought tolerance both at nursery condition (uniform sapling of 18 months old) by creating 'Rainout Shelter'.

Data Collection Parameters

The following 14 parameters regarding morphological, physiological and water relation traits were collected for drought assessment at nursery condition after 30, 60, 90, 120, 150 and 180 days of drought imposition:

Morphological traits

i. Plant height (PH): PH was measured from soil surface to shoot apex in centimeter (cm) scale.
ii. Base diameter (BD): BD was measured at one centimeter above soil in centimeter (cm) scale.
iii. Vertical root length (VRL): VRLs were measured in centimeter (cm) scale.
iv. Shoot dry weight (SDW): SDW (g) was measured after oven drying of shoot at 80 ± 2°C for 72 hours.
v. Root dry weight (RDW): RDW (g) was measured after oven drying of root at 80 ± 2°C for 72 hours.
vi. Total dry weight (TDW): TDW (g) was calculated by the addition of the SDW and RDW.

Physiological and water relation traits

i. Chlorophyll Stability Index (CSI): CSI (expressed as %) was calculated by the method described by Kaloyereas (1958).
ii. Proline content (PRL): PRL of leaves (μmol/g FW) was calculated by the method developed by Bates et al. (1973).
iii. Relative Water Content (RWC): RWC (expressed as %) was determined following the method of Barrs & Weatherley (1962).
iv. Stomatal conductance (*gs*): *gs* (mmol m^{-2} s^{-1}) was measured by using a portable gas analyzer (LCi-SD Photosynthetic system, ADC Bio Scientific Ltd., Hertfordshire, UK) (Figure Appendix 1).
v. Rate of photosynthesis (*A*): *A* (μmol CO_2 m^{-2} s^{-1}) was measured by using a portable gas analyzer (LCi-SD Photosynthetic system, ADC Bio Scientific Ltd., Hertfordshire, UK) (Figure Appendix 1).
vi. Transpiration rate (*E*): *E* (mol H_2O m^{-2} s^{-1}) was measured by using a portable gas analyzer (LCi-SD Photosynthetic system, ADC Bio Scientific Ltd., Hertfordshire, UK) (Figure Appendix 1).
vii. Water use efficiency (WUE): WUE was calculated in μmol/m mol by the formula of (de Almeida Lobo et al., 2023).
viii. Green Leaf Per Plant (GL): Shoots were collected and weighted in weight scale (g).

Data on 14 parameters were statistically analyzed to find out the statistical significance by Microsoft Excel 2019. The two-way clustering heatmap was performed by OriginPro 2024 software and graphs of 'percent (%) change of parameters in drought condition against control condition' were created by Microsoft Excel 2019.

Results and Discussions:

Morphological traits

The percent change in morphological parameters in drought condition (T_1) over control condition (T_0) of each genotype after 30, 60, 90, 120, 150 and 180 days of drought imposition were presented in Figure 1-6. It was found that, at drought stresses all the genotypes decrease their performances of morphological traits after 30, 60, 90, 120, 150 and 180 days of drought imposition (Figure 1-6). In water deficit condition, less reduction in morphological traits was observed in B/8/93 while BT10 was the most vulnerable to drought (Table A1 and Figure 1-6). 16.02%, 5.11%, 5.06%, 5.59%, 6.17%, 5.62% average reduction (average of % reduction of 30, 60, 90, 120, 150 and 180 days after drought imposition) in B/8/93 and 18.95%, 5.53%, 6.8%, 7.17, 7.57%, 7.25% average reduction in BT10 were observed in case of plant height (PH), base diameter (BD), vertical root length (VRL), root dry weight (RDW), shoot dry weight (SDW) and total dry weight (TDW) parameters compared to control condition respectively (Table A1).

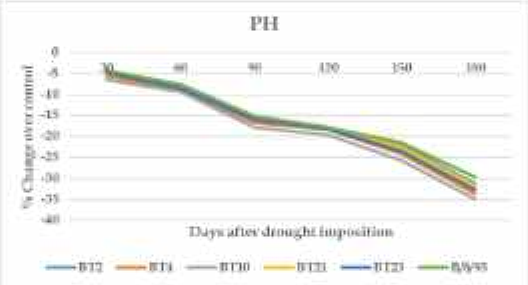

Figure 1. % change of plant height (PH) in drought condition over control

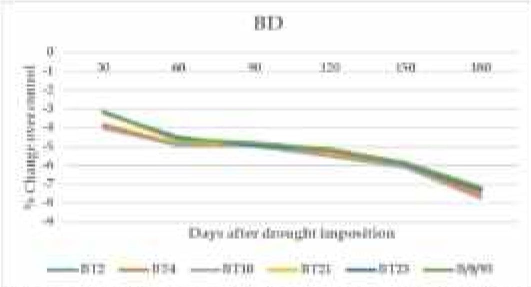

Figure 2. % change of base diameter (BD) in drought over control

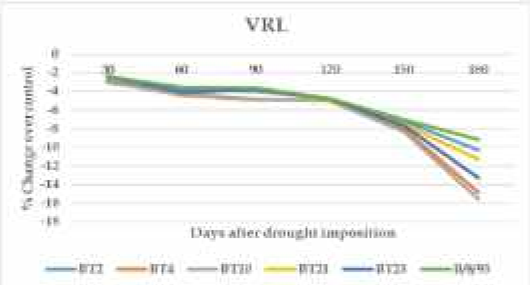

Figure 3. % change of vertical root length (VRL) in drought condition over control

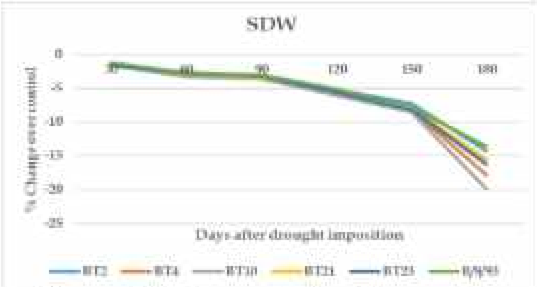

Figure 4. % change of shoot dry weight (SDW) in drought condition over control

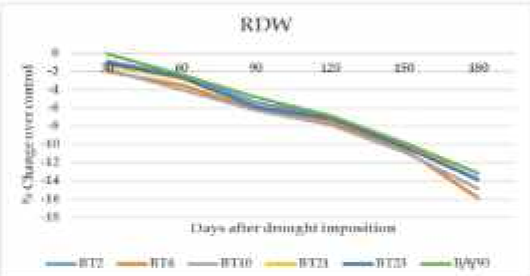

Figure 5. % change of root dry weight (RDW) in drought condition over control

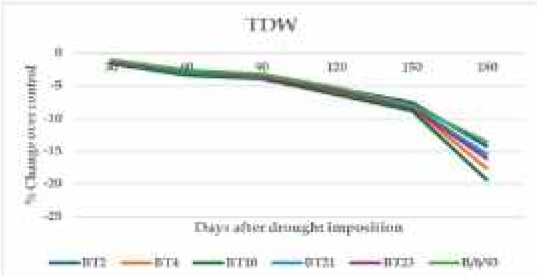

Figure 6. % change of total dry weight (TDW) in drought condition over control

Plant height is a commonly measured parameter in growth studies, serving as a general indicator of vigor. However, under drought conditions, a reduction in plant height is frequently observed (Yang et al., 2021). This is due to reduced cell elongation and division caused by water deficit. The inhibition of gibberellin biosynthesis, a hormone involved in stem elongation, under drought stress also contributes to stunted growth (Colebrook et al., 2013). Under drought conditions, base diameter tends to decline but generally less severely than plant height (Sumida et al., 2013). Vertical root length is one of the most critical traits for drought resistance in tea. Deep-rooted genotypes can access water from deeper soil layers, making them more resilient under prolonged dry conditions (Odone et al., 2023).

Increased vertical root growth is a direct adaptive response to surface-level moisture deficit. Vertical root length is also positively correlated with root dry weight and total dry weight (Carvalho & Foulkes, 2018). Genotypes with longer roots tend to accumulate more root biomass, contributing to overall plant dry matter despite a decline in shoot mass. Under drought conditions, many plants, including tea, increase their root-to-shoot ratio as a survival strategy. An increase in root dry weight under stress conditions suggests that the plant is prioritizing root development to enhance water and nutrient uptake (Lopez et al., 2023). However, drought stress typically reduces TDW due to inhibited photosynthesis, reduced leaf area, and lower water uptake.

Physiological and water relation traits

Under drought conditions, tea exhibits a complex interplay of physiological and biochemical traits that determine its capacity to withstand water deficit. Among these, Chlorophyll Stability Index (CSI), proline content (PRL), relative water content (RWC), stomatal conductance (*gs*), rate of photosynthesis (*A*), transpiration rate (*E*), water use efficiency (WUE), and green leaf per plant (GL) are critical indicators of drought tolerance and plant productivity. The performance of these traits in control (T_0) and drought condition (T_1) were given in Table A1, while the % increase or reduction of traits in drought condition (T_1) than the control situation (T_0) were given in Table A1 and Figure 7-14.

Here also, highest average reduction (average of % reduction of 30, 60, 90, 120, 150 and 180 days after drought imposition) of 8.75%, 7.75%, 10.51%, 25.75%, 21.78%, 6.54% and 18.47% were noticed in BT10, while lesser average decrease of 6.82%, 6.26%, 7.96%, 21.11%, 16.48%, 5.26% and 15.14 were found in B/8/93 in case of CSI, RWC, *gs*, *A*, *E*, WUE, and GL parameters (Table A1). Maximum average proline accumulation percentage was noticed in B/8/93 (8.52%) while minimum in BT10 (6.70%) (Table A1).

CSI reflects the integrity of the photosynthetic apparatus under stress, with higher CSI values indicating better membrane stability and chlorophyll retention; this is closely related to higher photosynthetic efficiency (A) and ultimately greater GL yield under drought (Sameena & Puthur, 2021; Wang et al., 2018). PRL, an osmoprotectant that accumulates in response to stress, helps maintain cellular osmotic balance, protect proteins and membranes, and stabilize subcellular structures; thus, increased PRL is generally associated with higher drought tolerance in tea (Deng et al., 2025). PRL often shows a negative correlation with RWC, as it tends to accumulate more when leaf water content drops, though both play essential and different roles in stress mitigation (Patanè et al., 2022).

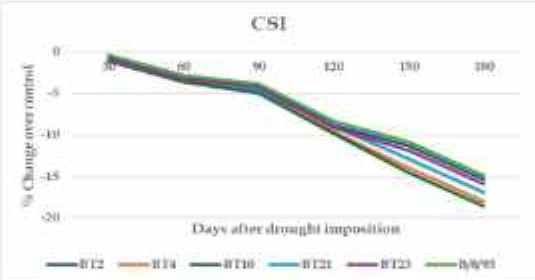

Figure 7. % change of chlorophyll stability index (CSI) in drought condition over control

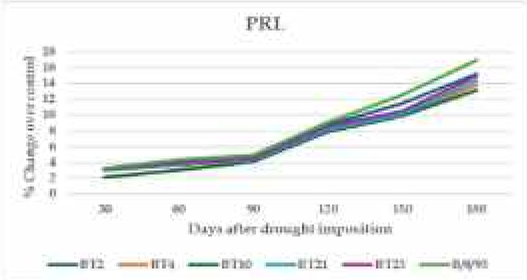

Figure 8. % change of proline content (PRL) in drought condition over control

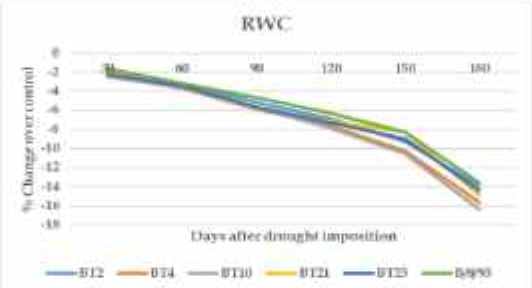

Figure 9. % change of relative water content (RWC) in drought condition over control

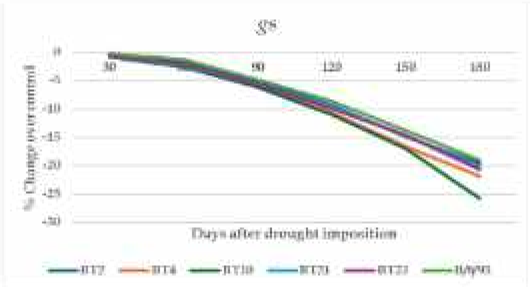

Figure 10. % change of stomatal conductance (*gs*) in drought condition over control

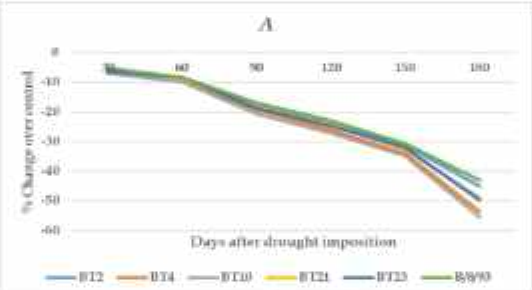

Figure 11. % change of rate of photosynthesis (*A*) in drought condition over control

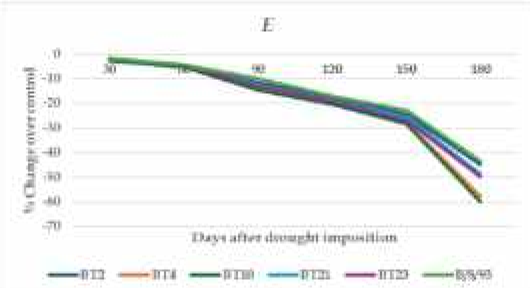

Figure 12. % change of transpiration rate (*E*) in drought condition over control

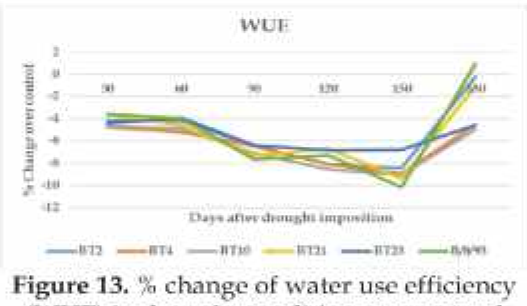

Figure 13. % change of water use efficiency (WUE) in drought condition over control

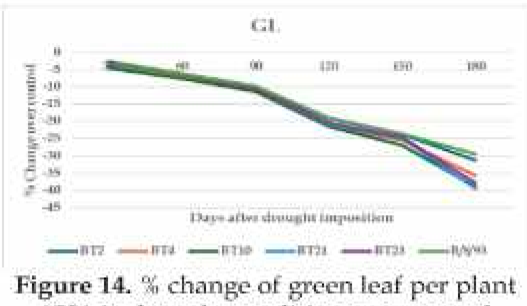

Figure 14. % change of green leaf per plant (GL) in drought condition over control

RWC, an indicator of plant water status, typically declines under drought but remains relatively high in tolerant genotypes; it has a positive relationship with *gs* and *A* because adequate water content is necessary for stomatal opening and CO_2 diffusion into leaves (Arab et al., 2023). However, under prolonged drought, plants often reduce *gs* to minimize water loss, which limits both *E* and *A*, leading to a physiological trade-off. While a lower *gs* reduces *E*, it also constrains photosynthesis unless compensated by mechanisms such as enhanced mesophyll conductance or biochemical resilience (reflected in high CSI) (Abinaya et al., 2025). WUE, defined as the ratio of *A* to *E*, becomes a key adaptive trait under drought; genotypes with higher WUE are able to assimilate more carbon per unit water lost, a desirable trait for drought resistance (Hatfield & Dold, 2019). High WUE is often seen in plants that maintain moderate *A* while keeping *E* low through stomatal regulation and osmotic adjustment (often aided by proline accumulation). Furthermore, green leaf number per plant (GL), a direct yield component in tea, is ultimately influenced by the interaction of all the above traits; plants that maintain high CSI, adequate RWC, and PRL accumulation, while optimizing *gs* and *E* to sustain A and improve WUE, tend to retain more functional leaves and produce higher GL yields under drought (Langaroudi et al., 2023). In summary, these traits are intricately linked: higher CSI and PRL contribute to cellular protection and metabolic stability; RWC and *gs* regulate the physiological water and gas exchange balance; *A* and *E* govern carbon gain and water loss; WUE reflects the efficiency of resource use; and all these parameters collectively influence green leaf production, making their interrelationship central to evaluating drought performance in tea.

Drought tolerance of genotypes

A two-way clustering heatmap with dendrogram provided visualizes the relative performance of six tea genotypes under drought stress across 14 critical morphological, physiological, and biochemical traits. Each trait reflects a specific aspect of the plant's response to water deficit, and together they form a comprehensive profile of drought tolerance. The intensity of coloration in each cell (light to dark green on the color scale) represents the magnitude of each trait—with darker colors indicating higher trait values. By comparing these patterns across genotypes and traits, we gained valuable indication of drought tolerant and promising genotypes for breeding and cultivation in drought-prone environments.

In Figure 15, all the 14 traits were grouped into three groups (G-1, G-2, G-3), G-1 contained the traits PH, *gs*, SDW, GL; G-2 possessed VRL, *A*, WUE, *E* and remaining were in G-3. In case of genotypic classification, the six genotypes were clustered into three clusters. Cluster-1 (C-1) had the highly drought tolerant genotypes B/8/93 and BT2 while C-2 possessed the moderate tolerant genotypes BT21 and BT23. Both BT4 and BT10 placed into C-3 which were susceptible to drought. B/8/93 performs consistently high across most traits and reflects a conservative yet efficient water-use strategy: it maintains leaf hydration, protects chlorophyll content, and achieves a high photosynthetic rate with moderate stomatal conductance. It also performs reasonably well in both shoot and root traits, making it the most balanced and productive genotype under drought. From this clustering heatmap we made a sequence (higher to lower) of tolerance ability of six tea genotypes in drought condition as B/8/93 > BT2 > BT21 > BT23 > BT4 > BT10.

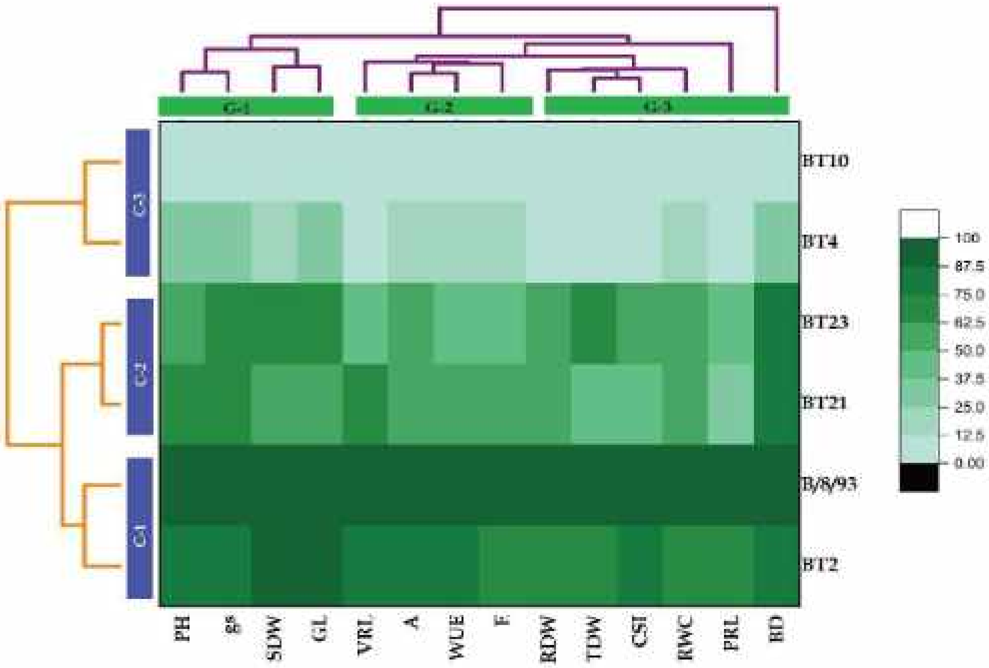

Figure 15. Two-way (row and column) hierarchical clustering heatmap with dendrogram showing grouping of six tea genotypes and their performance (average percent changes of 30, 60, 90, 120, 150 and 180 days after drought imposition than control condition) under 14 parameters at drought condition. The genotypes and their performance were grouped into three (row) and three (column) clusters, respectively. The mean values of traits are normalized and used to construct heatmap (scaling from 0 to 100)

Conclusion

The present study comprehensively evaluated the drought tolerance of six tea genotypes using a multi-trait approach encompassing 14 morphological, physiological, and biochemical parameters. The integration of traits such as plant height, base diameter, root architecture, chlorophyll stability, proline content, water use efficiency, photosynthetic performance, and green leaf yield etc. provided a holistic understanding of each genotype's adaptive strategy under water-deficit conditions. Among the genotypes, B/8/93 emerged as the most drought-tolerant, showing superior performance in both shoot and root traits, high chlorophyll stability, relative water content, and efficient water use—all contributing to its robust growth and productivity under stress along with BT2. Genotypes BT21 and BT23 demonstrated moderate tolerance. But the genotypes BT4 and BT10, on the other hand, exhibited comparatively lower performance across key traits, making it the least tolerant among the studied genotypes. The clustering heatmap clearly distinguishes the genotypes by tolerance level, leading to the following ranked sequence of drought tolerance: B/8/93 > BT2 > BT21 > BT23 > BT4 > BT10. This ranking provides valuable insights for tea breeding programs aimed at developing drought-resilient cultivars suitable for climate-stressed regions.

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Appendix

Figure Appendix 1 (a-d). Collection of data on gas exchange parameters of selected tea genotypes

Table A1. Performances of six tea genotypes in control (T_0) and drought condition (T_1) with average % change of drought effect after 30, 60, 90, 120, 150 and 180 days over control (Avg. % change) for 14 traits *viz.* plant height (PH), base diameter (BD), vertical root length (VRL), root dry weight (RDW), shoot dry weight (SDW) and total dry weight (TDW), Chlorophyll Stability Index (CSI), proline content (PRL), relative water content (RWC), stomatal conductance (*gs*), Rate of photosynthesis (*A*), transpiration rate (*E*), water use efficiency (WUE) and Green Leaf Per Plant (GL)

Genotypes	PH (cm) at control (T_0) condition						PH (cm) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	50.35	53.78	67.1	91.28	122.10	131.28	48.18	49.48	56.88	74.93	95.40	90.25	-16.42
BT4	48.7	51.35	63.78	84.05	114.13	121.55	45.98	46.78	53.05	68.65	86.58	80.65	-17.91
BT10	46.28	51.18	61.60	81.30	116.38	119.63	43.25	46.43	50.60	65.43	86.53	77.88	-18.96
BT21	50.38	53.53	66.35	89.03	119.55	126.63	48.05	49.10	55.95	73.08	92.48	86.43	-16.81
BT23	50.28	52.60	65.30	86.38	118.03	131.60	47.88	48.08	54.90	70.63	90.25	88.68	-17.29
B/8/93	51.35	56.60	68.03	91.35	123.78	134.03	49.18	52.28	57.65	75.08	97.13	94.30	-16.02
LSD (p=0.05)	0.05	0.09	0.04	0.06	1.25	2.47	0.08	0.07	0.18	1.07	1.26	0.95	

Genotypes	BD (cm) at control (T_0) condition						BD (cm) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	1.21	1.48	1.73	1.81	1.85	1.94	1.17	1.41	1.65	1.72	1.74	1.8	-5.16
BT4	1.19	1.41	1.73	1.75	1.79	1.88	1.14	1.34	1.64	1.66	1.68	1.74	-5.41
BT10	1.18	1.38	1.66	1.71	1.75	1.83	1.13	1.31	1.58	1.62	1.64	1.69	-5.53
BT21	1.24	1.47	1.71	1.78	1.81	1.94	1.2	1.4	1.63	1.69	1.7	1.8	-5.16
BT23	1.23	1.43	1.68	1.75	1.8	1.92	1.19	1.37	1.6	1.66	1.69	1.78	-5.16
B/8/93	1.25	1.56	1.79	1.83	1.89	1.98	1.21	1.49	1.7	1.74	1.78	1.84	-5.11
LSD (p=0.05)	0.04	0.06	0.02	0.07	0.06	0.04	0.03	0.1	0.02	0.04	0.03	0.07	

Genotypes	BD (cm) at control (T_0) condition						BD (cm) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	1.21	1.48	1.73	1.81	1.85	1.94	1.17	1.41	1.65	1.72	1.74	1.8	-5.16
BT4	1.19	1.41	1.73	1.75	1.79	1.88	1.14	1.34	1.64	1.66	1.68	1.74	-5.41
BT10	1.18	1.38	1.66	1.71	1.75	1.83	1.13	1.31	1.58	1.62	1.64	1.69	-5.53
BT21	1.24	1.47	1.71	1.78	1.81	1.94	1.2	1.4	1.63	1.69	1.7	1.8	-5.16
BT23	1.23	1.43	1.68	1.75	1.8	1.92	1.19	1.37	1.6	1.66	1.69	1.78	-5.16
B/8/93	1.25	1.56	1.79	1.83	1.89	1.98	1.21	1.49	1.7	1.74	1.78	1.84	-5.11
LSD (p=0.05)	0.04	0.06	0.02	0.07	0.06	0.04	0.03	0.1	0.02	0.04	0.03	0.07	

Genotypes	VRL (cm) at control (T_0) condition						VRL (cm) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	7.48	7.76	8.15	9.31	11.58	14.53	7.28	7.46	7.83	8.86	10.76	13.04	-5.44
BT4	7.41	7.63	7.91	9.11	11.21	13.85	7.2	7.3	7.53	8.66	10.32	11.8	-6.63
BT10	7.44	7.52	7.88	9.09	11.02	13.75	7.22	7.2	7.5	8.64	10.11	11.61	-6.8
BT21	7.49	7.74	7.95	9.2	11.23	14.34	7.32	7.42	7.66	8.75	10.39	12.73	-5.62
BT23	7.52	7.7	7.91	9.15	11.22	14.22	7.34	7.38	7.62	8.71	10.37	12.34	-5.98
B/8/93	7.51	7.77	8.34	9.53	12.39	14.85	7.33	7.49	8.04	9.08	11.53	13.5	-5.06
LSD (p=0.05)	0.02	0.08	0.06	0.06	0.19	0.28	0.04	0.17	0.12	0.14	0.19	0.08	

Genotypes	SDW (g) at control (T_0) condition						SDW (g) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	3.75	5.95	8.33	12.22	17.54	24.11	3.69	5.79	8.07	11.59	16.26	20.67	-5.66
BT4	3.69	5.74	7.98	11.94	15.86	21.28	3.63	5.56	7.69	11.22	14.55	17.5	-6.76
BT10	3.74	5.52	7.8	11.98	14.95	20.22	3.68	5.34	7.52	11.25	13.67	16.21	-7.16
BT21	3.77	5.88	8.21	12.29	16.55	23.47	3.72	5.71	7.93	11.65	15.24	19.83	-6.04
BT23	3.71	5.81	8.11	12.11	16.47	22.64	3.65	5.65	7.85	11.43	15.13	18.96	-6.26
B/8/93	3.72	6.54	8.95	12.48	18.97	25.84	3.67	6.36	8.68	11.85	17.48	22.33	-5.59
LSD (p=0.05)	0.09	0.18	0.14	0.14	0.98	1.28	0.54	0.15	0.43	0.21	0.83	0.27	

Genotypes	RDW (g) at control (T_0) condition						RDW (g) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	1.18	1.32	1.48	1.83	1.91	2.14	1.17	1.29	1.4	1.7	1.72	1.85	-6.54
BT4	1.08	1.25	1.35	1.68	1.75	2.05	1.06	1.21	1.27	1.55	1.57	1.73	-7.58
BT10	1.04	1.21	1.33	1.65	1.76	1.98	1.02	1.16	1.25	1.52	1.57	1.69	-7.57
BT21	1.14	1.28	1.41	1.72	1.83	2.11	1.12	1.24	1.33	1.6	1.65	1.82	-6.83
BT23	1.12	1.24	1.43	1.71	1.85	2.08	1.11	1.21	1.35	1.59	1.66	1.79	-6.79
B/8/93	1.24	1.38	1.53	1.81	1.95	2.21	1.24	1.35	1.46	1.69	1.76	1.92	-6.17
LSD ($p=0.05$)	0.04	0.09	0.04	0.07	0.11	0.88	0.03	0.01	0.08	0.11	0.43	0.14	

Genotypes	TDW (g) at control (T_0) condition						TDW (g) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	4.93	7.27	9.81	14.05	19.45	26.25	4.86	7.08	9.47	13.29	17.98	22.52	-5.78
BT4	4.77	6.99	9.33	13.62	17.61	23.33	4.69	6.77	8.96	12.77	16.12	19.23	-6.85
BT10	4.78	6.73	9.13	13.63	16.71	22.2	4.7	6.5	8.77	12.77	15.24	17.9	-7.25
BT21	4.91	7.16	9.62	14.01	18.38	25.58	4.84	6.95	9.26	13.25	16.89	21.65	-6.17
BT23	4.83	7.05	9.54	13.82	18.32	24.72	4.76	6.86	9.2	13.02	16.79	20.75	-6.32
B/8/93	4.96	7.92	10.48	14.29	20.92	28.05	4.91	7.71	10.14	13.54	19.24	24.25	-5.62
LSD ($p=0.05$)	0.02	0.18	0.85	0.47	1.51	1.64	0.43	0.09	0.54	0.09	1.27	1.11	

Genotypes	CSI (%) at control (T_0) condition						CSI (%) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	80.19	78.54	81.21	78.98	80.33	81.33	79.56	76.09	77.86	72.05	71.27	68.9	-7.23
BT4	80.11	79.5	78.57	81.24	80.34	80.55	79.23	76.7	74.78	73.47	69.13	66.09	-8.48
BT10	80.09	80.45	79.51	80.33	78.94	79.57	79.26	77.53	75.59	72.47	67.45	64.81	-8.75
BT21	80.11	80.22	80.11	79.58	79.67	80.21	79.38	77.64	76.48	72.47	69.43	66.69	-7.88
BT23	79.28	78.94	81.24	79.88	81.24	80.11	78.57	76.38	77.79	72.59	71.6	67.4	-7.54
B/8/93	80.14	80.47	81.22	80.24	80.64	81.57	79.86	78.2	78.12	73.6	71.89	69.46	-6.83
LSD ($p=0.05$)	0.04	0.11	0.09	0.04	0.08	0.09	0.08	0.04	1.01	0.94	0.93	1.21	

Genotypes	PRL (µmol/g FW) at control (T_0) condition						PRL (µmol/g FW) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	0.49	0.42	0.44	0.53	0.56	0.61	0.51	0.44	0.46	0.58	0.62	0.7	7.9
BT4	0.31	0.48	0.4	0.49	0.53	0.44	0.32	0.49	0.42	0.53	0.58	0.5	6.83
BT10	0.33	0.33	0.38	0.51	0.53	0.34	0.34	0.34	0.4	0.55	0.58	0.38	6.7
BT21	0.51	0.47	0.48	0.47	0.54	0.43	0.53	0.49	0.5	0.51	0.59	0.49	7.28
BT23	0.31	0.53	0.52	0.48	0.55	0.49	0.32	0.55	0.54	0.52	0.61	0.56	7.6
B/8/93	0.52	0.66	0.57	0.57	0.58	0.58	0.54	0.69	0.6	0.62	0.65	0.68	8.52
LSD ($p=0.05$)	0.01	0.03	0.04	0.03	0.08	0.05	0.08	0.02	0.06	0.07	0.02	0.03	

Genotypes	RWC (%) at control (T_0) condition						RWC (%) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	83.08	84.59	84.33	84.9	82.94	86.43	81.64	81.87	80	79.09	75.28	74.47	-6.67
BT4	83.11	83.3	87.16	80.9	86.52	83.24	81.21	80.27	82.03	74.72	77.68	70.24	-7.55
BT10	86.48	86.38	87.89	81.9	86.48	82.08	84.36	83.29	82.86	75.47	77.37	68.68	-7.75
BT21	86.95	87.06	77.8	84.9	82.38	85.9	85.26	83.99	73.33	78.83	75.58	73.14	-6.91
BT23	80.1	80.1	83.64	80.7	82.59	85.4	78.36	77.34	78.92	74.8	75.2	73.15	-6.98
B/8/93	86.83	82.46	88.12	83.4	86.82	86.1	85.46	79.85	84.02	78.14	79.67	74.41	-6.26
LSD ($p=0.05$)	0.05	0.09	19	0.54	0.08	0.47	0.09	0.94	0.46	0.38	0.28	0.64	

Genotypes	*gs* (mmol m⁻² s⁻¹) at control (T_0) condition						*gs* (mmol m⁻² s⁻¹) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	0.53	0.52	0.53	0.52	0.53	0.56	0.53	0.51	0.5	0.47	0.45	0.45	-8.5
BT4	0.52	0.44	0.42	0.42	0.48	0.48	0.52	0.43	0.4	0.38	0.4	0.38	-9.65
BT10	0.55	0.43	0.4	0.46	0.43	0.42	0.55	0.42	0.38	0.41	0.36	0.31	-10.51
BT21	0.4	0.42	0.38	0.46	0.34	0.42	0.4	0.41	0.36	0.42	0.29	0.34	-8.79
BT23	0.58	0.53	0.54	0.51	0.5	0.58	0.58	0.52	0.51	0.46	0.43	0.46	-8.89
B/8/93	0.5	0.55	0.5	0.6	0.54	0.54	0.5	0.54	0.48	0.55	0.47	0.44	-7.96
LSD (p=0.05)	0.02	0.03	0.04	0.03	0.05	0.01	0.03	0.04	0.08	0.03	0.04	0.06	

Genotypes	*A* (μmol CO_2 m⁻² s⁻¹) at control (T_0) condition						*A* (μmol CO_2 m⁻² s⁻¹) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	14.19	15.33	15.69	15.62	15.67	16.2	13.4	13.96	12.99	11.88	10.82	8.92	-21.93
BT4	12.58	15.8	15.7	15.82	14.29	15.88	11.73	14.24	12.66	11.73	9.44	7.36	-24.9
BT10	15.63	15.55	16	14.36	15.91	14.05	14.55	14.02	12.71	10.49	10.37	6.27	-25.75
BT21	15.85	14.95	16.08	15.83	16.05	16.05	14.96	13.66	13.1	12.01	10.83	8.19	-23.07
BT23	15.64	15.15	15.2	16.14	12.49	15.88	14.66	13.89	12.37	12.17	8.51	7.99	-23.23
B/8/93	15.81	15.31	15.6	15.47	16.3	15.88	14.98	14.05	12.97	11.94	11.32	9.08	-21.11
LSD (p=0.05)	0.05	0.08	0.04	0.03	0.08	0.09	0.84	0.47	0.29	0.73	0.56	0.98	

Genotypes	*E* (mol H_2O m⁻² s⁻¹) at control (T_0) condition						*E* (mol H_2O m⁻² s⁻¹) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	3.25	3.22	3.15	3.24	3.15	3.26	3.2	3.06	2.79	2.68	2.38	1.8	-17.41
BT4	3.13	3.4	3.26	3.05	3.28	3.12	3.06	3.23	2.81	2.46	2.38	1.32	-20.94
BT10	3.18	3.12	3.26	3.07	3.28	3.18	3.1	2.96	2.79	2.45	2.35	1.28	-21.78
BT21	3.21	3.25	3.38	3.1	3.01	3.22	3.14	3.11	2.97	2.52	2.24	1.66	-18.59
BT23	3.29	3.28	3.13	3.06	3.39	3.28	3.23	3.13	2.72	2.48	2.48	1.65	-19.1
B/8/93	3.11	3.17	3.22	3.21	3.25	3.11	3.06	3.03	2.9	2.67	2.51	1.76	-16.48
LSD (p=0.05)	0.05	0.04	0.02	0.08	0.03	0.05	0.45	0.28	0.72	0.22	0.18	0.38	

Genotypes	WUE (μmol/m mol) at control (T_0) condition						WUE (μmol/m mol) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	4.37	4.76	4.98	4.82	4.97	4.97	4.19	4.56	4.66	4.43	4.55	4.96	-5.25
BT4	4.02	4.65	4.82	5.19	4.36	5.09	3.83	4.41	4.51	4.77	3.97	4.86	-6.31
BT10	4.92	4.98	4.91	4.68	4.85	4.42	4.69	4.74	4.56	4.28	4.41	4.2	-6.54
BT21	4.94	4.6	4.76	5.11	5.33	4.98	4.76	4.39	4.41	4.77	4.83	4.93	-5.43
BT23	4.75	4.62	4.86	5.27	3.68	4.84	4.54	4.44	4.55	4.91	3.43	4.62	-5.48
B/8/93	5.08	4.83	4.84	4.82	5.02	5.11	4.9	4.64	4.47	4.47	4.51	5.16	-5.26
LSD (p=0.05)	0.09	0.08	0.02	0.04	0.04	0.05	0.09	0.11	0.17	0.19	0.09	0.09	

Genotypes	GL (g) at control (T_0) condition						GL (g) at drought (T_1) condition						Avg. % change
	30	60	90	120	150	180	30	60	90	120	150	180	
BT2	6.79	7.53	9.17	11.09	12.39	15.07	6.62	7.07	8.24	8.97	9.44	10.37	-15.5
BT4	6.78	7.96	9.15	11.51	12.75	14.9	6.5	7.4	8.15	9.05	9.48	9.6	-17.44
BT10	6.83	8.18	9.6	11.85	13.38	15.41	6.51	7.57	8.51	9.32	9.77	9.4	-18.47
BT21	6.84	8.08	8.96	11.51	13.18	14.96	6.6	7.57	8.03	9.11	9.89	9.06	-17.58
BT23	6.86	7.84	9.28	11.19	12.85	15.04	6.64	7.34	8.31	8.9	9.69	9.35	-17.13
B/8/93	6.78	7.52	9.64	10.96	13.27	15.29	6.58	7.06	8.71	8.88	10.13	10.78	-15.14
LSD (p=0.05)	0.03	0.04	0.03	0.02	0.08	0.09	0.03	0.04	0.03	0.09	0.12	0.19	

Tea J. Bangladesh 51, 16-26, 2025
https://doi.org/10.5281/zenodo.15684395
ISSN 0253-5483
Available online at http://www.btri.gov.bd

MECHANIZATION IN PRUNING AND ITS IMPACT ON THE YIELD OF TEA

Mohammad Masud Rana[1*], Toufiq Ahmed[2], Mohammad Sayadul Huq[3], Md. Imran Hossen[4] and S.M. Monwarul Islam[4]

Abstract

This study evaluated the efficiency and economic viability of mechanized pruning compared to traditional manual pruning in mature tea plantations of Bangladesh at the Bangladesh Tea Research Institute over a four-year period. This study is significant as it addresses the pressing issue of labour shortages in the tea industry and explores mechanized pruning as a sustainable solution to improve efficiency and profitability without compromising yield. The experiment tested three pruning treatments—manual pruning (T_1), mechanized pruning only (T_2), and mechanized pruning followed by manual repair (T_3)—across four pruning types: Light Pruning (LP), Deep Skiff (DSK), Medium Skiff (MSK), and Light Skiff (LSK). Mechanized pruning significantly reduced labour time, with T_2 being 1.3 to 3.0 times faster than T_1. Fuel consumption was highest in LP and lowest in LSK. Despite minor yield differences among treatments, mechanization showed no significant negative impact on productivity. In fact, T_2 and T_3 often slightly outperformed manual pruning in LP and DSK. Economic analysis indicated that T_3 was most profitable for LP and DSK, while T_1 remained optimal for MSK and LSK. These results suggest that targeted mechanization in tea pruning can enhance efficiency and profitability without compromising yield. However, the long-term impact of repeated mechanized pruning on bush health and sustainability was not assessed and warrants further investigation.

Keywords: Pruning, Mechanization, Fuel, Tea, Yield, Economic Analysis

[1]Principal Scientific Officer (Agronomy Division), Bangladesh Tea Research Institute, Srimangal, Moulvibazar
[2]Chief Scientific Officer (Agronomy Division), Bangladesh Tea Research Institute, Srimangal, Moulvibazar
[3]Senior Scientific Officer (Agronomy Division), Bangladesh Tea Research Institute, Srimangal, Moulvibazar
[4]Scientific Officer (Agronomy Division), Bangladesh Tea Research Institute, Srimangal, Moulvibazar

*Corresponding author's email: ranabtri@yahoo.com (Mohammad Masud Rana)

Introduction

In tea cultivation, pruning is an essential management practice (Zhang et al., 2023). It involves the removal of older branches and leaves to stimulate new growth, improve yield, and ensure the long-term sustainability of the plant (Liu et al., 2022; Zhang et al., 2023; Hibstu, 2025). The primary aim of pruning is to check the apical dominance and keep the bushes in vegetative stage and to divert the energy towards production of leaves (Kumar et al., 2015). It also promotes increased branching, resulting in a higher number of tender leaves (Satyanarayana et al., 1994; Ravichandran, 2004; Kumar et al., 2015). Continuous harvesting of tea shoots over the years causes the bush to grow taller, making it difficult for pluckers to reach. It also leads to fewer shoots, an increase in dormant shoots (banjies), and more flower buds. Additionally, a dense canopy can accumulate weakened branches and dead wood. Therefore, to keep the bushes at a manageable height, encourage robust new growth, and ensure long-term plant health, regular pruning is necessary. Pruning significantly affects the yield and quality of fresh tea leaves (Zhang et al., 2021). Pruning alters the activity of inter-root soil enzymes and the microbial functional diversity of tea plants (Kan et al., 2024). This improves the soil's nutrient conversion capacity and promotes the tea plant's nutrient uptake capacity, ultimately leading to improved growth (Zhang et al., 2023). At the same time, tea bush pruning could reduce the labour force and improve the efficiency of tea harvesting (Tian et al., 2015; Wijeratn, 2018; Zhang et al., 2021).

Traditionally, pruning has been a manual task, carried out by skilled labourers using pruning knife or sickles. Now a day, the tea gardens of Bangladesh, particularly in the Sylhet and Panchagarh region, are facing an increasing scarcity of labour force, which is becoming a pressing issue for the tea industry. Traditionally, tea plantations in Bangladesh have relied on a community of indigenous workers, many of whom have been employed for generations (Rahman et al., 2021). However, with greater access to education and alternative employment opportunities in urban areas, younger people from these communities are moving away from tea gardens. The labour shortage is further exacerbated by the fact that many tea workers are aging, and there is a lack of young replacements. In addition to the labour shortage, there was a sharp rise of labour and other input costs in the past few years which increased the cost of production to such a point that the tea industries in Bangladesh have become almost non-profitable. Therefore, with the rising costs of labour, the decline in the availability of skilled workers, and the need for increased productivity, the mechanization of pruning has become an important consideration for the tea industry.

The mechanization of pruning offers several advantages, especially in large-scale tea plantations where labour shortages and high labour costs are significant concerns. By using pruning machines, tea estates can achieve greater operational efficiency and reduce dependency on manual labour. Manual pruning is labour-intensive and time-consuming. With the use of machines, the time taken for pruning can be reduced, which can stimulate healthier growth and improve harvest quality. In addition to time savings, mechanized pruning may help reduce costs associated with pruning labour. While the initial investment in machinery may be high, the long-term savings in labour costs can offset these initial expenses. While the advantages of mechanized pruning are evident, it does have its limitations. One of the primary concerns is the potential for damage to tea bushes. Tea bushes are delicate plants that require precise and careful pruning to avoid damage to the stems and branches that will later generate new growth. Mechanized pruners, may not have the same level of precision as skilled manual labourers, leading to the risk of heavy-pruning or uneven cuts that can negatively affect the health of the tea bush. Therefore, to address these issues an experiment was undertaken at Bangladesh Tea Research Institute to understand the impact of pruning mechanization on the yield of tea and to find out the best pruning policy using pruning machine.

Materials and Methods

The study was conducted from 2019 to 2023 on a mature tea plantation (clone: BT2) at the main farm of the Bangladesh Tea Research Institute, Srimangal, Moulvibazar.

The experiment aimed to evaluate the effects of three different pruning policies, tested across four distinct pruning types: Light Prune (LP), Deep Skiff (DSK), Medium Skiff (MSK), and Light Skiff (LSK).

A Randomized Complete Block Design (RCBD) was employed with three replications, resulting in a total of 36 experimental plots. Each plot measured 45 m^2. Standard intercultural operations—including fertilizer application, weeding, and pest and disease management—were uniformly applied across all plots as needed.

During the pruning operations, data were collected on time requirements for both manual and mechanical pruning, as well as fuel consumption for mechanical pruning. Yield data were recorded every seven days, on average, throughout the study period, expressed as green leaf weight (kg/plot). For yield comparison, green leaf data were converted to made tea yield (kg/ha), assuming a 23% recovery rate. The collected data were analyzed statistically using SPSS software (SPSS, 2006).

Treatments

The experiment evaluated the effects of different pruning policies applied using both a traditional pruning knife and a mechanical pruning machine (Figure 1). The traditional manual pruning method served as the control treatment. Three distinct pruning policies were evaluated across four types of pruning operations- LP, DSK, MSK, and LSK. The treatments were organized as follows:

a) Pruning Policies

- Manual pruning using traditional pruning knife (T_1) (Control)
- Mechanized pruning only (T_2)
- Mechanized pruning followed by manual repair (T_3)

b) Pruning Types

- Light Prune (LP)
- Deep Skiff (DSK)
- Medium Skiff (MSK)
- Light Skiff (LSK)

Figure 1. Photos of the pruning machine and the traditional pruning knife

Results and Discussion

Time Requirement for Pruning

The time required (in hours per hectare) for various pruning treatments across four pruning types- LP, DSK, MSK, and LSK is illustrated in Figure 2. Across all pruning types, T_2 (mechanized pruning only) consistently required the least amount of time per hectare, demonstrating the efficiency advantage of mechanized pruning over traditional manual pruning. The greatest time savings were observed in the Light Prune (LP) category, where T_2 reduced time requirements to approximately one-third of T_1 (manual pruning), highlighting the labour-intensive nature of LP when performed manually. Treatment T_3 (mechanized pruning followed by manual repair) generally required more time than T_2 (mechanized pruning only), but remained less time-consuming than T_1 (manual pruning). This indicates that although the addition of manual touch-ups increases the time compared to mechanized-only pruning, it still offers a notable improvement in efficiency over fully manual pruning methods.

In the LP treatment, the time requirements were significantly different among the three treatments (Figure 2). The treatment of manual pruning (T1) recorded the highest time requirement (457 hours/ha), followed by T_3 (240 hours/ha), and T_2 (168 hours/ha), with all differences statistically significant ($p < 0.05$). For the DSK, MSK, and LSK operations, T_2 consistently recorded the lowest time consumption (79, 63, and 46 hours/ha, respectively), while T_1 and T_3 showed similar trends, with T_3 slightly lower or comparable to T_1 in some cases. However, the statistical differences between T_1 and T_3 treatments for DSK, MSK and LSK were non-significant.

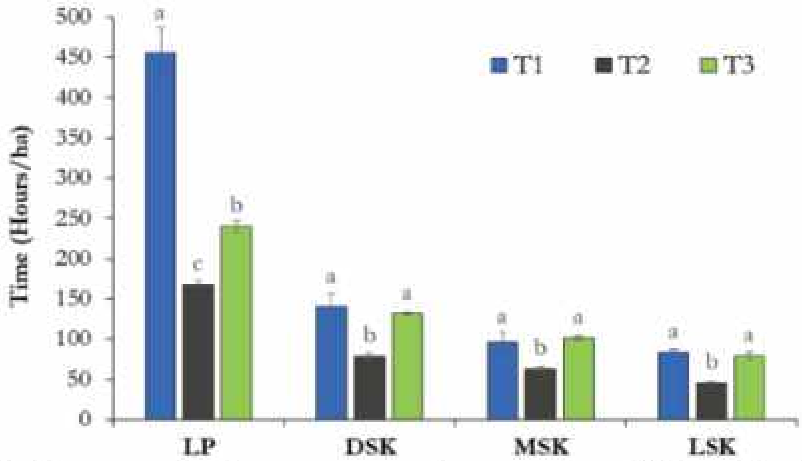

Figure 2. Time required to prune one hectare of tea field under different treatment conditions across different pruning types. Different letters above the bars indicate significant differences within the group at $P < 0.05$

Though the tea bushes are best pruned manually as it paves the way for individual removal of branches, manual pruning requires a large number of skilled workers

(TRI, 2013). Furthermore, pruning needs to be completed within a certain period of time in the year *i.e.* within a few months to avoid the dry weather. Timely pruning of tea bushes is known to positively influence both the quantity and quality of the final product (Firouzi and Azarian, 2019). Given the shortage of workers, there is significant potential for utilizing motorized machines to prune tea plantations. The above results clearly demonstrate that mechanized pruning, particularly when done without manual repair, significantly reduces labour time across all pruning types. These findings support the potential of mechanization in improving labour efficiency in tea plantation management.

From the Figure 2, it is also evident that pruning time per hectare varies significantly across different pruning types. LP (light pruning) demands the most time, underscoring its labour-intensive nature. DSK requires a moderate amount of time, while MSK and LSK are the least time-consuming. This trend highlights that more intensive pruning methods like LP require substantially more labour compared to lighter methods such as DSK, MSK, and LSK, regardless of treatment conditions.

Fuel Consumption in Pruning

The amount of fuel (in liters per hectare) needed to prune one hectare of tea field under three different treatment conditions (T_1, T_2, and T_3) for each of the four pruning types- LP, DSK, MSK, and LSK is shown in Figure 3. The treatment T_1 required no fuel input, as no machine was involved, compared to the other treatments (T_2 and T_3). Among the different pruning types, LP required the highest fuel input, with treatments T_2 and T_3 consuming about 72.59 and 73.33 L/ha, respectively. These values were significantly higher ($p < 0.05$) than that of T_1, which required no fuel. The fuel requirement for T_2 and T_3 were statistically comparable to each other in LP.

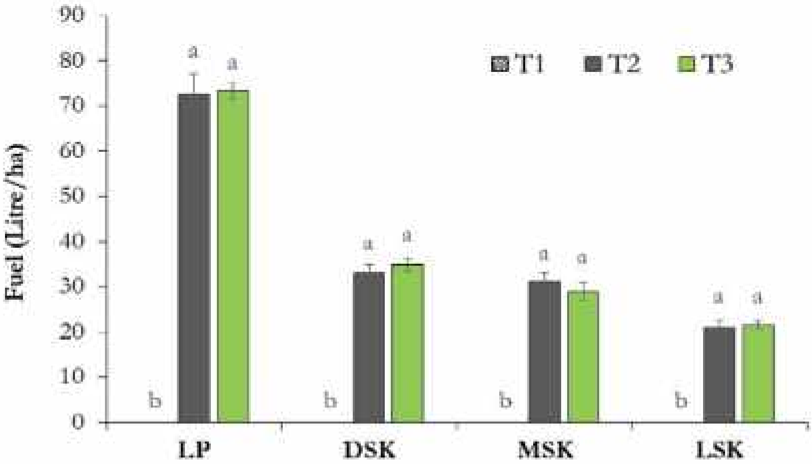

Figure 3. Fuel required to prune one hectare of tea field under different treatment conditions across different pruning types. Different letters above the bars indicate significant differences within the group at $P < 0.05$

Fuel consumption decreased progressively from LP to DSK, MSK, and LSK across the treatments. In each of these skiffing methods, the fuel consumption in T_2 and T_3 was significantly higher than in T_1, but the differences between T_2 and T_3 were not statistically significant. The mean data showed that DSK required about 33.89 L/ha fuel followed by MSK (30.00 L/ha), and LSK (21.30 L/ha).

This trend highlights the energy demand associated with the intensity of pruning operations. LP, being the most severe pruning type, requires deeper cutting and removal of more biomass, thereby demanding greater machine effort and fuel input. In contrast, skiffing operations, particularly LSK, are relatively shallow and involve lighter cuts, thus requiring less energy and fuel.

Comparison of Manual and Mechanized Pruning

The efficiency of manual versus mechanized pruning, based on the number of bushes pruned per hour, across four distinct pruning types- LP, DSK, MSK, and LSK is presented in Figure 4.

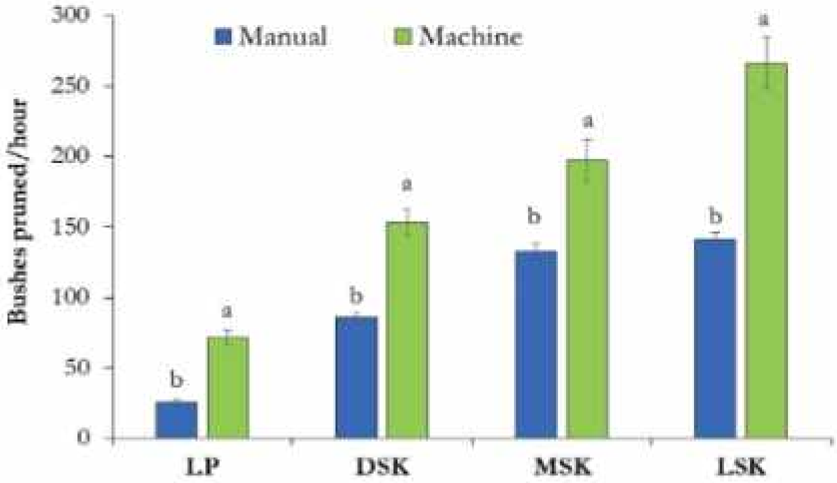

Figure 4. Comparison of efficiency between manual and mechanized pruning, measured as number of bushes pruned per hour across different pruning types. Different letters above the bars indicate significant differences within the group at $P < 0.05$

It was observed that in the case of LP, mechanized pruning achieved a mean output of about 71.17 bushes/hour, significantly outperforming manual pruning, which pruned only about 25.65 bushes/hour. For DSK, manual pruning achieved around 85.44 bushes/hour, while mechanized pruning significantly increased the rate to around 153.12 bushes/hour. Similarly, for MSK, mechanized pruning exhibited a significantly higher productivity (about 196.86 bushes/hour) compared to manual pruning (about 132.06 bushes/hour). The highest pruning efficiency was observed in LSK, where mechanized pruning reached nearly 266.13 bushes/hour—almost double the manual pruning rate of around 141.89 bushes/hour.

Overall, the data underscore the superior performance of mechanized pruning across all pruning types. These findings highlight the potential for mechanized pruning to significantly reduce labour input and operational time in large-scale tea plantations.

Effect of Pruning Treatment on Tea Yield

The made tea yield (kg/ha) recorded under three different treatment conditions (T_1, T_2, and T_3) across four pruning types- LP, DSK, MSK, and LSK is illustrated in Figure 5. For LP, tea yields were relatively modest, with T_1, T_2, and T_3 producing about 1821, 1897, and 1973 kg/ha made tea, respectively. Although a slight increasing trend is observable from T_1 to T_3, the differences was not statistically significant. In the case of DSK, yields improved substantially across all treatments. The treatment T_1 yielded around 2371 kg/ha, while T_2 and T_3 achieved approximately 2475 and 2608 kg/ha, respectively. This suggests that when deeper pruning is combined with improved treatment conditions (notably T_3) may have a synergistic effect on enhancing tea yield, though the yield increment was not statistically significant.

The MSK treatments exhibited relatively stable yields across T_1 and T_2 (2566 & 2586 kg/ha, respectively), with a slight decrease under T_3 (2431 kg/ha), though the difference was insignificant. The LSK treatments yielded the highest productivity overall. T_1 yielded approximately 2701 kg/ha, whereas T_2 and T_3 produced around 2709 kg/ha and 2677 kg/ha, respectively. The yield differences were not statistically significant. These findings imply that lighter forms of pruning can maximize productivity. Despite the general consistency in yield, the minor reduction observed in T_3 for the MSK and LSK may indicate that this treatment, under the MSK and LSK condition, could potentially make more stress on the tea plants.

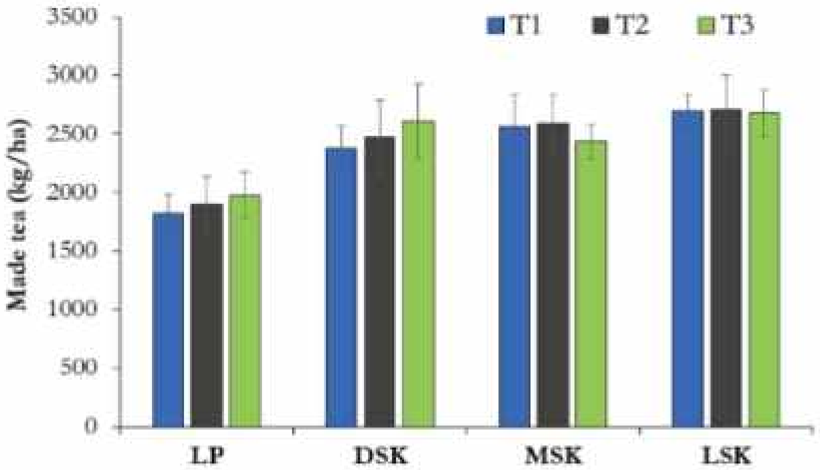

Figure 5. Tea yield under different treatment conditions across different pruning types

In LP and DSK, T_2 and T_3 consistently outperformed T_1 in terms of made tea yield, suggesting that these treatments may have provided more favorable conditions for enhanced bush performance in these two pruning types. It is known that manual pruning often leads to wood splitting, particularly in LP and DSK, where branches are thicker at the pruning height. This damage can harm axillary buds, reducing the number of shoots and plucking points. In contrast, MSK and LSK involve thinner branches, making such injuries less frequent or less severe. The yield data in this study reflect these observations, as T_2 and T_3 showed greater yield improvements over T_1 in LP and DSK, likely because cleaner, more efficient cuts had a bigger impact where pruning damage is usually higher. In contrast, the difference between treatments was smaller in MSK and LSK, where thinner branches result in less pruning damage. Mechanized pruning, when applied with appropriate speed and pressure, delivers cleaner, more uniform cuts that minimize wood splitting and preserve axillary buds. This enhances shoot regeneration and supports higher yield potential. This is in agreement with Amiri and Asil, 2007 and Yan et al. (2022), who reported that the number of plucking points is always closely associated with the yield in tea plants and higher number of plucking points always leads to higher yield. Additionally, Zeiss and Braber (2001) also highlighted the positive correlation between plucking points and tea yield.

From the results it is also evident that while treatment choice does influence yield to some extent, pruning type exerts a more pronounced effect on tea productivity. From the analysis result of yield data, it was observed that yield significantly varied due to different pruning types. The average yield from LP was significantly lowest (1897 kg/ha) than the other pruning types. Yield progressively increased in DSK (2485 kg/ha), MSK (2528 kg/ha), and LSK (2696 kg/ha), although their yields are not significantly different from each other (α = 0.05). Similar trends have been reported by previous studies. Kumar et al. (2015) observed lower yields in the first year after pruning, likely due to reduced bush size and lower leaf area index. Akbar et al. (2014) found that top-pruned bushes had higher leaf productivity owing to a greater number of plucking points and increased leaf biomass. Hossen et al. (2021) also reported that Level of Skiffing (LOS) and LSK resulted in higher yields compared to LP, further supporting the advantage of skiffing methods. These findings confirm the advantage of skiffing over light pruning in maximizing tea productivity.

Cost-Benefit Assessment

The effects of three treatment levels (T_1, T_2, T_3) across four pruning types- LP, DSK, MSK, and LSK on yield, cost, and profitability are presented in the Table 1. For LP and DSK, yield and gross margin increased progressively from T_1 to T_3, with T_3 offering the highest margin (Tk 368132/ha and Tk 508331/ha for LP and DSK, respectively) despite increased costs, indicating a positive return on mechanization. In MSK, although T_2 produced a slightly higher yield than T_1, but T_1 provided better gross margin (Tk 508719/ha) due to its balance between cost and productivity. LSK followed a similar trend where T_2 achieved the highest yield (2,709 kg/ha), whereas T_1 provided the highest gross margin (Tk 536195/ha). Overall, mechanization enhanced economic returns in LP and DSK. However, in the cases of MSK and LSK, mechanization did not lead to improved returns; instead, T_1 (manual pruning) yielded the highest gross margins, albeit marginally, indicating that the balance between cost and productivity favored manual practices. Thus, while mechanization proved beneficial for LP and DSK, it was less effective for MSK and LSK in terms of economic gains.

Table 1. Partial budget analysis of different treatments on the yield of tea

Pruning Types	Treat	Yield (kg/ha)	Man-days		Fuel		Deprecia-tion cost* (Tk)	Total cost (Tk)	Gross return (Tk/ha)	Gross margin (Tk/ha)
			Value	Cost (Tk)	Liter	Cost (Tk)				
(1)	(2)	(3)	(4)	(5) =(4)×373	(6)	(7) =(6)×130	(8)	(9) =(5)+(7)+(8)	(10) =(3)×200	(11) =(10)-(9)
LP	T_1	1821	57.10	21298	0.00	0	0	21298	364158	342860
	T_2	1897	21.01	7835	72.59	9437	5882	23154	379319	356165
	T_3	1973	30.00	11192	73.33	9533	5765	26491	394623	368132
DSK	T_1	2371	17.59	6562	0.00	0	0	6562	474200	467637
	T_2	2475	9.83	3666	32.96	4285	2752	10702	495066	484363
	T_3	2608	16.50	6155	34.81	4526	2632	13313	521643	508331
MSK	T_1	2566	12.04	4490	0.00	0	0	4490	513209	508719
	T_2	2586	7.87	2936	31.11	4044	2204	9184	517103	507919
	T_3	2431	12.73	4749	28.89	3756	2074	10578	486203	475624
LSK	T_1	2701	10.49	3914	0.00	0	0	3914	500121	536195
	T_2	2709	5.71	2128	21.11	2744	1597	6470	541860	535390
	T_3	2677	9.98	3723	21.48	2793	1527	8043	535330	527287

Note: Gross return = yield × price; Gross margin = gross return - total cost. Assuming overall labour cost (including related benefits) per man-days 373Tk, selling price of made tea 200Tk/kg, and fuel price 130Tk/liter.
** This cost is for the treatments where machine was involved. Calculated depreciation cost of machine 35Tk/hour.*

Conclusion

The results of this study highlight the substantial benefits of mechanized pruning in improving labour efficiency and reducing operational time in tea plantations. While mechanization significantly enhanced pruning efficiency across all pruning types, its economic advantages were most pronounced in more labour-intensive operations like Light Pruning (LP) and Deep Skiff (DSK). However, for less intensive pruning types such as Medium Skiff (MSK) and Light Skiff (LSK), the added cost of mechanization did not yield proportional economic returns, making manual pruning a more cost-effective option. The findings indicate that targeted use of mechanized pruning in tea cultivation can significantly improve operational efficiency and profitability while preserving yield levels. Future research should investigate the long-term effects of repeated mechanized pruning on tea bush health and productivity to ensure sustainable implementation.

Recommendations

1. Tailor Mechanization Based on Pruning Type

Economic returns from mechanization are not uniform across all pruning types. Prioritize mechanization in pruning types with clear economic benefit (LP, DSK), and use manual method for pruning types where it is more cost-effective (MSK, LSK).

2. Adopt Mechanization for LP and DSK

T_3 (mechanized pruning followed by manual repair) should be adopted for LP and DSK, as it offers the best economic returns despite slightly higher input costs.

3. Maintain Manual or Mechanized-only Pruning for MSK and LSK

Continue with T_1 (manual pruning) or T_2 (Mechanized-only pruning) for MSK and LSK to maintain cost-effectiveness. Avoid T_3 (mechanized pruning followed by manual repair) in these pruning types, as it reduces profitability due to higher operational costs without proportional gains in yield.

4. Further Research and Field Trials

Although the current findings offer valuable insights, results may vary depending on site-specific factors such as topography, soil conditions, labour availability, and machinery efficiency. Therefore, regular evaluations are essential to adapt pruning strategies in response to changing input costs (e.g., fuel and labour rates) and advancements in technology. Additionally, it is crucial to examine the long-term effects of mechanized pruning on tea bush health, regrowth patterns, and future yields to ensure sustainable productivity.

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Tea J. Bangladesh 51, 27-36, 2025
https://doi.org/10.5281/zenodo.15684322
ISSN 0253-5483
Available online at http://www.btri.gov.bd

A SUSTAINABLE APPROACH TO TEA CULTIVATION: VERMICOMPOST AND INORGANIC FERTILIZER DYNAMICS

Apu Biswas[1*], Naim Mustafa Ali[2], Kanij Fatema Tuz Zohora[1], Farhana Jahan Chowdhury[3], Abdul Qayyum Khan[4], Ashim Kumar Saha[4] and Shuva Das[5]

Abstract

An investigation in the field was carried out at the Bilashcherra Experimental Farm of the Bangladesh Tea Research Institute (BTRI) from 2016 to 2020 to assess the impact of vermicompost applications on tea yield (*Camellia sinensis* L.) while reducing dependency on inorganic fertilizers. Eight distinct treatments, incorporating varying rates of vermicompost and chemical fertilizers, were evaluated with three replications. Throughout the plucking season, harvesting data were recorded every week. Treatment T_8 (6 t/ha vermicompost with 60% of recommended chemical fertilizer dose) produced the most manufactured tea (2405 kg/ha), a 14.34% increase over the control. But it was shown to be more economical to combination of 3 t/ha vermicompost with 80% of chemical fertilizers. Tea yield improved significantly ($^{ANOVA}F$ = 6.87, p< 0.05) across treatments when higher vermicompost applications were paired with reduced chemical fertilizer rates. Treatment-specific soil property improvements were also observed. Treatment T_7 demonstrated the greatest increase in soil pH (5.2 ± 0.09), calcium (85.44 ± 3.27 mg/kg), and magnesium (22.64 ± 1.79 mg/kg). Organic carbon (1.63 ± 0.02%) and total nitrogen (0.165 ± 0.00%) were maximized in plots treated with T_6, while available phosphorus (95.99 ± 2.59 mg/kg) and potassium (90.32 ± 5.85 mg/kg) were highest in the T_2-treated plots. These changes represented significant improvements over initial soil conditions. It can be concluded that 3 tons/ha vermicompost with 80% recommended chemical fertilizers is most effective dose considering economic viewpoint which has been shown to reduce the reliance on chemical fertilizers as well as promoting sustainable agricultural practices.

Keywords: Vermicompost, Chemical Fertilizer, Yield, Tea

[1]Senior Scientific Officer, Soil Science Division, Bangladesh Tea Research Institute, Srimangal, Moulvibazar
[2] Scientific Officer, Soil Science Division, Bangladesh Tea Research Institute, Srimangal, Moulvibazar
[3]Ex-Scientific Officer, Soil Science Division, Bangladesh Tea Research Institute, Srimangal, Moulvibazar
[4]Ex-Principal Scientific Officer, Soil Science Division, Bangladesh Tea Research Institute, Srimangal, Moulvibazar
[5]Scientific Officer, Soil Science Division, Bangladesh Tea Research Institute Substation, Fatickchhari, Chattogram

*Corresponding author's email: biswas16feb@gmail.com (Apu Biswas)

Introduction

Tea, being a perennial crop, faces challenges related to soil fertility loss, which is crucial for sustaining production and productivity. The use of either organic or inorganic fertilizers alone can yield both beneficial and detrimental impacts on soil health, plant development, and nutrient accessibility. Organic fertilizers improve the soil physical and biological properties but typically contain lower nutrient levels, necessitating higher application rates for effective plant growth (Liang et al., 2003). On the other hand, inorganic fertilizers are readily available and provide essential nutrients for plants. However, their exclusive and continuous use can deplete soil organic matter, leading to soil acidification, and contributing to environmental pollution (Chen, 2008; GTZ, 2009).

The integrated nutrient management system provides a cost-effective and efficient alternative for maintaining soil fertility (Smith et al., 2020). This approach reduces the need for inorganic fertilizers by combining them with organic products such animal manure, crop leftovers, green manure, and composts (Johnson & Lee, 2019). The use of both organic and inorganic fertilizers is critical for sustaining soil fertility since it raises microbial biomass, improves soil health, boosts the efficiency of inorganic fertilizers, and lowers their overall cost (Garcia et al., 2021). The optimal balance of mineral fertilizers and organic manures depends on specific land-use practices and ecological conditions (Brown & Davis, 2018).

The use of vermicompost as an organic fertilizer is gaining significant popularity. Vermicompost is a thoroughly decomposed organic substance, resembling peat, known for its exceptional water retention, high porosity, soil preservation qualities, and vibrant microbial activity. It is produced through the interaction of microorganisms and earthworms, which degrade, stabilize, and mineralize various organic substances under mesophilic conditions at around 25°C (Aslam and Ahmad, 2020). Its application enhances crop growth and yield. By lowering the carbon-to-nitrogen (C:N) ratio and supplying readily available nutrients such as nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca), vermicompost stabilizes soil and benefits plant rhizospheres. The larger surface area of vermicompost particles provides ample space for microbial activity, including bacteria, fungi, and actinomycetes, which regulate soil nutrients and significantly impact yield parameters (Nuss & Tanumihardjo, 2010; Chen & Aviad, 1990). However, limited research has been conducted on the effects of vermicompost on tea cultivation. The goal of this study was to assess the effects and ideal dosage of vermicompost to minimize reliance on chemical fertilizers, while ensuring sustainable tea production and maintaining the profitability of tea gardens.

Materials and Methods

To investigate the impact of vermicompost on soil characteristics and the yield of mature tea plants, a five-year experiment was carried out at the Bilashcherra Experimental Farm (BEF). The experiments were arranged in a Randomized Complete Block Design (RCBD) with three replications and eight treatments. Each experimental plot covered an area of 13.40 square meters. Using urea, triple super phosphate (TSP), and muriate of potash (MOP), respectively, nutrients like nitrogen (N), phosphorus (P), and potassium (K) were provided. Based on the pH of the soil and the presence of sufficient moisture, dolomite was administered to all plots (apart from the control) prior to fertilization. Chemical fertilizers were broadcasted annually after a significant rainfall, with urea and MOP administered in two split doses.

Fifteen days before to applying chemical fertilizers, vermicompost was incorporated into the soil using light forking in two separate dosages. The vermicompost was obtained from the Vermicompost Production Unit of the Soil Science Division, Bangladesh Tea Research Institute. Each year, the initial fertilizer dose was applied in April, followed by the second dose in the first week of August.

Treatment details

T_1 = Control (No organic manure and chemical fertilizer)
T_2 = 100% RCFD* (N^{100}, P^{30}, K^{60} kg/ha)
T_3 = 80% RCFD
T_4 = 60% RCFD
T_5 = VC @ 6t/ha
T_6 = VC @ 1.5 t/ha + 100% RCFD
T_7 = VC @ 3 t/ha + 80% RCFD
T_8 = VC @ 6 t/ha + 60% RCFD

**RCFD = Recommended Chemical Fertilizer Dose, VC= Vermicompost*

The weight of green leaves, which represents the tea yield, was masured every seven days interval during the harvest season. Irrigation, pruning, pest control, and other intercultural activities were performed as needed. To assess a range of physico-chemical characteristics, such as soil texture, pH, organic carbon (%), total nitrogen (%), available phosphorus (mg/kg), potassium (mg/kg), calcium (mg/kg), and magnesium (mg/kg), soil samples were taken from a depth of 0 to 9 inches both before and after the harvest. The hydrometer method was used to determine the texture of the soil, and a pH meter was used to measure the pH of the soil at a ratio of 1:2.5 to distilled water. Soil organic carbon was determined using the wet oxidation method developed by Walkley and Black. The Micro Kjeldahl steam distillation method, as outlined by Huq and Alam (2005), was used to analyze total nitrogen. The ascorbic acid method was used to colorimetrically measure the amount of available phosphorus, calcium, magnesium, and potassium were extracted using a 77% ammonium acetate solution. Calcium and magnesium were measured using an atomic absorption spectrophotometer (AAS), whereas potassium was detected using a flame photometer. The vermicompost applied in the study was also analyzed for its physical and chemical properties prior to field application. Blume's (1985) approach was used to calculate the moisture content as a percentage. Using the technique developed by Jodice et al. (1982), the pH of vermicompost was determined in a compost–water suspension (1:10). Organic matter, along with total nitrogen, phosphorus, and potassium, was analyzed following procedures described by Jackson (1973).

Data Analysis

The arithmetic mean values with standard errors were used to display the yield and soil fertility statistics. One-way ANOVA was performed to compare the effects of different treatments on the yield of tea and soil quality parameters. At the 5% significance level, differences were compared using Duncan's Multiple Range Test (DMRT). IBM Corp., Armonk, NY, USA's SPSS software, version 20.0, was used to conduct the statistical analyses.

Results and Discussion

The physico-chemical analysis of vermicompost applied during the experiment reveals that, it is an excellent source of organic C (16.34%) and it also contain total N (1.64%), P (1.36%), and K (0.97%) respectively. The analytical results show that the vermicompost meets all government-approved critical limits (Table 1).

Table 1. Physico-chemical properties of vermicompost

Parameter	Analytical result	Government Approved Critical Limits (Ahmmed et al., 2018)
Color	Dark Grey to Black	Dark Grey to Black
Odor	Absence of foul odor	Absence of foul odor
Physical Condition	Non granular	Non granular
Moisture%	15.94	10 - 20
pH	6.9	6.0 - 8.5
Organic Carbon %	16.34	10 - 25
Total Nitrogen %	1.64	0.5 - 4.0
C:N	10:1	20:1(max)
Total Phosphorous %	1.36	0.5 - 3.0
Total Potassium %	0.97	0.5 - 3.0
Total Calcium %	0.71	-
Total Magnesium %	0.07	-
Total Zinc %	0.03	0.1 (max)

The vermicompost exhibits ideal physical, chemical, and biological properties, making it suitable for agricultural use. The low C:N ratio and balanced nutrient profile indicate that the compost is mature and will enhance soil fertility effectively without causing nitrogen immobilization or nutrient imbalances.

Tea can be cultivated on a variety of geological soil types. Most soils in Bangladesh are recent alluvia and quaternary. Heavy weathering, high acidity, and low fertility are characteristics of tea garden soils. In addition, flooding does not deposit fertile silt on these soils, rather suffering from erosion (Naim et al., 2024; Saha et al., 2022). The soil analytical results showed that the study area had a pH, organic carbon (OC), total nitrogen (N) within the critical limit and available phosphorus (Av. P), available potassium (Av. K), available calcium (Av. Ca), and available magnesium (Av. Mg) below the critical limit of tea soil (Table 2). The initial soil is marginally fertile but has deficiencies in phosphorus, potassium, calcium, and magnesium. While organic carbon and nitrogen levels are adequate, the soil acidity (low pH) and nutrient deficiencies highlight the need for soil amendments and fertilization to optimize fertility for crop production.

Table 2. The initial soil fertility status in the experimental field

Location	Texture	pH	O.C (%)	Total N (%)	Av. P (mg/kg)	Av. K (mg/kg)	Av. Ca (mg/kg)	Av. Mg (mg/kg)
BEF	SCl	4.5	1.01	0.12	5.49	48.31	49.26	9.52
Critical value	SL – L	4.5-5.5	1.00	0.10	10.00	80.00	90.00	25.00

SCL- Sandy Clay Loam, SL- Sandy Loam L- Loam, O.C-Organic Carbon

Table 3. Soil analysis findings at the conclusion of the experiment

Treat	Texture	pH	O.C (%)	Total N (%)	Av. P (mg/kg)	Av. K (mg/kg)	Av. Ca (mg/kg)	Av. Mg (mg/kg)
T_1	SCl	5.0 ± 0.13^{a}	1.18 ± 0.15^{c}	0.12 ± 0.02^{b}	83.91 ± 4.76^{ab}	57.11 ± 1.25^{c}	68.85 ± 2.20^{b}	11.74 ± 1.67^{d}
T_2	SCl	4.7 ± 0.03^{b}	1.57 ± 0.09^{ab}	0.16 ± 0.01^{ab}	95.99 ± 2.59^{a}	90.32 ± 5.85^{a}	81.92 ± 2.42^{a}	16.81 ± 1.22^{bc}
T_3	SCl	4.9 ± 0.09^{a}	1.27 ± 0.12^{bc}	0.13 ± 0.01^{ab}	59.22 ± 5.08^{c}	40.19 ± 5.35^{d}	82.11 ± 4.02^{a}	16.57 ± 1.76^{bcd}
T_4	SCl	5.0 ± 0.06^{a}	1.60 ± 0.06^{ab}	0.16 ± 0.01^{ab}	70.94 ± 7.43^{bc}	57.73 ± 6.26^{c}	79.37 ± 3.29^{ab}	14.48 ± 0.90^{cd}
T_5	SCl	4.6 ± 0.12^{b}	1.60 ± 0.08^{ab}	0.16 ± 0.01^{ab}	57.65 ± 7.37^{c}	79.04 ± 5.41^{ab}	77.89 ± 4.65^{ab}	13.96 ± 1.73^{cd}
T_6	SCl	5.1 ± 0.03^{a}	1.63 ± 0.02^{a}	0.17 ± 0.00^{a}	73.74 ± 6.14^{bc}	58.99 ± 2.89^{c}	81.35 ± 4.34^{a}	17.85 ± 1.78^{abc}
T_7	SCl	5.2 ± 0.09^{a}	1.47 ± 0.16^{abc}	0.15 ± 0.02^{ab}	74.80 ± 4.56^{bc}	65.26 ± 7.05^{bc}	85.44 ± 3.27^{a}	22.64 ± 1.79^{a}
T_8	SCl	5.0 ± 0.06^{a}	1.42 ± 0.12^{abc}	0.14 ± 0.01^{ab}	86.27 ± 8.08^{ab}	42.07 ± 5.66^{d}	82.61 ± 5.51^{a}	19.95 ± 1.58^{ab}

Note: Duncan's multiple range test (DMRT) indicates significant differences at $p \leq 0.05$ when the mean ± standard error within each row is followed by a different letter.

An increase in soil pH, available calcium (Ca), and available magnesium (Mg) compared to their initial levels was observed across all plots, including the control. The most substantial increases in these parameters were observed in plots treated with T_7 where 3 tons/ha of vermicompost were applied along with 80% of the recommended dose of chemical fertilizers. The observed improvements in pH, Ca, and Mg in plots receiving vermicompost, as well as in those with a combination of vermicompost and inorganic fertilizers, can be attributed to the annual application of dolomite. The soil's organic carbon content showed an increase in all treatments relative to its initial levels. The most significant rise was noted in the T_6-treated plot (1.63 ± 0.02%), followed by the T_4 and T_5 plots. The increase in organic carbon in the plots treated with vermicompost is likely attributed to the direct infusion of organic matter through the manure. Conversely, in plots treated with a combination of vermicompost and inorganic fertilizers, the increase might be attributed to improved plant growth, resulting in greater organic residue accumulation in the soil. Additionally, the close proximity of the plots could have influenced the organic carbon content across treatments. Raju and Reddy (2000) found similar results, stating that the addition of green manure considerably raised the levels of soil organic carbon relative to the starting values. Additionally, the treatment T_6 treated plot displayed the highest rise in total nitrogen (0.165 ± 0.00%). The increase in total nitrogen content in the soil under treatments with vermicompost, either alone or combined with chemical fertilizers, may stem from the accumulation of organic matter resulting from the application of organic manure. Organic matter also reduced nitrogen losses, which raised the overall N content. The maximum increase in available phosphorus (95.99 ± 2.59 mg/kg) and potassium (90.32 ± 5.85 mg/kg), over its initial value was found in case of treatment T_2 treated plots receiving 100% of recommended doses of chemical fertilizers.

The impact of various treatments on the average tea yield is depicted in Figure 1. This bar chart illustrates the yield of tea (kg/ha) under different treatments (T_1 to T_8), with percentage increases relative to the T_1 treatment (control). The average yield is shown by each bar, and the variability is shown by the error bars. Treatments are grouped based on statistical significance, indicated by the letters ("a," "b," "c"). The outcome demonstrated that the mean yield for each treatment was higher than the control. Yields obtained from different treatments reveals that comparatively higher mean yield of 2405 kg/ha was obtained from the treatment T_8 (vermicompost@ 6 t/ha+ 60% RCFD) that was closely followed by the yield of 2376 kg/ha from the treatment T_7 (vermicompost @ 3 t/ha + 80% RCFD). These treatments are the most effective, likely due to a combination of optimal vermicompost and chemical fertilizer application, leading to enhanced soil fertility and crop performance.

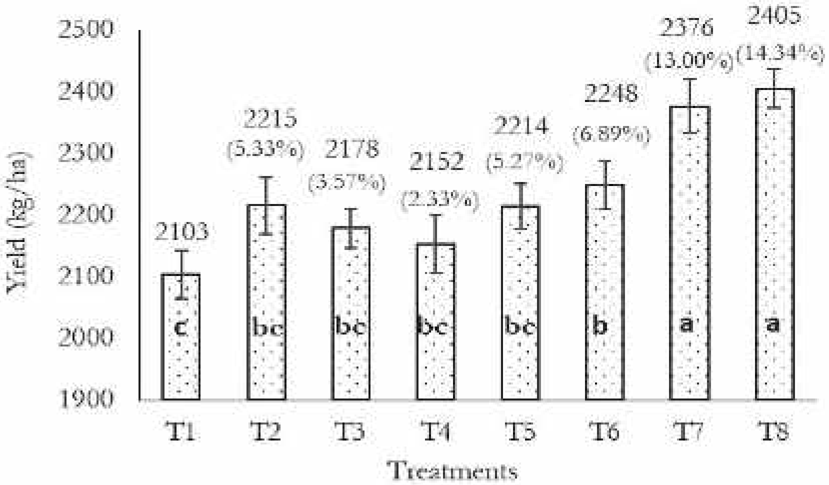

Figure 1. Impact of various treatments on tea yield. The % in the brackets above each bar represent the rate of increase of over control. According to Duncan's multiple range test (DMRT), a significant difference at $p \leq 0.05$ is indicated by the unique letter for each bar

The treatment T_1, which received no fertilization, produced the lowest yield (2103 kg/ha). Nevertheless, the results showed that the greatest yield increase was in the treatment T_8 followed by the treatment T_7 which is 14.34 % and 13.00% over control, respectively and lowest of that was for T_4 which is 2.33%. The yield increase brought about by the various treatments was statistically significant at the 5% level. ($F= 6.87$, $p<0.05$, CV= 3.11).Treatments T_7 and T_8 significantly enhance tea yield compared to the control and other treatments, with T_8 achieving the highest increase. These findings demonstrate the effectiveness of combining vermicompost with chemical fertilizers to optimize tea production.

In the present study, it has been observed that there is no significant difference on T_7 and T_8 which means applying vermicompost @ 3 t/ha with 80% recommended fertilizer dose is as effective as vermicompost @ 6 t/ha with 60% recommended fertilizer dose. But both of the treatments are more effective than applying vermicompost @ 1.5 tons/ha with 100% recommended fertilizer dose and applying vermicompost @ 6t/ha solely. Similar researches have shown that applying vermicompost increased yields of okra, strawberry, eggplant, potato, cucumber cultivars, peppers, crossandra, lettuce, and Amaranthus species (Ansari and Kumar, 2010; Singh et al., 2008; Moraditochaee et al., 2011; Alam et al., 2007; Azarmi et al., 2009; Vijaya and Seethalakshmi, 2011; Arancon et al., 2005; Gajalakshmi and Abbasi, 2002; Papathanasiou et al., 2012 and Uma and Malathi, 2009).

Table 4. Partial budget analysis of the treatments applied on the yield of tea

Treatment	Yield of Made Tea (kg/ha)	Variable Cost			Gross Return (Tk/ha)	Net Return (Tk/ha)
		Fertilizer (Tk/ha)	Labour (Tk/ha)	Total (Tk/ha)		
T_1	2103	0	0	0	420595	420595
T_2	2215	11808	1020	12828	443000	430172
T_3	2178	9441	850	10291	435600	425309
T_4	2152	7094	680	7774	430400	422626
T_5	2214	48000	11220	59220	442775	383555
T_6	2248	23808	3570	27378	449600	422222
T_7	2376	33441	5950	39391	475267	435876
T_8	2405	55094	10880	65974	480933	414959

Note: Gross return = yield × price of a particular product; net return = gross return - variable cost. Assuming that vermicompost costs 10 Tk/kg, urea costs 22 Tk/kg, TSP costs 20 Tk/kg, and MOP costs 13 Tk/kg, the cost of made tea costs 200 Tk/kg, and the labor wage is 170 Tk/day.

From the partial budget analysis (Table 4) it can be seen that highest gross margin was in the treatment T_7 (435876Tk/ha), which was followed by the treatment T_2 (430172 Tk/ha), T_4 (422222Tk/ha), T_3 (425309Tk/ha) and the lowest was in the treatment T_5 (383555Tk/ha). Therefore, T_7 (3 tons/ha vermicompost + 80% recommended chemical fertilizer) is the most profitable treatment due to its high gross margin (Tk 435,876) and relatively lower input costs compared to T_8 (4 tons/ha vermicompost + 100% recommended chemical fertilizer), while yielding the highest production, has diminished profitability due to high input costs. Treatments T_2 to T_6 show varying profitability, with T_6 providing a decent balance between cost and returns. The control (T_1) has no input cost but produces the least yield, indicating that some level of fertilization is necessary to enhance economic returns in tea production. Hence, the dose 3 tons/ha vermicompost with 80% RCFD is more effective considering economic viewpoint.

Conclusion

A crucial aspect of effective tea plantation management lies in the proper supply of nutrients, which is predominantly achieved through using chemical fertilizers. However, it is widely recognized that optimizing crop yield requires a balanced approach to fertilizer use, complemented by the efficient integration of other agricultural inputs. One promising strategy involves the application of vermicompost at a rate of 3 tons per hectare within tea plantations. This practice has been shown to reduce the reliance on chemical fertilizers by up to 20%, thereby promoting sustainable agricultural practices while simultaneously mitigating environmental pollution. Research findings underscore the significant benefits of combining vermicompost with chemical fertilizers, compared to relying solely on either input. This integrated approach not only enhances nutrient availability but also improves soil health, resulting in superior tea production outcomes. Such practices align with the principles of sustainable agriculture, balancing productivity with environmental stewardship.

Acknowledgements

The authors express their gratitudeto the authorities of Bangladesh Tea Board and Director of Bangladesh Tea Research Institute for providing the required facilities for the experiment.

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Tea J. Bangladesh 51, 37-45, 2025
https://doi.org/10.5281/zenodo.15684236
ISSN 0253-5483
Available online at http://www.btri.gov.bd

STANDARDIZATION OF QUALITY ASSESSMENT PARAMETERS OF GREEN TEA FOR ORGANOLEPTIC TASTING METHOD IN BANGLADESH

Md. Ismail Hossain[1]*, Mohammad Masud Rana[2], Md. Riyadh Arefin[3]

Abstract

The quality of green tea, a growing sector in Bangladesh's tea industry, is predominantly assessed through organoleptic methods involving human sensory tasting. However, the absence of standardized evaluation parameters often leads to inconsistencies in grading and quality assurance. This study aims to standardize the quality assessment parameters for green tea in Bangladesh using the organoleptic tasting method. Tea samples from various estates were evaluated based on three primary sensory attributes: Dry Leaf Appearances, Infused Leaf Appearances, and Liquor Characteristics. Dry Leaf Appearance was graded alphabetically from A (Extraordinary) to D (Poor), with emphasis on leaf uniformity, curl, twist, color, and aroma. Infused Leaf Appearances were classified by color and structural integrity, ranging from bright green whole leaves (Excellent) to dull or broken leaves (Poor). Liquor quality was rated on a numerical scale from 1 (Poor) to 5 (Extraordinary), considering factors such as greenish color, astringency, bitterness, body, brightness, freshness and tea characters. The proposed grading system offers a structured approach to sensory evaluation, supporting consistent quality determination across different tea estates. By aligning grading descriptors with sensory benchmarks, the system enhances communication among producers, tasters, and buyers while fostering quality control and transparency in the domestic and international green tea market. The adoption of these standardized parameters is expected to improve the credibility and marketability of Bangladeshi green tea, while also serving as a foundation for training professional tea tasters and promoting industry-wise best practices.

Keywords: Green Tea, Organoleptic, Tea Tasting, Dry Leaf, Infused Leaf, Appearances, Liquor Characteristics

[1]Director (in-charge), Bangladesh Tea Research Institute, Srimangal, Moulvibazar
[2]Principal Scientific Officer (Agronomy Division), Bangladesh Tea Research Institute, Srimangal, Moulvibazar
[3]Scientific Officer (Botany Division), Bangladesh Tea Research Institute, Srimangal, Moulvibazar

*Corresponding author's email: directorbtri@gmail.com (Md. Ismail Hossain)

Introduction

Green tea, processed from the unoxidized leaves of *Camellia sinensis*, holds a prominent position among globally consumed beverages due to its reputed health benefits, delicate flavor, and cultural appeal (Arefin et al., 2020; Prasanth et al., 2019). From its ancient Asian traditions, green tea has become increasingly popular worldwide, including in Bangladesh, where both production and consumption have seen a notable rise over the past decade (Zohora & Arefin, 2022). This upward trend is driven not only by increased health consciousness but also by a growing local and international market that values premium quality tea products (Cabrera et al., 2006). Currently there are 170 tea estates in our country (BTB, 2025) producing a total of 93.04 million kg in 2024 (BTB, 2024) while 1% of these teas were green tea (PDU, 2019). Globally green teas are categorized into two main groups on the basis of manufacturing protocols *viz.* 'green tea by steaming (Japanese Style)' and 'green tea by pan-firing (Chinese Style)' (Arefin et al., 2020). But in our country mainly two premium classes of green teas are available, which are- 'Wiry green tea' and 'Curly green tea'.

In tea-producing countries, the evaluation of tea quality is crucial at every stage of the supply chain, from plucking and processing to packaging and marketing (Rana et al., 2023). Among various assessment techniques, the organoleptic tasting method remains the most traditional and widely employed (Hossain, 2024). This sensory-based evaluation technique relies on the human senses—primarily taste, smell, sight, and touch—to judge the overall quality of the tea (Aaqil et al., 2023). Parameters such as pale green liquor color, mouthfeel are typically considered (Moreira et al., 2024). Despite being a time-honored and essential practice in tea quality assessment, the organoleptic method is inherently subjective, often lacking uniformity and reproducibility, especially in regions where formal training and standardized protocols are not well established (Turgut et al., 2022).

In Bangladesh, the tea industry has made commendable progress, but the absence of a standardized framework for organoleptic tasting has created significant disparities in quality grading. This leads to inconsistencies not only within domestic markets but also in the export sector, where Bangladeshi green tea must compete with products from countries like China, Japan, and India that follow rigorous sensory evaluation standards (Rahman et al., 2021). As the demand for high-quality green tea increases, particularly in health-conscious consumer segments, the need for a scientifically grounded and standardized approach to sensory evaluation becomes imperative.

This research aims to address this critical gap by identifying and standardizing the key organoleptic parameters relevant to the evaluation of green tea produced in Bangladesh. The study involves a systematic investigation of existing tasting practices, the calibration of sensory attributes, and the development of a consistent evaluation to the unique characteristics of Bangladeshi green tea. By engaging with experienced tea tasters, industry stakeholders, and scientific methodologies, this study seeks to contribute to the professionalization and modernization of green tea quality assessment in Bangladesh, ultimately supporting the country's aspiration to position itself as a reliable source of premium green tea on the global stage.

Materials and Methods

A lot of green tea samples from home and abroad, local markets, local manufacturer and BTRI made were collected and evaluated for tasting purposes. Different grades on the basis of size and appearance of green teas were available in our country. Grades were classified as recommended by BTRI (2009) which is given below in Table 1.

Table 1. Different leaf grades of green teas in our country

Sl. No.	Kind of teas	Grade name	Nomenclature
1	WHOLE LEAF	YH	Young hyson
2		FYH	Fine young hyson
3	BROKENS	H	Hyson
4		FH	Fine hyson
5	FANNINGS	SOUMEE	Soumee
6	DUSTTS	DUST	Dust

For organoleptic tasting, at first, liquor was prepared by pouring boiling distilled water in a mug of a capacity of 142 ml in which 2.5 g tea was contained. After three (3) minutes brewing, the lid covered mug the liquor was poured into a bowl and the infused leaf was shaken from the mug into the inverted lid, which was placed on top of the mug. Lastly tea was assessed under three quality assessment parameters, such as: 'Dry Leaf Appearances', 'Infused Leaf Appearances' and 'Liquor Characters' which is described below (Hossain, 2023):

Tea Tasting Technique

For organoleptic tea tasting and scoring, green teas were evaluated by following three steps:

- Dry Leaf Appearance
- Infused Leaf Appearance
- Liquor Characteristics

Dry Leaf Appearance

Assessing the characteristics of dry leaves is a very effective method for determining the overall quality of tea. This evaluation is conducted by spreading the dry leaves on a white sheet of paper and observing their external appearance, aroma, and make. During the evaluation, the following aspects are taken into consideration:

- Uniformity of the leaf grade
- Color of the dry leaves
- Structure and type of the dry leaves
- Nose and Shine of the dry leaves
- Overall impression (or Sensory feel)

Standard Method for Preparing Infused Leaves and Tea Liquor

For organoleptic tea tasting, the process of preparing the tea liquor begins with placing 2.5 grams of tea into a mug with a capacity of 142 ml. Then, 142 ml of boiling water (either distilled water or rainwater) is poured into the mug. The mug is covered with a designated lid and allowed to steep for 3 minutes. After 3 minutes, the tea liquor is poured into a bowl from the covered mug. Once the liquor is fully poured out, the infused leaves are carefully placed on the lid, and the lid is set on top of the now-empty mug.

Infused leaf Appearance

During the evaluation of the infused leaves, special attention must be given to their color, external appearance and aroma. A bright green color is the most desirable in case of green teas, but other colors such as fairly bright green color, quite bright green color, fair green color, only green or dullish may also be observed.

Liquor Characteristics

To taste green tea liquor, a taster must take a small amount of liquor using a tasting spoon and sip it loudly into the mouth. The liquor is then swirled around the tongue and brought into contact with the upper surface of the inside-mouth and the gums. In this way, the taster evaluates the thickness (density) of the liquor, detects the astringency using the back of the tongue, and assesses the bitterness and pungency based on feelings received from the tongue and parts of the mouth. These characteristics together determine the astringency, bitterness, body, brightness, freshness and character of the tea. Additionally, to evaluate the aroma and flavor of the tea, the liquor is drawn toward the back of the oral cavity up to the olfactory nerves in the nose. This process helps the taster perceive the liquor, take in its aroma, and taste it before spitting it out into a spittoon.

Results and Discussions:

Different qualities of tasting parameters like 'Dry Leaf Appearances', 'Infused Leaf Appearances' and 'Liquor Characteristics' are described below:

Dry Leaf Appearances

Typically, dry leaf quality was assessed using an alphabetical rating system (A, B, C, and D). As shown in Table 2, leaves of 'Extraordinary' quality received an 'A' rating and were described as having attractive grades — 'Uniform grade, excellent made, well curled and well twisted, bright green color with excellent shine and extraordinary nose, which were commendable in all respect' which is also recommended in various studies (Wang et al., 2004). Excellent quality leaves were rated 'A-', characterized as 'Uniform grade, well made, well curled and well twisted, bright green color with good shine and good nose which were also commendable in all respect.' Ratings of 'B+', 'B', and 'B-' corresponded to Best, Good, and Fairly Good quality teas, respectively. Meanwhile, Fair, Average, and Below Average teas were rated as 'C+', 'C', and 'C-'. Finally, teas of Poor quality received a 'D' rating and are described as dull, poorly processed, and visually unappealing. Green tea dry leaves may vary with the types of tea and manufacturing procedure. For example, Gyokuro and Kabusecha green tea dry leaves are mainly dark greenish color (Yoshidome et al., 2015) while Kamairicha, Sencha or Bancha are generally light greenish color (Radeva-Ilieva et al., 2025). The size and appearance also differ with the nature of the teas, such as Tencha has the whole leaf appearance, Temomicha is needle shaped while Konacha is found in powder form (Gebely, 2016). So, it is necessary to know about the grades (Table 1) and types of green tea before categorizing the dry leaves.

Table 2. Dry leaf category and ratings with their description

Sl. No.	Description of different types of dry leaf	Dry Leaf Quality	Dry Leaf Rating
1	Bright green color with excellent shine and extraordinary nose. Uniform grade, excellent made, well curled and well twisted. Commendable in all respect.	Extraordinary	**A**
2	Bright green color with shine and excellent nose. Uniform grade, well made, well curled and well twisted, Commendable in all respect.	Excellent	**A-**
3	Fairly bright green color and good nose. Attractive grade, well made, well curled and well twisted.	Best	**B+**
4	Quite bright green color, quite a good made and fairly curled, fairly twisted	Good	**B**
5	Fair green color, fairly curled and twisted	Fairly Good	**B-**
6	Some green color, fair curled and fair twisted.	Fair	**C+**
7	Only fair green color, some curled and some twisted	Average	**C**
8	Little green color, little curled, little twisted.	Below Average	**C-**
9	Dullish greenish, poor make and poorly curled.	Poor	**D**

Infused Leaf Appearances

Table 3 provided various categories of infused leaf based on color and appearances. The infused leaf was classified as "Excellent" when its color was "Bright green color" Conversely, the color "Fairly bright green" was classified as "Best," while "Quite Bright green" was classified as "Good." Again, the infused leaf was classified as 'Average' and 'Below Average' when the color was "Fair green" and "Only fair". The phrase "Dullish" was employed to describe an infused leaf that was "Dull and Poor" in color. Different colors of infused leaves of different green teas are found in numerous countries which vary with type of teas and manufacturing procedure (Gebely, 2016).

Table 3. Different category of 'Infused Leaf' based on colour and appearance

Sl No	Category	Infused leaf colour and appearance
1	Excellent	Bright green color
2	Best	Fairly bright green
3	Good	Quite bright green
4	Average	Fair green
5	Below Average	Only fair green
6	Dullish	Dull and poor

Liquor Characteristics

In organoleptic tea tasting, the quality of the liquor is judged to determine pale liquor color, astringency, bitterness, body, brightness, freshness and character and any manufacturing faults (Yan et al., 2022). In the following table (Table 4), various grades of liquor are presented along with their respective ratings and descriptions. A numerical scale from 1 (lowest quality) to 5 (highest quality) is used for grading the tea.

Table 4. Liquor quality and rating of different types of liqour

Sl. No.	Description of different types of liquor	Liquor Quality	Liquor Rating
1	Exceptionally good teas having very good pale green colour, useful astringency, bitterness, body, brightness, excellent freshness and character (flavour). Commendable in all respect	Extraordinary	**5**
2	Very good pale green liquor colour, useful astringency, bitterness, body, good brightness, good freshness and character (flavour)	Excellent	**4+**
3	Very good pale green liquor colour, useful astringency, bitterness, body, fair brightness, fair freshness and character (flavour)		**4**
4	Good pale green liquor colour, useful astringency, bitterness, body, some brightness some freshness and character (flavour)		**4-**
5	Paler green liquor colour, good astringency and bitterness and good body	Good	**3+ pref (preference)**
6	Paler green liquor colour, good astringency, bitterness and fair body		**3+**
7	Paler green liquor colour, good astringency and bitterness and some body		**3**
8	Paler green liquor colour, good astringency and bitterness, little body		**3-**
9	Fair green liquor colour some astringency and bitterness	Medium/ Average	**2+**
10	Some green liquor color with only a little astringency and bitterness		**2**
11	Plain and thin, only a little green colour	Below Average	**2-**
12	Poor/ Faulty/ Unacceptable tea	Poor	**1**

'Exceptionally good teas having very good pale green colour, useful astringency, bitterness, body, brightness, freshness and also a lot of character (flavour) which were commendable in all respect' were placed in 'Extraordinary' category and ratings of '5' which is also desirable in many studies (Ukers, 1935). 'Excellent' quality but rating of '4+' was described as the liquor of 'pale green liquor colour, useful astringency, bitterness, body, brightness, freshness and good character (flavour)'. Ratings of '4' and '4-' were differed from '4+' in 'fair character' and for 'some character' parameter. Below excellent categories teas there are four categories of teas were placed in 'Good' category but rated as '3+pref (preference)', '3+', '3'and '3-' differently sharing common character – 'paler green liquor colour, good astringency' good bitterness, but differed from each other by 'good', 'fair', 'some' and 'little' body. On the other hand, both liquor of '2+' and '2' were for 'Medium/ Average' quality, were described as 'fair green liquor colour and some astringency and bitterness and 'some green color with only a little astringency and bitterness respectively. When liquor was 'Plain and thin, with only a little green color was termed as 'Below Average' with the rating of '2-'. Liquor of 'Poor/ Faulty/ Unacceptable' quality was termed as 'Poor' with the rating of '1'.

The liquor quality of tea is one of the most critical indicators for assessing consumer preference, market value, and overall sensory appeal. As seen in the present grading system, teas are evaluated based on pale liquor colour, astringency, bitterness, body, brightness, freshness and character (flavour). These parameters align with established literature where organoleptic evaluation remains the prime standard for quality assessment in tea (Okinda Owuor & Obanda, 1998).

High-quality teas, such as those had ratings of 5, 4+, 4 and 4- were characterized by a pale green liquor colour and a balance of astringency, bitterness, body, brightness, freshness and along with pronounced tea character (flavour). These attributes are commonly associated with the presence of catechins, flavonoids, and amino acids, which contribute to both the colour and taste of tea liquor (von Staszewski et al., 2011).

The teas of 3+pref, 3+, 3 and 3- ratings demonstrate acceptable paler liquor color, good astringency and bitterness but vary in terms of body. These differences often arise from variations in plucking standard, leaf age, and processing methods, all of which influence polyphenolic composition and enzymatic activity during fermentation (Obanda et al., 2001).

There are many reasons behind the low quality of green tea, such as, improper steaming, improper fixation, under or excessive cooling and rolling, under or excessive drying etc. (Hamasaki et al., 2016). Average teas, particularly those rated 2+ and 2, lack the essential traits such as green colour, astringency and bitterness while 2- are often described as plain or thin and one are faulty teas respectively. These deficiencies may be due to poor leaf quality or improper steaming and improper roasting and uneven rolling processes (Hamasaki et al., 2016).

Conclusion

This study aimed to establish a standardized framework for assessing the quality of green tea through organoleptic tasting, with a specific focus on the context of Bangladesh. By evaluating key sensory parameters such as Dry Leaf Appearance, Infused Leaf Appearances, and Liquor Attributes, a comprehensive and structured grading system was developed to align with international best practices while incorporating region-specific characteristics of Bangladeshi green tea. The findings underscore the importance of objective and consistent sensory evaluation in ensuring product quality, market competitiveness, and consumer satisfaction. The proposed standardization offers a valuable reference for tea growers, tasters, and quality control professionals, promoting greater uniformity and transparency in quality assessment across the industry. Moving forward, the adoption of these standardized parameters can significantly enhance the branding and export potential of Bangladeshi green tea, while also contributing to the development of skilled tea tasters and a more robust quality assurance system.

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Tea J. Bangladesh 51, 46-58, 2025
https://doi.org/10.5281/zenodo.15715559
ISSN 0253-5483
Available online at http://www.btri.gov.bd

ORGANIC COMPOSITE MANURE: A SUSTAINABLE APPROACH TO IMPROVE SOIL HEALTH AND YIELD IN MATURE TEA

Kanij Fatema Tuz Zohora[1*], Apu Biswas[1], Naim Mustafa Ali[2]

Abstract

Assessment of soil fertility and microbial activity is crucial for preserving soil health and ensuring sustained tea production. This study evaluates the impact of newly developed organic resource-based composite manure, applied through broadcasting methods, on tea yield and soil health, as well as reducing reliance on inorganic fertilizers. The research was conducted at BTRI Farm between 2022 and 2023, using eight treatments and three replications. Harvesting data was collected at weekly interval throughout the plucking season. Treatment T_8, which combined 2.0 t/ha of composite manure with 40% of the recommended chemical fertilizer dose, resulted in the highest yield (2550 kg/ha), a 26.70% increase compared to the control. Although T_8 produced the highest tea yield, the partial economic analysis showed that the most economically viable treatment for mature tea was T_6, which combined 1.5 t/ha of composite manure with 60% of the recommended chemical fertilizer dose, achieving the highest Marginal Rate of Return (21.16%). Higher doses of composite manure paired with reduced chemical fertilizer rates significantly improved tea yield ($^{ANOVA}F$ = 63.348, p < 0.05). Regardless of treatment, soil chemical parameters and microbial activity increased compared to the control. The highest microbial activity (0.58±0.02 mg CO_2/g) was observed in T_8. Treatment T_8 also showed the greatest increase in soil pH (5.53±0.23), organic carbon (1.45%±0.04), total nitrogen (0.130%±0.002), available phosphorous (174.52±2.1 mg/kg), and available potassium (75.97±5.2 mg/kg). Meanwhile, the highest available calcium (400.76±2.2 mg/kg) and available magnesium (103.86±1.6 mg/kg) were found in T_3 and T_5-treated plots, respectively. These changes represent significant improvements over the initial soil conditions, and the organic composite manure can enhance not only the soil properties but also increase the yield of mature tea. Therefore, it can be summarized that the most effective dose of composite manure is 1.5 t/ha, which can reduce 40% of the use of chemical fertilizers.

Keywords: Composite Manure, Microbial Activity, Yield, Tea

[1] Senior Scientific Officer, Soil Science Division, Bangladesh Tea Research Institute, Srimangal, Moulvibazar
[2] Scientific Officer, Soil Science Division, Bangladesh Tea Research Institute, Srimangal, Moulvibazar

*Corresponding author's email: kanij@btri.gov.bd (Kanij Fatema Tuz Zohora)

Introduction

Tea is a widely consumed and reasonably priced beverage prepared from the leaves of *Camellia sinensis* (L.) O. Kuntze plants that are grown for commercial purposes (Saha et al., 2022). Optimal tea production requires the addition of external nutrient and regular fertilizer application. According to Khan et al (2013), fertilizer is a key agro-input that enhances productivity in tea crops. To maintain the soil health and yield of tea bushes, fertilization needs to be balanced at regular intervals throughout the year especially application of both natural and synthetic fertilizers in an appropriate integrated approach (Sarwar et al., 2007 & Khan et al., 2013).

The primary necessity for soil conservation and sustainable crop production is proper nutrient resource management and soil fertility preservation, which can be achieved through a combination of inorganic and organic fertilizer applications (Khan et al., 2013). Organic manure provides a longer residual effect, releasing nutrients gradually and ensuring prolonged retention in the soil, which enhances nutrient availability (Sing et al., 2011). The another research also illustrated that, organic fertilizer also serves as a nutrient reservoir; when added to soil it can boost water retention and make nutrients more accessible to plants (Khan et al., 2013; Zohora et al., 2022).

The new formulation of organic recourses based composite manure is such a organic substance which can be effect on both nutrient addition and microbial activity influencer. To make this organic fertilizer different types of organic resources, plant materials and animals residues such as vermicompost, trichocompost, Neem leaf, Bashok leaf, Onion peel, Banana Peel, Egg shell, Rice husk ash, Bone meal , Horn meal are used.

In addition to their antibacterial and antioxidant qualities, onion peels are a good source of sulfur, magnesium, salt, calcium, quercetin, potassium, phosphorus, zinc, iron, iodine, vitamins, pectins, saponins, flavonoids, and other beneficial compounds that can affect plant growth and yield (Source: 1). Neem, which contains azadirachtin (AZTA) and other active ingredients, works especially well against pests of stored grains, such as maize worms, beetles, tunnels, thrips, and white flies. Neem is effective against almost 200 types of insects, it turns out tea bushes' well-being and achieving a good yield (Source: 2). Eggshells are made from crushed eggshells, which are high in calcium carbonate, a mineral reinforcing plant cell walls. The shells also contain other elements (such as magnesium, phosphorus, and potassium) that help plants thrive. As a result, eggshells provide a cheap and efficient fertilizer for plant and soil (Source: 3). Vermicompost and trichocompost include plant growth-promoting elements created by microorganisms (Tomati et al., 1988; Grappelli et al., 1987). Nuss & Tanumihardjo, (2010); Chen & Aviad, (1990) claimed that by lowering the carbon-to-nitrogen (C:N) ratio and supplying readily available nutrients like nitrogen, phosphorus , potassium, calcium, and magnesium vermicompost application enhances plant rhizospheres, stabilizes soil, and encourages crop growth and production. Furthermore, vermicompost promotes microbial activity, including bacteria, fungi, and actinomycetes, which regulate soil nutrients and significantly impact yield characteristics.

It has been discovered that bashok leaves have a pesticidal effect on *Helopeltis* that why different tea gardens in Bangladesh use the plant as hedge on the tea sections , banana peel is a great source of potassium; where Bone meal and Horn meal is also a resourvour for phosphorous. According to Silvasy et al. (2021), the high (9–10%) nitrogen (N) concentration of bone meal has made it a desirable option for organic fertilization. Rice husk ash, on the other hand, is a soil supplement that significantly affects both pest infestation and plant development.

Tea, a monoculture crop, is the world's least expensive beverage. For continuous cultivation of tea, it has need proper fertilizations as well as for sustainable production tea needs not only chemical fertilizer but also organic fertilizer for balanced nutrition (Zohora et al., 2022). The use of both organic and inorganic fertilizers is critical for sustaining soil fertility since it raises microbial biomass, improves soil health, boosts the efficiency of inorganic fertilizers, and lowers their overall cost (Garcia et al., 2021). At the same time tea plant requires highest microbial activity for nutrient uptake. However, there are rare conducted on all of the materials which was used for the manure formulation. That's why the new formulation organic resources based composite manure is produced.

This study aims to assess the effects and ideal doses of the composite manure required for broadcasting applications to reduce reliance on chemical fertilizers, improve soil health, and increase the economically viable yield of mature tea.

Materials and Methods

At BTRI Farm (Latitude: 24˚17′36.7″N, Longitude: 91˚44′53.7″E, and Altitude: 40m), an experiment was conducted from January 2022 to December 2023 to examine the effects of composite manure on soil properties and the yield of mature tea plants. Using a Randomized Complete Block Design (RCBD), the study included three replications and eight treatments with the unit plot size was 11.77 sq.m to evaluate the influence of organic resource-based composite manure on soil characteristics and yield of mature tea.

Treatment details

T_1= Control
T_2= 100% BTRI recommended fertilizer application (N^{100}, $P_2O_5^{30}$, K_2O^{60} kg/ha)
T_3= Composite manure 1.0 ton/ha
T_4 = Composite manure 1.0 ton/ha + 80% T_2
T_5 = Composite manure 1.5 ton/ha
T_6 = Composite manure 1.5 ton/ha + 60% T_2
T_7 = Composite manure 2.0 ton/ha
T_8 = Composite manure 2.0 ton/ha + 40% T_2

Formulation of composite manure

A sustainable proportion of ten different types of organic resources, including plant and animal residues, such as vermicompost, trichocompost, neem leaf and bashok leaf, onion peels, banana peels, egg shells, rice husk ash, bone meal, and horn meal, were used to create the organic resources-based composite manure. Vermicompost and trichocompost were made in BTRI. Neem and Bashok leaves were collected from nearby forest vegetation while onion peels, banana peels, and egg shells were collected from nearest local market with cheap price. They were dried in sun and grinded by a grinder matchine. To make rice husk ash, straw were bought from local market and burn in standerd method. On the other hand bone meal, and horn meal were purchased with cheap price. All prepared materials were combined to create this composite manure.

Fertilizer application

Based on the experimental plot's average production over the previous five years nitrogen, phosphorus, and potassium nutrients were administered using urea, triple superphosphate (TSP), and muriate of potash (MOP). TSP was applied during the first fertilizer application split, while urea and muriate of potash fertilizer were applied in two splits. When the soil had enough moisture, the first dose of inorganic fertilizer was given in April. The second dose was put during the first week of August. Before 15 days of chemical fertilizer application throughout the year, organic resources-based composite manure was spread out and combined with the soil using light forking in two separate dosages. Prior to fertilization, dolomite was administered in all experimental plots except the control, contingent on the pH of the soil and enough soil moisture.

Yield of tea and soil sample collection and analysis method

Fresh tea leaves were weighed at intervals of seven days. Pest management, pruning, irrigation, and other intercultural tasks were carried out as needed. Surface soil (0–23 cm) samples were collected from all of the experimental plots' during before and after the experiment. Soil texture, pH, organic carbon (%), total nitrogen (%) available phosphorus (mg/kg), available potassium (mg/kg), available calcium (mg/kg), available magnesium (mg/kg), and soil microbial activity were all assessed.

The hydrometer method was used to determine the texture of the soil (Bouyoucos, 1962). However, a pH meter (InoLab pH 7110) was used to measure the pH (soil: distilled water = 1: 2.5) (Mclean, 1982). The Micro Kjeldahl steam distillation method was used to determine the total nitrogen (Bremner and Mulvaney, 1982). To determine the amount of organic carbon in soil, the Walkley and Black wet oxidation method was used (Walkley and Black, 1934). The Bray-II ascorbic acid (Blue Color) method was used to colorimetrically estimate the amount of phosphorus that was accessible (Murphy and Riley, 1962). Organic carbon and accessible phosphorus were measured using a Jenway 6300 spectrophotometer.

According to Peterson (2002), a 77% ammonium acetate solution was used to extract the available potassium, calcium, and magnesium. A BUCK- Scientific PEP7 flame photometer was used to measure the amount of potassium that was available, and an Analytikjena atomic absorption spectrophotometer (AAS) was used to measure the amounts of calcium and magnesium.

Manure analysis method

The moisture content was computed as a percentage using Blume's (1985) method. A JISICO Muffle Furnace (Model: J-FM-28) was used to measure the manure's Organic Matter (%) and Organic Carbon (%) at 550°C (Nelson and Sommers, 1982 & Yeomans and Bremner JM 1988). A pH meter (InoLab pH 7110) was used to measure the manure samples' pH. Distilled water was used to create the manure suspension in a 1:10 manure:water ratio (Jodice et al., 1982). The Micro Kjeldahl steam method was used to calculate the total nitrogen (N) (Haq and alam, 2005). The colorimetric approach, also known as the Blue color method, was employed to determine the total P using a spectrophotometer (JENWAY 6300). The manure sample's total potassium (K), total calcium (Ca), total magnesium (Mg), total zinc (Zn), and total copper (Cu) were measured using the Atomic Absorption Spectrophotometer (AAS) (Analytikjena. Model: novAA 400P) Jackson (1973) after being digested using the nitric acid-perchloric acid digestion method (Haq and alam, 2005).

Soil microbial activity

The soil samples were meticulously blended and treated with 0.4% glucose in order to estimate glucose-induced respiration. In order to absorb CO_2, 10 milliliters (ml) of 0.05N NaOH were added to the vials. Once more, 20g of soil were placed in the jar, sealed tightly, and allowed to incubate for four hours. The generated and absorbed carbon dioxide was then measured titrimetrically, much like in soil respiration. The result was expressed as mg CO_2/g of soil (Bauer et al., 1991).

Statistical and economic analysis

The yield and soil fertility data were presented as the arithmetic mean values with standard errors. All the data were documented and statistically examined by using Microsoft excel, Statistix 10 software. The data were analyzed using one-way ANOVA the Analysis of Variance of Simple Classification. Treatments that were significant were analyzed with Tukey's post hoc test at 5% level of significance. Marginal rate of return was calculated by subtraction of marginal net return and marginal total variable cost to find out the most cost-effective doses of the newly made organic resources based composite manure.

Results and Discussion

Analysis of the Composite Manure

A physico-chemical study of the newly created composite manure used in the experiment shows that it contains total N (2.96%), P (3.87%), and K (2.44%) in addition to being a great source of organic C (24.94%) as well. The analytical results show that the composite manure meets all government-approved critical limits (Table 1). It exhibits ideal physical, chemical, and biological properties, making it suitable for agricultural use. The low C:N ratio and balanced nutrient profile indicate that the manure is well prepared and will enhance soil fertility effectively without causing nitrogen immobilization or nutrient imbalances. On the other hand, the heavy metals like zinc (0.09%), manganese (0.08%) and copper (0.03%) which are in safe level for application in soil respectively.

Table 1. Physico-chemical properties of Composite manure

Parameter	Analytical result	Government Approved Critical Limits (Ahmmed et al., 2018)
Color	Dark Gray	Dark Grey to Black
Odor	Absence of foul odor	Absence of foul odor
Physical Condition	Non granular	Non granular
Moisture%	12.22	10 - 20
pH	8.74	6.0 - 8.5
Organic Carbon %	24.94	10 - 25
Total Nitrogen %	2.96	0.5 - 4.0
C:N	8.43:1	20:1(max)
Total Phosphorous %	3.87	0.5 - 3.0
Total Potassium %	2.44	0.5 - 3.0
Total Calcium %	2.97	-
Total Magnesium %	1.44	-
Total Zinc %	0.09	0.1 (max)
Total Manganese %	0.08	0.1 (max)
Total Copper %	0.03	0.05

Changes of Soil Physiochemical Properties

Both Table 2 and Figure 1 provide the analytical results of the soil samples that were taken from the experimental plots both before and after the experiment was set up. The textural class of the soils of the experimental plots were Sandy Clay Loam.

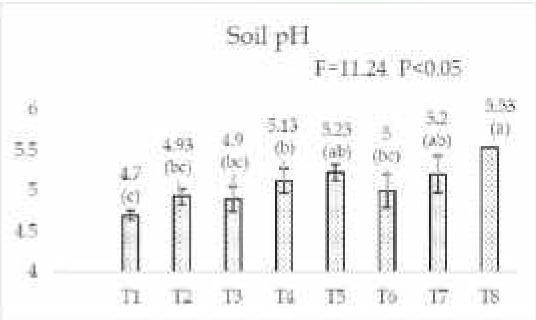
The soil analytical results showed that (Table 2) the study area had a pH, organic carbon (O.C), within the critical limit but total nitrogen (N), available phosphorus (Av. P), available potassium (Av. K), available calcium (Av. Ca), and available magnesium (Av. Mg) below the tea soil's crucial threshold (Table 2). Although the original soil is somewhat fertile, it lacks calcium, magnesium, potassium, and phosphorus. Although the soil has sufficient amounts of organic carbon and nitrogen, its nutrient shortages make fertilization and soil amendments necessary to maximize fertility for improverd crop production.

Table 2. Preliminary physiochemical characteristics of the experimental site's soil

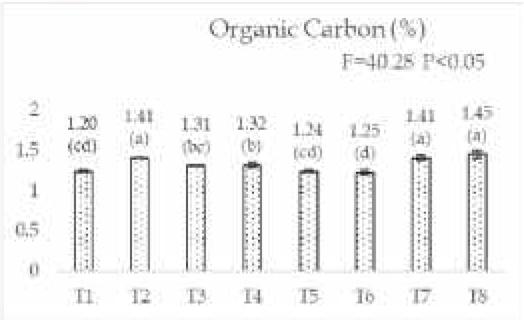
Location	Texture	pH	O.C (%)	Total N (%)	Av. P (mg/kg)	Av. K (mg/kg)	Av. Ca (mg/kg)	Av. Mg (mg/kg)
BTRI Farm	SCl	4.8	1.01	0.097	8.12	35.78	67.74	18.61
Critical value	SL – L	4.5-5.5	1.0	0.1	10	80	90	25

Following the conclusion of the experiment, Figure 1 shows that the soil textural class remained unchanged. Treatment T_8 had the highest pH (5.53), while T_1 had the lowest pH (4.70). The pH variation in the surface soils (0–23 cm) of several treatment plots is shown in a bar chart in Figure 1. The variations in soil pH between treatment groups were statistically significant ($^{ANOVA}F= 11.24$, $P<0.05$). The same letter states that there are no significant variations among the groups receiving treatment.

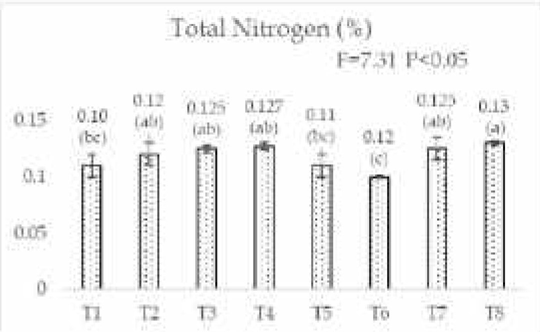
The highest OC (1.45%) was found in treatment T_8 and the lowest OC (1.20%) was found in case of treatment T_1, which is presented in Figure 1. It is evident from Table 2 and Figure 1 that the application of chemical fertilizer in conjunction with the composite manure had an impact on the increase of soil organic carbon content over initial soil carbon. The differences of OC were statistically significant ($ANOVA^F$= 40.28, P<0.05). Improved plant development in the plots that received the combined application of inorganic and composite manure was probably the reason for the higher levels of organic residues in the soil. These outcomes closely align with Hegde's findings (Hedge, 1996 & Zohora et al., 2022).



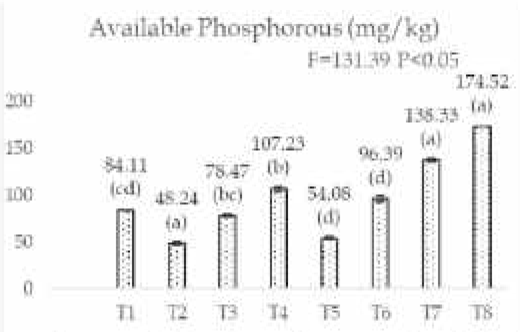
(a) Soil pH



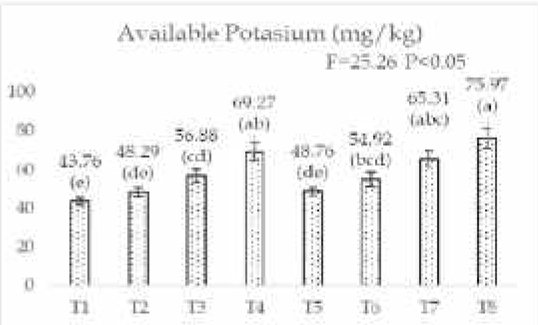
(b) Organic Carbon%



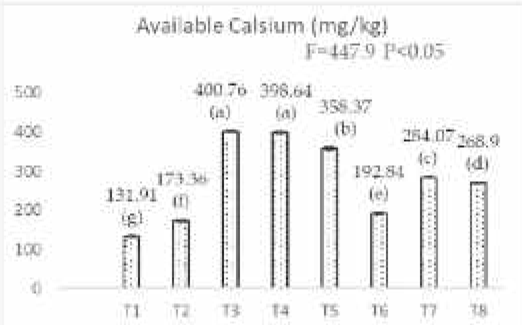
(c) Total Nitrogen%



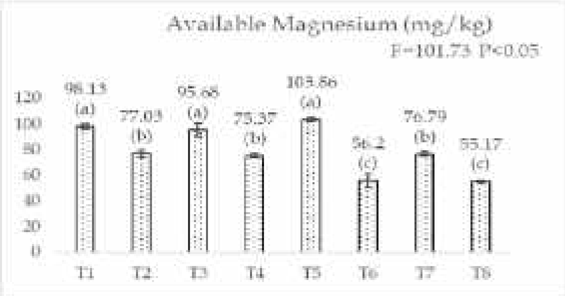
(d) Available Phosphorous (mg/kg)



(e) Available Potassium (mg/kg)



(f) Available Calsium (mg/kg)



(g) Available Magnesium (mg/kg)

Figure 1. (a) Soil pH, (b) Organic Carbon%, (c) Total Nitrogen%, (d) Av.Phosphorus (mg/kg), (e) Av.Potassium (mg/kg) , (f) Av.Calcium (mg/kg), and (g) Av.Magnesium (mg/kg) in the soil of different treatments at the conclusion of the experiment are displayed in bar chart. Sample numbers are indicated by figures in parenthesis. An analysis of variance (ANOVA) test yielded the F-value and P-value are included. The F-value and P-value stand for the F-ratio, which shows how much variance there is among the treatments and how significant that variation is, respectively. The grouping for the treatment obtained using one-way ANOVA to distinguish pair-wise the mean of each treatment is indicated by the Tukey letters a, b, c,d,e,f, g. There aren't many notable differences between the treatments that have the same letters

The application of manure and the combination of chemical fertilizers under the treatments caused organic matter to accumulate, which in turn increased the amount of total nitrogen in the soil by reducing nitrogen losses through organic matter (Saha et al., 2022). In (Figure 1) total N content is higher (0.13%) in case of T_8 the lowest total N (0.10%) was found in case of treatment T_1. The differences of total N among the different treatment was statistically significant ($ANOVA^F= 7.31$, $P<0.05$). The same letter states that there are no notable variations among the groups receiving treatment.

Furthermore, the effects of various treatments on the variations in soil Av.P, Av.K, Av.Ca, and Av.Mg are depicted in Figure 1. T_8 had the highest soil Av.P (174.52 mg/kg) and Av.K. (75.97 mg/kg), while T_2 had the lowest (48.24 mg/kg) Av.P and T_1 had the lowest (43.76 mg/kg) Av.K. The maximum Av.Ca and Av.Mg were found in T_3 (400.76 mg/kg) and T_5 (103.56 mg/kg), respectively. Figure 1 illustrates the notable variation in Av.P, Av.K, Av.Ca, and Av.Mg across all treatments. The same letter that contained treatment did not significantly differ from one another.

Soil Microbial Activity analysis

The most significant microbial characteristic that affects soil health is thought to be microbial activity (MA), which affects biological processes, soil physical and chemical characteristics, and, ultimately, agricultural ecosystem productivity (Sanjida et al., 2024). According to the treatment application the microbial activity increased over control (Figure 2). The highest microbial activity was found in T_8

(0.58 mg CO_2/g). Depending on soil management, Sanjida et al. (2024) also showed that organic matter levels may increase soil microbial activity while lowering the need of chemical fertilizers and pesticides and minimizing their detrimental impacts on soil microbes. The increase of microbial activity with various treatment was statistically significant (^{ANOVA} $F= 357.07$ $P<0.05$).

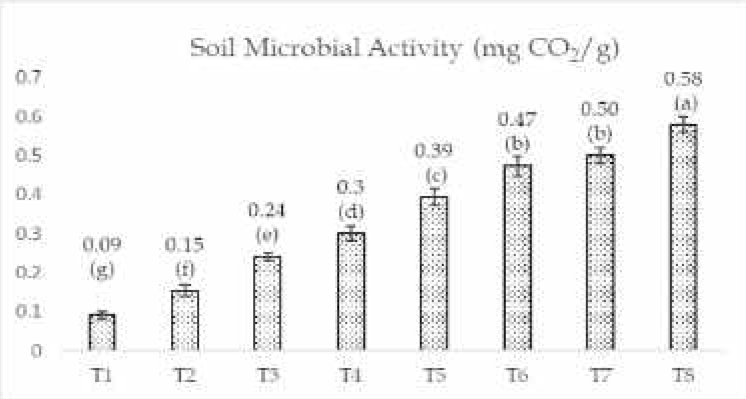


Figure 2. Variations in treatments' effects on soil microbial activity. The rate of rise in over control is shown by the (mg CO_2/g) in the brackets above each bar. According to the Tukey post hoc test, significant differences are indicated by a distinct letter above each bar at p≤0.05

Analysis of Tea Yield

Figure 3 illustrates the impact of composite manure on tea yield. Every treatment has seen an increase in yield compared to the control. Treatment T_8, which involved applying 40% of the suggested chemical fertilizers together with 2 tons of composite manure per hectare, produced the highest amount of tea (2550 kg/ha).

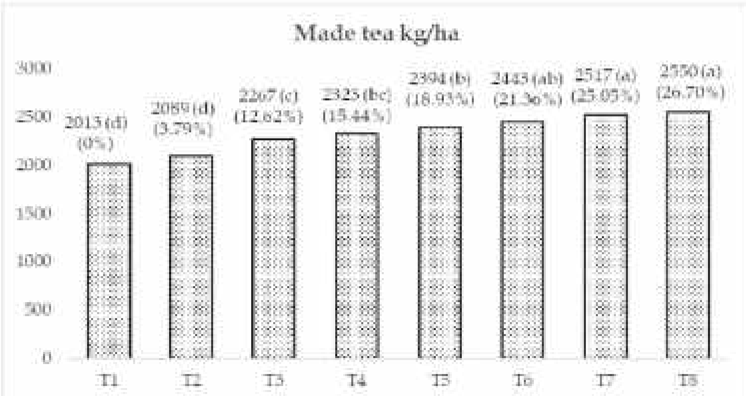


Figure 3. Impact of various treatments on tea yield. The rate of rise over control is shown by the percentage in the brackets above each bar. According to the Tukey post hoc test, significant differences are indicated by a distinct letter above each bar at p≤0.05

In the instance of treatment T_8, 26.70% was the rate of increase over the control. The second-best treatment, T_7, produced 2517 kg of tea per hectare and increased at a rate of 25.05% over the control. In treatment T_2, where only 100% of the required dosages of chemical fertilizers were applied, the yield of produced tea rose by 3.79% compared to the control. There was a statistically significant difference in tea yield across all treatments ($ANOVA^F = 63.348$, $p < 0.05$).

Economic analysis

All of the treated plots saw a considerable increase in tea yield when compared to the control plot. Average Cost of composite manure = 40 tk/kg, Urea = 22 Tk/kg, TSP = 20 Tk/kg and MOP = 13 Tk/kg, Made tea price = 195 Tk/kg, labour wage = 178.50 Tk/day.

- A product's gross return is equal to its yield times its price;
- Net return is equal to its gross return less its variable cost.

The yield generated in the manure-treated plot was the same, increasing from 2013 kg/ha to 2550 kg/ha. From the economic analysis (Table 3) it can be seen that highest net return was in the treatment T_8 (392473 TK/ha) with 2.80% rate of increase over control and treatment T_1 had lowest net return (381775 Tk/ha).

Table 3. Net Return rate of percentage from yield of different Treatments

Treatment	Made tea (kg/ ha)	Total Variable cost (Tk/ha)	Gross Return (Tk/ha)	Net Return (Tk/ha)	Rate of increase over control (%)
T_1	2013	10710	392485	381775	0.00
T_2	2089	23644	407346	383702	0.50
T_3	2267	55220	442022	386802	1.32
T_4	2323	65363	453073	387709	1.55
T_5	2394	77220	466791	389571	2.04
T_6	2443	85082	476317	391235	2.48
T_7	2517	99220	490797	391577	2.57
T_8	2550	104802	497275	392473	2.80

Partial budget analysis

Nevertheless, T_8 (2 tons/ha composite manure + 40% RFD) had a far greater tea production and performance. Comparing all treatments from an economic perspective, however, T_6 (1.5 tons/ha composite manure plus 60% RFD) had the highest marginal rate of return (21.16%), whereas T_7 (2 tons/ha composite manure) had the lowest marginal rate of return (2.42%) (Table 4). So, T_6 (1.5 ton/ha composite manure + 60% RFD) is the most economically acceptable doses of the new formulation composite manure for application in mature tea plantation as broadcasting.

Table 4. Partial budget of different dose of composite manure applied in mature tea

Treatment	Net Return (Tk/ha)	Marginal Net Return (Tk/ha)	Variable Cost (Tk/ha)	Marginal Variable Cost (Tk/ha)	Marginal Rate of Return (%)
T_8	392473	896	104802	5582	16.06
T_7	391577	342	99220	14138	2.42
T_6	391235	1664	85082	7862	21.16
T_5	389571	1861	77220	11857	15.70
T_4	387709	907	65363	10143	8.95
T_3	386802	3100	55220	31576	9.82
T_2	383702	1927	23644	12934	14.90
T_1	381775	0.00	10710	0.00	0.00

- Marginal Net Return: A farm's revenue increase caused by increasing one extra unit of inputs.
- Marginal Variable Cost: The increase in the variable cost of farm caused by increased output by one extra unit
- Marginal Rate of Return % : (a/b*100)
- RFD= Recommended chemical fertilizer dose

Conclusion

Around tea plantations a crucial component of nutrition management is the use of chemical fertilizers to provide nutrients. However, to improve the soil qualities of tea and boost up tea production, both organic and inorganic fertilization are necessary. Treatment T_8 (composite manure 2.0 tons/ha plus 40% recommended fertilizer dosages) produced the maximum yield (2550 kg/ha) in this study, which was 26.70% more than the control. Moreover, treatment T_2, recommended dose of chemical fertilizer 100%, has given the lowest yield 2089 kg/ha (3.79%). From partial economic analysis it can be concluded that though T_8= Composite manure 2.0 ton/ha + 40% recommended fertilizer dosages has given the highest yield (2550 kg/ha, 26.70%) but the Marginal Rate of Return is the highest (21.16%) at treatment T_6 = composite mature 1.5 ton/ha + 60% recommended which is the most economical viable dose of this fertilizer for broadcasting application. Tea planters could use NPK fertilizers with the new formulated composite manure in two splits at 15-day interval to reduce the enormous loss of inorganic fertilizers and their damaging effects on the soil. This experiment made it abundantly evident that applying composite manure in addition to chemical fertilizer can increase tea yield. It might be suggested as an organic fertilizer to enhance the microbiological and physiochemical characteristics of soil and to increase the yield of mature tea.

Acknowledgements

The authors are grateful to the Bangladesh Tea Board and the Director of the Bangladesh Tea Research Institute for providing the necessary facilities for the experiment.

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Tea J. Bangladesh 51, 59-66, 2025
https://doi.org/10.5281/zenodo.15684119
ISSN 0253-5483
Available online at http://www.btri.gov.bd

EFFECT OF DIFFERENT GERMINATION MEDIA ON TEA SEED GERMINATION AND EARLY GROWTH PARAMETERS OF SEEDLINGS

Md. Riyadh Arefin[1*], Md. Ismail Hossain[2], Md. Abdul Aziz[3]

Abstract

Tea (*Camellia sinensis*) is a commercially important crop, and successful seed germination plays a critical role in ensuring uniform seedling establishment and plantation sustainability. This study investigated the effects of seven different germination materials or media—soil (T_1), polythene sheet (T_2), jute sack (T_3), plant ash (T_4), sawdust (T_5), straw (T_6), and sand (T_7)—on the germination and early growth of tea seedlings. Significant differences were observed in germination percentages among treatments. Sand (T_7) and sawdust (T_5) recorded the highest germination rates at 92.92% and 92.18%, respectively which are statistically similar, likely due to their favorable physical properties such as good aeration and moisture balance. In contrast, polythene sheet (T_2) showed the lowest germination (52.38%), possibly due to poor gas exchange and excess heat accumulation. Early growth parameters—including plant height, basal diameter, number of branching, root dry matter, shoot dry matter and total dry matter accumulation—showed no statistically significant differences ($p > 0.05$) among treatments. Overall, the results highlight that germination media significantly affects seed emergence, while its influence on early seedling growth is less pronounced under controlled conditions. Sand and sawdust are recommended as effective germination media for tea propagation, but subsequent seedling growth may be limited under controlled conditions, and mostly dependent on post-germination environmental conditions as well as cultural practices.

Keywords: Tea, Seed, Germination, Sand, Sawdust

[1]Scientific Officer (Botany Division), Bangladesh Tea Research Institute, Srimangal-3210, Moulvibazar
[2]Director (in-charge), Bangladesh Tea Research Institute, Srimangal-3210, Moulvibazar
[3]Chief Scientific Officer (Botany Division), Bangladesh Tea Research Institute, Srimangal-3210, Moulvibazar

*Corresponding author's email: riyadh.btri@gmail.com (Md. Riyadh Arefin)

Introduction

Tea (*Camellia sinensis* L.) is a perennial evergreen shrub native to Southeast Asia and is widely cultivated for its young leaves, which are processed to produce one of the most consumed beverages in the world—tea (Kouidhi et al., 2015). As a significant commercial crop, tea contributes substantially to the economy of several countries, including Bangladesh, where it supports both large-scale plantations and smallholder farmers (Ibrahim et al., 2025). The successful establishment of tea plantations depends heavily on the initial stages of plant development, particularly multiplication by both cuttings (asexual propagation) and seedlings by tea seed (Mukhopadhyay & Mondal, 2017). Plants raised from seeds contains tap root system, help them to survive in extreme drought condition than the plants from cutting (fibrous root system) (Qian et al., 2018). However, the germination of tea seeds is often inconsistent and influenced by various biotic and abiotic factors, including the type of germination medium used.

Tea seeds possess a relatively hard seed coat and exhibit physiological dormancy, which can result in delayed and uneven germination (Chen et al., 2012). Therefore, creating a conducive microenvironment for seed germination is essential for increasing germination rates in nurseries. Traditionally, sand has been used as the standard germination medium in tea and other crops due to its excellent drainage, ease of aeration, and minimal compaction (Chagonda et al., 2023; Tobe & Gao, 2007; Alam, 2003). However, reliance on sand alone may not be sustainable or cost-effective in all regions, particularly where it is not readily available or where other local materials may provide similar or improved results.

In light of these considerations, we have been exploring alternative materials that could enhance the germination performance of tea seeds and promote better early growth of seedlings. The choice of germination medium plays a pivotal role in determining the water-holding capacity, aeration, temperature regulation, and microbial activity around the seed, all of which are vital for breaking dormancy and supporting the physiological processes involved in germination (Nautiyal et al., 2023). The use of locally available and low-cost materials as germination media not only offers economic benefits but may also improve the environmental sustainability of tea nurseries.

This study investigates the effect of seven different germination materials—only soil, polythene sheet, jute sack, plant ash, sawdust, rice straw, and sand—on the germination and early growth of tea saplings. Among these, sand serves as the control, as it is the medium most commonly used in conventional tea nurseries. Each of the alternative materials offers unique physical and chemical properties that may influence the germination environment (Hilhorst & Karssen, 2000). By exploring diverse and locally adaptable germination materials, this research aims to contribute practical insights to nursery management practices, helping tea growers enhance the efficiency of seed propagation and reduce losses during the critical early stages of growth. The specific objectives of this study are:

- To evaluate the germination performance of tea seeds under seven different germination media.
- To assess the early growth parameters of tea saplings, such as height, number of branches, dry weights and root development, etc. in each medium.
- To identify the most effective and practical alternatives to sand for use in tea nurseries.

Materials and Methods

Tea seeds of BTS1 seedstock (released seedstock variety of BTRI) were collected from Bilashcherra Experimental Farm and seeds were cleaned by washing and kept under water for three hours for viability test by sinker-floating test (Patel et al., 2018). Viable seeds were collected and kept in nursery for germination (cracking) by covering following different treatments (T_1-T_7) media. All covering materials or germination medias were preliminary sterilized and then used for germination test. 100 seeds were used for counting the germination percentage for all treatments

(Figure 1 and 2) Watering was applied with every alternate day to facilitate the germination (Visser & Dewaas, 1958). Treatments were:

- T_1= Germination media of 'Soil'
- T_2= Germination media of 'Polythene sheet'
- T_3= Germination media of 'Jute sack'
- T_4= Germination media of 'Plant Ash'
- T_5= Germination media of 'Sawdust'
- T_6= Germination media of 'Straw'
- T_7= Germination media of 'Sand'

Figure 2. Cracked seed placement in polybag

Figure 1. Placing of seeds on different media

Figure 3. Observation of seedling growth

Following data were collected during the experiment:

a. Germination percentage (GP %): The percent of GP was calculated by the equation of GP % = (number of germinated (cracked) seed / number of seeds used for germination) x 100 (Ghaleb et al., 2022).

Germinated (cracked) seeds were planted in polybag and following growth related traits were collected after 10 months (Figure 3)-

b. Plant height (PH): The plant's height (PH) was measured in centimeters (cm) from the soil's surface to the tip of the shoot.

c. Base diameter (BD): BD was measured at 1 cm above soil surface in centimeter (cm) scale.
d. Number of branches (NB): NB is the branches of each seedling (Ahmed et al., 2024).
e. Vertical root length (VRL): The VRLs of each treatment were calculated after carefully washing the roots (keeping intact) in centimeter (cm) scale.
f. Shoot dry weight (SDW): After the shoots were oven-dried for 72 hours at 80 ± 2°C, SDW (g) was measured.
g. Root dry weight (RDW): RDW (g) was measured after oven drying of root at 80 ± 2°C for 72 hours.
h. Total dry weight (TDW): TDW (g) was calculated by the formula, TDW= (SDW+RDW).

The experiment was conducted with 3 replications by RCBD design. Means of growth traits of each replication were calculated by averaging of data of 10 saplings. Analysis of variance (ANOVA) was analyzed by using Minitab (developed by Minitab, LLC-2024) and the graph was made by Microsoft Excel-2019.

Results and Discussion

Germination percentages of tea seed

Figure 4 illustrated the germination percentages of tea seeds under seven different germination materials: soil (T_1), polythene sheet (T_2), jute sack (T_3), plant ash (T_4), sawdust (T_5), straw (T_6), and sand (T_7). Among these, sand (T_7) showed the highest germination percentage at 92.92%, closely followed by sawdust (T_5) at 92.18% but statistically similar, indicating that these materials provided the most favorable conditions for seed germination, likely due to their good moisture retention and aeration.

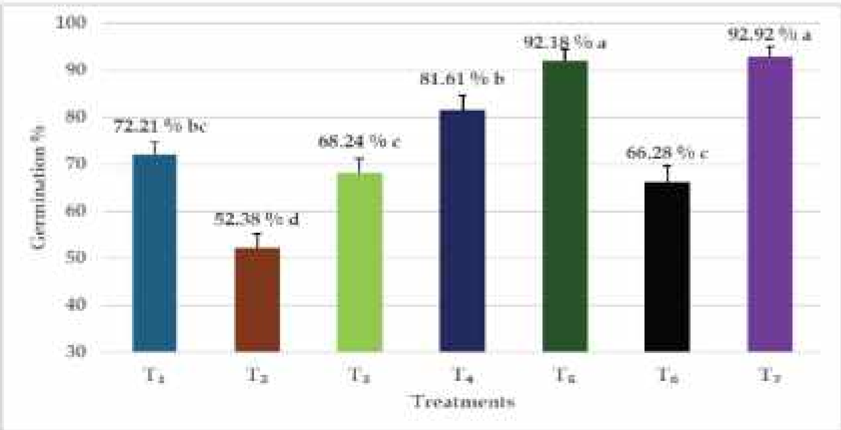

Figure 4. Effect of different germinations media (treatments T_1-T_7) on tea seed germination %. T_1, T_2, T_3, T_4, T_5, T_6 and T_7 were the used germination media of 'soil', 'polythene sheet', 'jute sack', 'plant ash', 'sawdust', 'straw' and 'sand' respectively

Plant ash (T_4) and soil (T_1) also performed relatively well, with 81.61% and 72.21% germination, respectively. Jute sack (T_3) and straw (T_6) resulted in moderate germination rates of 68.24% and 66.28%, while the polythene sheet (T_2) showed the lowest germination at 52.38%.

The observed variation in tea seed germination percentages across different treatments reflects the influence of physical and environmental properties of germination materials on seed physiology. Sand (T_7) and sawdust (T_5), which exhibited the highest germination rates (92.92% and 92.18%, respectively), likely provided optimal aeration, moisture balance, and drainage—conditions critical for uniform water uptake and gas exchange, which support rapid metabolic activation and radicle emergence (Abeyrathna et al., 2015). The performance of plant ash (T_4, 81.61%) and soil (T_1, 72.21%) may be attributed to their moderate water-holding capacity and nutrient content, which can enhance enzymatic activities and cellular processes necessary for germination. In contrast, jute sack (T_3, 68.24%) and straw (T_6, 66.28%) possibly offered inconsistent moisture retention and reduced root anchorage, resulting in suboptimal conditions. The lowest germination percentage was recorded under the polythene sheet treatment (T_2, 52.38%), which may have created a hypoxic microenvironment due to restricted gas exchange and elevated temperature, impairing respiration and delaying or inhibiting germination (Díaz-Hernández & Salmerón, 2012). These findings underscore the importance of selecting germination media that maintain a balance between moisture availability and aeration to promote optimal seed germination in tea cultivation. Overall, the results suggest that sand and sawdust are the most effective germination materials for tea seeds among those tested.

Growth parameters of seedlings

The data in Table 1 summarizes the influence of seven different germination media (T_1–T_7) on several early growth parameters of tea seedlings: plant height (PH), basal diameter (BD), number of branches (NB), vertical root length (VRT), root dry weight (RDW), shoot dry weight (SDW), and total dry matter (TDM). While differences were observed among the treatments, statistical analysis revealed that none of the parameters were significantly affected by the type of germination material used ($P > 0.05$ for all traits), indicating a lack of strong treatment effects on early seedling vigor beyond the germination phase.

Treatment T_7 (sand), which had the highest germination rate, also recorded the highest total dry matter (13.08 g) and shoot dry weight (10.19 g), suggesting that the favorable physical properties of sand (e.g., aeration, drainage) may contribute positively to early shoot biomass accumulation. T_5 (sawdust), also associated with high germination performance, showed the highest number of branches (4.05), which may imply enhanced shoot differentiation and early vegetative growth potential. Conversely, T_4 (plant ash) showed slightly lower RDW (2.93 g) but relatively high SDW (10.01 g), which might reflect a shift in biomass allocation favoring aboveground parts—possibly due to higher nutrient availability or finer texture.

Table 1. Effect of different germination media on vegetative growth of tea seedlings

Treatment	PH (cm)	BD (cm)	NB	VRT (cm)	RDW (g)	SDW (g)	TDM (g)
T_1	48.65	1.83	3.85	8.95	3.24	9.73	12.97
T_2	48.91	1.85	3.58	8.63	3.25	9.3	12.55
T_3	49.09	2.01	3.84	8.91	3.18	9.56	12.74
T_4	48.33	1.82	3.92	9.24	2.93	10.01	12.94
T_5	49.61	1.89	4.05	9.21	3.62	9.05	12.67
T_6	48.93	1.83	3.74	9.34	3.24	9.45	12.69
T_7	48.67	2.01	3.67	8.89	2.89	10.19	13.08
p value	0.08	0.09	0.11	0.08	0.06	0.07	0.08
Significance	ns	ns	ns	ns	ns	ns	Ns

Treatments T_1, T_2, T_3, T_4, T_5, T_6 and T_7 were the used germination media of 'soil', 'polythene sheet', 'jute sack', 'plant ash', 'sawdust', 'straw' and 'sand' respectively. Growth parameters were- plant height (PH), basal diameter (BD), number of branches (NB), vertical root length (VRT), root dry weight (RDW), shoot dry weight (SDW), and total dry matter (TDM). Data yielding a $p<0.05$ or $p<0.01$ is considered statistically significant.

Treatment T_3 (jute sack) and T_6 (straw), though moderate in germination performance, supported comparable growth in PH and TDM, which may suggest these organic materials provided a stable but less aerated medium that didn't restrict early seedling development. T_2 (polythene sheet), which had the lowest germination rate, did not show clear disadvantages in early growth traits such as PH (48.91 cm) and TDM (12.55 g), perhaps indicating that the surviving seedlings were able to compensate post-emergence under uniform growing conditions.

Overall, the absence of statistical significance in early growth metrics may suggest that while germination media strongly influence the emergence phase, subsequent seedling growth is likely more dependent on post-germination environmental conditions and management. These findings highlight the resilience of tea seedlings in adjusting to their growing environment, once germination has occurred successfully.

Conclusion

This study evaluated the effects of seven different germination materials—soil (T_1), polythene sheet (T_2), jute sack (T_3), plant ash (T_4), sawdust (T_5), straw (T_6), and sand (T_7)—on the germination and early growth performance of tea seedlings. Among the treatments, sand (T_7) and sawdust (T_5) demonstrated the highest germination percentages, 92.92% and 92.18% respectively which were statistically similar, suggesting these materials provide optimal conditions such as adequate aeration, moisture retention, and temperature regulation for seed emergence. In contrast, the polythene sheet (T_2) resulted in the lowest germination rate (52.38%), likely due to restricted gas exchange and unfavorable micro-environmental conditions. Although there were variations among treatments in early seedling growth parameters—including plant height, basal diameter, branching, root dry matter, shoot dry matter and total dry matter accumulation—none were statistically significant. This suggests that while germination media greatly influence seed emergence, their impact on subsequent seedling growth may be limited under controlled conditions, and mostly dependent on post-germination environmental conditions and cultural practices.

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Tea J. Bangladesh 51, 67-84, 2025
https://doi.org/10.5281/zenodo.15683892
ISSN 0253-5483
Available online at http://www.btri.gov.bd

HARNESSING SOLAR ENERGY IN THE TEA INDUSTRY OF BANGLADESH: A REVIEW OF NECESSITY, FEASIBILITY, AND FUTURE PROSPECTS

Mohammad Masud Rana[1]*, Md. Ismail Hossain[2] and Md. Abdul Aziz[3]

Abstract

This article explores the potential of solar energy as a sustainable alternative for addressing the energy needs of the tea industry of Bangladesh. The review highlights the critical role of tea in the national economy and the challenges posed by reliance on conventional energy sources like diesel and coal. Solar energy presents a viable solution to reduce production costs, ensure uninterrupted power, and support sustainable practices. The study examines the favorable geographical conditions of Bangladesh for solar energy generation, with high solar radiation in tea-growing regions. Technological advancements and government incentives further enhance the feasibility of solar installations in tea gardens. Case studies from India, China, and Sri Lanka demonstrate successful solar energy integration in tea estates. The study concludes that integrating solar power into the tea industry supports Bangladesh's renewable energy goals and provides sustainable economic and environmental advantages over the long term. However, challenges like high initial costs and space constraints need to be addressed through pilot projects and government support.

Keywords: Solar, Green, Energy, Feasibility, Tea, Garden

[1]Principal Scientific Officer (Agronomy Division), Bangladesh Tea Research Institute, Srimangal, Moulvibazar
[2]Director (in-charge), Bangladesh Tea Research Institute, Srimangal, Moulvibazar
[3]Chief Scientific Officer (Botany Division), Bangladesh Tea Research Institute, Srimangal, Moulvibazar

*Corresponding author's email: ranabtri@yahoo.com (Mohammad Masud Rana)

Introduction

Bangladesh is one of the world's leading tea-producing nations, with its tea industry playing a pivotal role in the national economy through domestic consumption and export revenue generation. At present there are 170 tea estates in Bangladesh (BTB, 2025). The tea industry employs thousands of workers and plays a vital role in sustaining the livelihoods of numerous communities, especially in the northeastern and southeastern parts of the country. Despite the tea industry's economic significance, several challenges threaten its long-term sustainability, including energy shortages, high production costs, and environmental concerns associated with conventional energy sources. To ensure the continued growth and sustainability of the tea sector, modern technological interventions are necessary, with renewable energy sources, particularly solar power, emerging as a promising solution.

Tea production is an energy-intensive process requiring both electrical and thermal energy (Palaniappan and Subramanian, 1998). Electrical energy is primarily sourced from the national power grid, while diesel generator is used on the off-grid. Thermal energy, on the other hand, is generated through the combustion of natural gas, coal, fuelwood, and furnace oil. These conventional energy sources pose several challenges, including high costs, supply inconsistencies, and negative environmental impacts. Studies indicate that energy expenses account for approximately 8% of the total production costs in the tea industry, with around 30% of processing costs attributed to energy consumption (SLSEA, 2014; Sharma et al., 2019). The rising costs of fossil fuels and concerns over their long-term availability further exacerbate these issues.

Fossil fuel dependency has raised major environmental concerns, including greenhouse gas emissions, deforestation, and pollution. Standby diesel generators, tea-processing boilers, and transport vehicles contribute significantly to air pollution. Unlike renewable energy sources such as solar, wind, biomass, and hydropower, fossil fuels are finite and non-renewable (Heinberg and Fridley, 2016; Hall and Klitgaard, 2018; Friedemann, 2021). Global studies suggest that, at the current rate of consumption, fossil fuel reserves could be depleted as early as 2050 (Ulyanin et al., 2018; Holechek et al., 2022). Additionally, fossil fuel depletion could have severe economic implications, with potential shortages expected as early as the 2030s. Given these projections, transitioning to renewable energy sources has become an urgent necessity for industries worldwide, including tea estates in Bangladesh. Currently, fossil fuels account for over 80% of global energy consumption, with petroleum, coal, and natural gas comprising 31%, 27%, and 24%, respectively (Dale, 2022). Renewable energy, including wind and solar power, accounts for only a small fraction of global energy consumption, despite its immense potential for sustainable industrial applications. The excessive reliance on fossil fuels has exacerbated climate change, leading to rising global temperatures, biodiversity loss, soil degradation, water pollution, and ecosystem destruction (Ryerson, 2010; Ripple et al., 2017; Gustafson et al., 2020; Ripple et al., 2021). The adverse environmental impact of fossil fuel consumption in the tea industry necessitates the exploration of cleaner, more sustainable energy alternatives.

Bangladesh is geographically well-positioned to harness solar energy due to its tropical location, receiving an average solar radiation of 4–6.5 kWh/m^2 per day (Baky et al., 2017). This abundant solar resource presents an opportunity to implement solar power systems in tea estates, reducing reliance on conventional energy sources and mitigating environmental impacts. The adoption of solar power can address key challenges in the tea industry, including energy reliability, production costs, and carbon emissions. Solar energy offers a cost-effective and environmentally friendly solution, ensuring the sustainable development of the tea industry while enhancing energy security.

This review explores the feasibility and potential benefits of integrating solar power systems in tea estates throughout Bangladesh. It examines how solar energy can enhance efficiency, reduce costs, and promote sustainability in tea production. The study provides a comprehensive analysis of the challenges and opportunities in adopting solar energy within the tea industry.

Energy Scenario in Bangladesh and the Push for Renewables

Natural gas is the primary fuel used for generating electricity in Bangladesh (Rahman, 2022). The country is also depending on other fossil fuels sources such as diesel, furnace oil, coal, hydro and few renewable sources to generate electricity (Hossain and Rahman, 2021). Bangladesh has a total installed electricity generation capacity of 27536 MW (as of May 2025), categorized by fuel type (BPDB, 2025a). Figure 1 illustrates the distribution of this capacity, highlighting the country's significant reliance on natural gas. Currently, natural gas accounts for 44.79% of the total installed capacity. In 2019, the share of natural gas was 68% (BPDB, 2019), but this share is now reduced due to the gas shortage. Remaining gas reserves and cumulative expenditures in Bangladesh from 1961-2031 is presented in the Figure 2. The country's cumulative original recoverable gas reserve stands at 29.93 trillion cubic feet (Tcf) (Figure 2). As of June 2024, a total of 21.10 Tcf has already been extracted, leaving 8.83 Tcf of recoverable reserves in the proven plus probable category (HCU, 2024). With the current annual gas consumption rate of approximately 916 billion cubic feet (Bcf) (EMRD, 2024), the remaining reserves are projected to last for about 9.64 years.

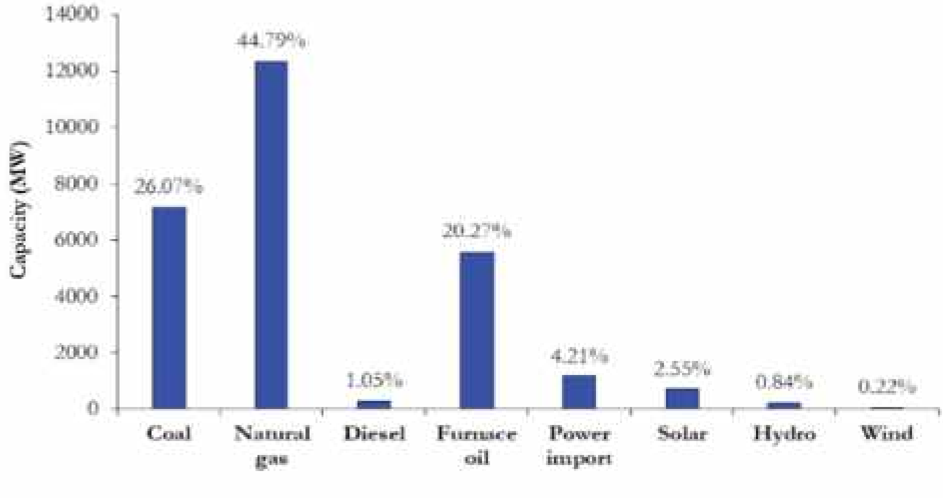

Figure 1. Electricity generation scenario (in MW) of Bangladesh in May 2025 (BPDB, 2025a)

Therefore, it's clear that Bangladesh is facing challenges in meeting its growing energy demand with declining local gas production. Bangladesh's power sector is currently facing significant challenges due to limited gas availability and the pressures of rapid economic growth (Miskat et al., 2023). Fuel shortages have led to frequent power outages, highlighting a growing gap between energy supply and demand. With energy needs rising sharply, projections indicate that demand could reach 33,708 MW by 2030 (BPDB, 2025b). To address this challenge, Bangladesh has begun investing in renewable energy sources.

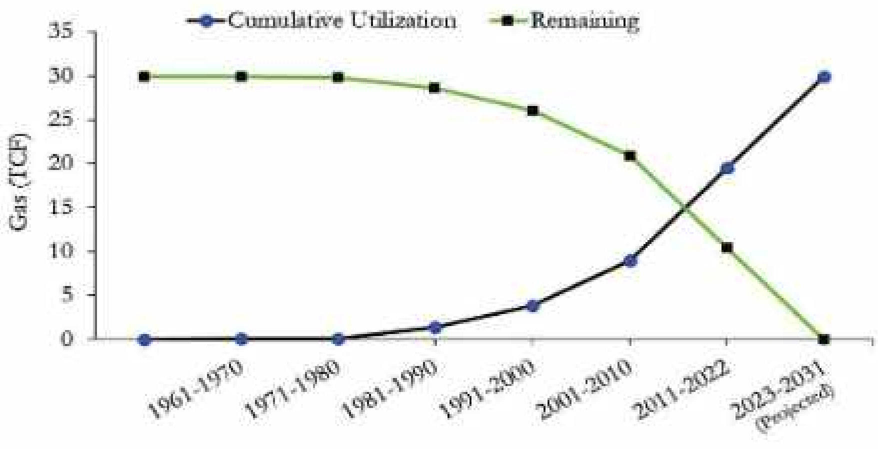

Figure 2. Remaining natural gas reserves and cumulative consumption in Bangladesh from 1961-2031 (EMRD, 2022)

Trends in solar energy adoption in major tea-producing countries in Asia

According to the statistics from International Renewable Energy Agency (IRENA, 2024), a consistent rise in solar energy use by different Asian tea-growing countries was observed across the years from 2014 to 2023 (Table 1). While larger economies such as China, India, and Japan exhibit significant absolute increases, Bangladesh's progress is notable for its consistent year-over-year growth. China leads with a dramatic rise from 28,399 MW in 2014 to 609,921 MW in 2023, followed by India, which increased from 3,776 MW to 73,109 MW in the same period. Japan shows steady growth, expanding from 23,339 MW to 89,077 MW. In contrast, Vietnam showed minimal solar use until 2018, when it surged from 105 MW to 17,077 MW by 2023. Bangladesh showed gradual growth from 169 MW to 748 MW, while Sri Lanka, starting from a low base of 22 MW, reached 966 MW by 2023.

Table 1. Growth of solar energy use in major tea-producing countries in Asia (IRENA, 2024)

Country	Solar Energy Use (MW) in different years									
	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Bangladesh	169	196	165	217	240	280	343	506	523	748
China	28399	43549	77819	130832	175262	204971	253864	306973	393032	609921
India	3776	5697	9982	18257	27485	35250	39705	49950	63390	73109
Japan	23339	34150	42040	49500	56162	63192	71868	78413	85066	89077
Sri Lanka	22	37	71	154	228	350	436	624	800	966
Viet Nam	5	5	5	8	105	4994	16661	16661	16698	17077

From the above data, it is observed that during this period Bangladesh's solar energy use increased by 4.42 times, China more than 21 times, India nearly 19 times, Japan nearly 3.8 times, Sri Lanka over 43 times and Vietnam saw its solar energy consumption skyrocket by over 3400 times (Figure 3). The growth in solar capacity is critical for Bangladesh, a country that faces both high energy demand and environmental challenges. By investing in solar energy, Bangladesh is not only working to improve energy security but also reducing its reliance on fossil fuels.

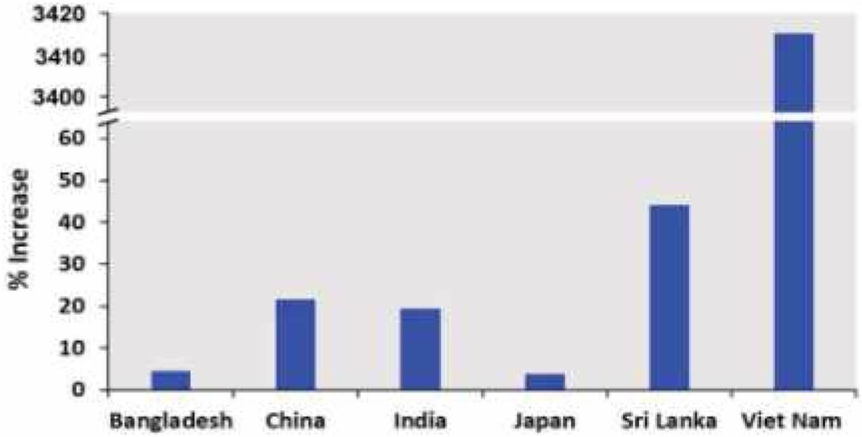

Figure 3. Percentage of increase of solar energy use from 2014 to 2023 by some of the tea producing countries in Asia (IRENA, 2024)

Energy consumption patterns in the tea industry

The consumption of both specific electrical and thermal energy in the tea sector depends on the scale of production (Thirunavukkarasu and Sawle, 2022). In the tea industry, the primary source of electrical energy is the national grid, whereas diesel is used during power cuts and in off-grid areas. Thermal energy needs are met using coal, natural gas, or firewood. Energy expenses constitute about 8% of the overall production costs in the tea industry (SLSEA, 2014). Tea processing is highly energy-intensive, relying on both electrical and thermal energy sources (Palaniappan & Subramanian, 1998). Electrical energy is essential for all stages of the process, whereas thermal energy is primarily required for withering and drying operations (Mitra & Totan, 2016). Energy expenses account for approximately 30% of the overall cost involved in tea processing (Sharma et al., 2019). Withering, rolling, drying, grading, packing and lighting are the major energy consuming areas in a tea factory. Sharma et al. (2019) reported that through the stages such as withering, drying, grading, and packing, requires 14.4-64.8 MJ of energy for producing one kilogram of made tea. According to Baruah and Bhattacharya (1996), about 21% of the energy utilized in tea processing comes from electricity, with the other 79% supplied by traditional fuel sources. Taulo and Sebitosi (2016) highlighted that withering and drying are the most energy-demanding stages in tea processing, contributing between 78% and 94% of the total energy use in tea processing. In another literature it is mentioned that tea manufacturing processes consume thermal and electrical energy in the ratio of 85:15 (Kumar and Visvanathan, 2002). In general, for each kilogram of made tea, the specific energy consumption ranges between 14.4-144.4 MJ (Baruah et al., 2012; Kumar and Visvanathan, 2002). A study conducted in India reported that the total specific thermal energy consumption for producing made tea ranges from 4.45 to 6.84 kWh/kg, while the specific electrical energy consumption lies between 0.4 and 0.7 kWh/kg (Sundaram and Kumar, 2021). In another study in Sri Lanka, it has been reported that tea factories consume between 0.63 and 0.75 kWh of electricity per kilogram of made tea, while thermal energy demand ranges from 1.5 to 1.7 kg of firewood per kilogram of made tea (Wijeratne et al., 2025). A study conducted in Malawi by Taulo and Sebitosi (2016) calculated the specific energy consumption for making per kilogram of tea to be 0.64 kWh for electrical energy and 13.41 kWh for thermal energy. Sharma et al. (2019) reported that for producing 100 kg of tea, the specific electrical energy consumption for withering, maceration, drying, and grading is 5.54 kWh, 8.63 kWh, 6.23 kWh, and 3.95 kWh, respectively. In terms of thermal energy, 49.75 kWh is required for withering and 497.53 kWh for drying, indicating that the drying process demands significantly more thermal energy than withering.

The plantation and transportation activities within an estate also consume substantial amounts of energy, primarily in the form of petro-fuels. And finally, the workers of the industry also consumes energy for their household purpose in the form of firewood (Saikia et al., 2013).

The Necessity of Installing Solar Power Systems in the Tea Industry of Bangladesh

Overcoming Power Shortages and Transitioning to Sustainable Energy Sources

Many of Bangladesh's tea gardens are located in remote areas, where access to the national power grid is limited. This disrupts tea production. Additionally, the high cost of electricity and frequent load shedding present major problems. As a result, tea factories often rely on expensive diesel-powered generators, which significantly increase production costs. Solar energy can help bridge this power gap, reducing the reliance on diesel generators and lowering production expenses.

Maintaining Production Continuity

Solar energy can provide a stable and uninterrupted power supply, reducing the risk of load shedding or power outages. This can shorten tea processing times, increase productivity, and improve the quality of processed tea through more consistent operations.

Optimizing Land Use

The roofs of tea factories and workers' quarters are often underutilized. Additionally, some parts of tea estates remain fallow for years. Installing solar panels in these areas would make better use of available land within the tea gardens.

Reduce Production Expenses

Once installed, solar panels can supply electricity for up to 20–25 years with minimal maintenance costs. In the long run, adopting solar energy will significantly decrease total production expenses.

Eco-Friendly Production

Tea production consumes a significant amount of electricity, most of which is generated from fossil fuels. Furthermore, some traditional fuels, such as coal and diesel, are harmful to the environment. Solar energy, on the other hand, is completely eco-friendly. Using solar power can reduce carbon emissions, contributing to environmental protection.

Supporting Sustainable Development Goals (SDG)

In September 2015, the United Nations Assembly launched the 2030 Agenda, consisting of 17 Sustainable Development Goals. The United Nations' Sustainable Development Goal 7 (SDG7) aims to ensure universal access to affordable, reliable, sustainable, and modern energy for all by 2030 (Chundi et al., 2024). The goals emphasize the need to increase the use of renewable energy. Implementing solar energy in the tea industry would support this goal and contribute to Bangladesh's commitments to global sustainability targets.

Feasibility of Installing Solar Power Systems in the Tea Industry of Bangladesh

Favorable Geographical Location

Bangladesh's geographical position makes it highly suitable for the use of solar energy. The country receives around 3,000 hours of sunlight annually, making it an ideal location for solar energy generation. According to the data from Global Solar Atlas (GSA, 2024), Bangladesh ranks fourth in terms of solar radiation potential among the tea-producing countries (Table 2). Kenya has the highest solar radiation, while Vietnam has the lowest. This high solar radiation in Bangladesh indicates a strong potential for solar power generation.

Table 2. Solar Radiation in Some Tea-Producing Countries (GSA, 2024)

Serial No.	Country (Tea-Producing Region)	kWh/m²/day	kWh/m²/year	Rank
01	China (Zhejiang)	3.73	1360	9th
02	India (Assam)	4.69	1712	6th
03	Kenya (Nakuru)	6.04	2204	1st
04	Sri Lanka (Kandy)	5.12	1870	3rd
05	Turkey (Rize)	3.55	1294	10th
06	Indonesia (West Java)	4.80	1753	5th
07	Vietnam (Yen Bai)	3.47	1265	11th
08	Japan (Shizuoka)	4.43	1617	8th
09	Iran (Mazandaran)	4.60	1678	7th
10	Argentina (Misiones)	5.26	1922	2nd
11	Bangladesh (Moulvibazar)	4.93	1798	4th

Additionally, different tea-growing regions in Bangladesh also receive substantial solar radiation, with Chittagong and Bandarban being the most favorable regions for solar power generation (Table 3).

Table 3. Solar Radiation in Tea-Producing Regions of Bangladesh (GSA, 2024)

Serial No.	Region	kWh/m²/day	kWh/m²/year	Rank
01	Sylhet	4.91	1792	5th
02	Moulvibazar	4.93	1798	4th
03	Habiganj	4.89	1784	7th
04	Chittagong	5.25	1917	2nd
05	Bandarban	5.26	1920	1st
06	Panchagarh	4.93	1801	3rd
07	Thakurgaon	4.90	1790	6th
08	Nilphamari	4.84	1765	8th
09	Lalmonirhat	4.81	1757	9th

Technological Advancements

Over recent years, solar panel technology has improved significantly, and the cost has decreased. The government, alongside various private organizations, is also investing in solar energy projects, which is creating a favorable environment for the adoption of this technology in the tea industry. Bangladesh has already established several solar power plants (Solar Parks). Some of the prominent ones include a 200 MW solar park by Beximco Power Co. Ltd. in Gaibandha, a 100 MW solar plant in Mongla by Energion Technologies and China Sunergy Co. Ltd., a 75 MW solar power plant in Sonagazi, Feni, a 50 MW solar park in Gauripur, Mymensingh, a 35 MW solar park in Shibaloy, Manikganj, and a 30 MW solar park in Gangachara, Rangpur (SREDA, 2025). These advancements indicate the significant potential for using solar energy to generate electricity in the tea industry.

Favorable Government Incentives and Policies

At present, renewable energy is a top priority for the government of Bangladesh. Various tax exemptions, subsidies, and loan facilities are provided for solar energy projects, making solar energy adoption in tea gardens financially viable. The Bangladesh Power Development Board (BPDB, 2025a) and the Infrastructure Development Company Limited (IDCOL, 2025) are actively promoting numerous research and development projects to enrich the country's renewable solar energy capacity. Such support ensures strong prospects for using solar energy in the tea industry.

Huge Opportunities for Solar Energy Integration in Tea Gardens

There are various areas where solar energy can be used in tea gardens. Below are some of the key areas-

- *Power Supply to Tea Processing Factories:* Tea leaf processing requires a lot of electricity to run the necessary machinery (Mitra and Totan, 2016). By using electricity generated from solar panels, the cost of electricity for tea processing can be significantly reduced. Solar energy can also be used as a backup power source.

• *Power Supply for Tea Packaging:* Solar energy can be very effective in the tea packaging process. Machines like filling machines, sealing machines, and labeling machines used in tea packaging require electricity. Using solar energy for these machines can reduce electricity costs. After packaging, tea needs to be stored, often in storage or cold storage systems. These storage units can be operated with solar power, reducing electricity costs and providing a long-term sustainable solution to power outages. Furthermore, solar-charged electric vehicles can be used for transporting packaged tea, which reduces fuel costs and is environmentally friendly.

• *Irrigation System:* Irrigation is an essential activity in tea gardens, requiring a large supply of water. This is usually done using diesel or electric-powered pumps. Solar-powered water pumps can meet this need. During the daytime, electricity generated from solar panels can be directly used to operate water pumps, extracting water from reservoirs, deep tube wells, or wells to irrigate different parts of the tea garden using sprinkler systems. In other sectors of Bangladesh, solar irrigation projects have been producing 57.36 MWp of electricity from 3381 pumps (Ahmed et al., 2024). This innovative approach lowers greenhouse gas emissions and reduces operating costs for farmers, promoting more sustainable agricultural practices. The tea industry stands to benefit from adopting this technology as well.

• *Solar Dryers:* The traditional process of drying tea leaves requires a significant amount of fuel. By using solar dryers, tea leaves can be dried quickly and efficiently using natural sunlight. This reduces fuel consumption and makes the drying process more environmentally friendly. Various capacities of solar tea leaf dryers have already been developed.

• *Garden Road Lighting:* Lighting is required to ensure the security and operations of tea gardens and factories. By using a solar lighting system, specific areas of the tea garden can be illuminated, which will reduce electricity costs.

• *Electricity Supply to Tea Workers' Residences*: Solar panels can be used to provide electricity to the residences of tea garden workers. This will make their daily lives easier and reduce dependence on grid electricity.

Solar-powered tea gardens are achieving success globally

Many tea gardens around the world have already started using solar systems. Information about some of these gardens is provided below-

• *Chengmari Tea Estate, India:* Chengmari Tea Estate, known as the largest tea estate in Asia (with 1,450 hectares of tea plantation), located in Jalpaiguri, India, successfully launched a 1.04 MW bifacial solar system project in early 2024 with the support of Tata Power Renewable Energy Limited (TPREL, 2024), a leading organization in India's renewable energy sector. The project installed 1900 bifacial PV modules over an area of approximately 1 hectare. It is expected that this project will generate around 1.5 million units of electricity annually (Basak, 2024). Currently, the solar system is generating enough energy to run the tea factory, irrigation, and other auxiliary tasks. The garden is using this solar energy to operate 15 irrigation pumps in the tea plantation. Additionally, it provides electricity to offices, bungalows, employee residences, labor quarters, and similar places. It is estimated that this will reduce carbon emissions by about 29420 tons per year.

• *Rosekandy Tea Garden, India:* Rosekandy Tea Garden in Cachar, Assam, installed a rooftop solar plant in 2020 at a cost of INR 25 million. It is capable of meeting its electrical demands entirely through solar power during daylight. However, during the night and periods of low sunlight, it depends on grid electricity (Goswami, 2022).

• *Xishuangbanna Tea Garden, China*: In 2015, a solar project was initiated at the Xishuangbanna Tea Garden in Yunnan Province, China. The project uses 197800 transparent dual-glass modules, designed to ensure that they do not hinder the growth and development of tea plants. This allows for the optimal use of both land and solar energy. The annual production capacity of this project is approximately 80,000 kWh (Anonymous, 2025a). As it is connected to the national grid, it also contributes to the grid.

• *Ratnasiri Wickramanayake National Training Center, Sri Lanka:* In February 2024, the first 85 kW hybrid semi-transparent solar panel project was introduced at the Ratnasiri Wickramanayake National Training Center's tea garden in Hantana, Kandy, Sri Lanka. (Anonymous, 2025b). The project was jointly implemented by the Asian Development Bank (ADB), the Ministry of Plantation Industries (MOPI), and the Ministry of Power and Energy (MOPE). This plant includes a system to store 24 kWh of battery energy, which can supply electricity to 100 families while also contributing to the national grid. The solar panels in this project are installed 2 meters above the tea plants in the training center's tea plantation. Covering an area of 800 square meters, this project is expected to generate 102 MWh of electricity annually.

• *Peria Karamalai Tea & Produce estate:* The Peria Karamalai Tea & Produce estate in Madurai District, India installed solar and wind power plants to reduce energy costs, CO_2 emissions, and local air pollution. The annual output of solar plants is estimated at 4.5 million units, while the capacity of wind farms stands at 2.3 MW. Over the past 20 years, the total power generation has exceeded 95 GWh. The excess electricity generated by the power plant is connected to the grid. After successfully installing renewable technologies, 7,000 tonnes of CO_2 emissions have been reduced per annum (Thirunavukkarasu and Sawle, 2022).

The description above suggests that the use of solar power in Bangladesh's tea estates holds great potential. The tea-producing regions of the country receive ample sunlight, making them suitable for solar energy generation. In many areas where electricity supply is often unstable, the use of solar energy can ensure an uninterrupted power supply to the tea industry. By utilizing solar power for tea processing, irrigation, lighting, and transportation in tea gardens, it is possible to reduce costs and increase productivity.

Future Prospects of Installing Solar Power Systems in the Tea Industry of Bangladesh

The future prospects for implementing solar power systems in Bangladesh's tea industry are highly promising. As a key contributor to the national economy, the tea industry relies heavily on a consistent supply of electricity for its production processes. However, frequent power shortages and supply disruptions pose significant challenges. Solar energy presents a sustainable and reliable solution to these issues. The adoption of solar power in the tea industry holds strong potential due to the following factors:

Government Policies and Support for Renewable Energy

The Government of Bangladesh has been prioritizing renewable energy to transform the country into an energy-secure nation by utilizing a mix of sustainable sources such as solar, wind, hydro, and biomass alongside conventional energy sources including oil, gas, and coal (Hossain & Rahman, 2021). The government has adopted various policies and provided financial incentives to promote the growth of renewable energy. The tea industry can also benefit from these incentives. Bangladesh has an ambitious goal for renewable energy use, including the establishment of a leading solar power system. The country plans to generate 4100 MW of clean energy by 2030, with 2277 MW coming from solar power and the rest from hydropower and wind energy (Koons, 2024). Furthermore, Bangladesh has set a target to produce 40% of its electricity from clean energy sources by 2041 (Moazzem et al., 2022). Hence, the use of solar energy in the tea industry will also contribute to achieving national goals.

Availability of Advanced Technology

Since tea cultivation requires some shade, solar panels can be scattered throughout tea gardens, allowing for both tea cultivation and solar energy use without wasting land. Additionally, solar panels can be deployed in the unused open spaces within tea gardens. Currently, transparent solar panels have been invented that do not negatively impact the growth and development of tea plants.

Meeting the Growing Demand for Electricity

Bangladesh currently has an electricity generation capacity of around 26,364 MW, which is insufficient to meet the growing demand. As a result, load shedding is often used to manage this shortfall. The current per capita electricity consumption in Bangladesh is about 33 kWh, which is much lower than in developed countries, such as the United States, where it is 11730 kWh per capita (IndexMundi, 2020; Baky et al., 2017). As the standard of living improves, it is expected that electricity demand will increase and could reach 33708 MW by 2030, according to data from the Bangladesh Power Development Board (BPDB). If electricity generation capacity does not increase accordingly, the frequency of load shedding will rise, disrupting production in tea factories. In this case, the use of solar power in the tea industry will help meet its own demand and contribute to meeting the growing national electricity demand.

Reducing Electricity Bills

The Bangladesh Power Development Board (BPDB, 2023) indicates that electricity retail prices have risen by almost 130% over the last 14 years due to gradual, periodic increases. It is expected that these prices will continue to rise in the future. Tea processing requires a large amount of electricity. Observations show that about 70% of the total energy cost in tea production is spent on dryers when using gas, and about 91% when using furnace oil or coal. Solar power can also be used in tea processing to generate this heat energy. Installing solar panels in tea factories can meet part or all of their electricity needs. This could significantly reduce electricity bills and lower tea processing costs. Although the initial cost of installing solar panels is relatively high, once installed, they remain functional for many years with low maintenance costs, making it economically beneficial in the long run by reducing electricity bills and ensuring a continuous energy supply.

Reducing the Use of Fossil Fuels

Bangladesh primarily relies on fossil fuel-based power plants to meet its electricity needs. According to the Bangladesh Power Development Board, approximately 57% of the electricity generated comes from natural gas, and 32% comes from liquid fuels, mainly furnace oil and diesel. A study shows that in 2021-22, Bangladesh had a gas reserve of 10.42 trillion cubic feet, and the annual extraction rate was about 0.84 trillion cubic feet. If the use of fossil fuels is not reduced and the use of renewable energy is not increased, the remaining gas reserves may only last for another 7-10 years. Afterward, gas imports will be required to meet demand, or there will be a severe shortage of electricity production. To safeguard the future of the tea industry, solar energy must be adopted now.

Increasing the Use of Sustainable and Renewable Energy

According to the Sustainable and Renewable Energy Development Authority (SREDA) of Bangladesh, the country currently generates about 1378 MW of electricity from renewable energy sources. Of this, 1085 MW comes from solar panels, 63 MW from wind, 230 MW from hydropower, 0.69 MW from biogas, and 0.4 MW from biomass. This means that only 5.23% of the total electricity currently produced comes from renewable energy sources. It is also noteworthy that the country receives solar radiation sufficient to produce energy of $1,018 \times 10^{18}$ joules per square meter daily. However, only 0.11% of this vast solar energy potential is being harnessed through solar panels. Therefore, there is immense potential in this country for the use of solar energy. The Bangladesh government's plan is to increase the use of renewable energy to 30% by 2030 and 40% by 2041. To achieve this goal, the use of solar energy alongside conventional electricity in the tea industry is imperative.

Opportunity to Avail Government Incentives

The government provides various incentives to implementers and investors in renewable energy projects. Financing activities have been expanded through various financial institutions including Bangladesh Bank, IDCOL, and private commercial banks. Additionally, the government has provided duty exemption incentives on certain renewable energy products such as solar panels, solar panel components, charge controllers, inverters, LED lights, solar-powered lamps, etc.

Opportunities for Institutional Services and Loans

Currently, there are several government and private institutions in Bangladesh that provide necessary advice, technical support, and financing for installing solar projects of various sizes. Among them, notable ones are the Sustainable and Renewable Energy Development Authority (SREDA), Infrastructure Development Company Limited (IDCOL), and North-West Power Generation Company Limited (NWPGCL). These institutions provide necessary advice, technical support, and loan facilities depending on the project. SREDA implements projects with 50% grants, 30% soft loans, and 20% equity. IDCOL offers loans with a repayment period of 8-10 years for project installations. The institution provides loan facilities for up to 80% of the total project cost at an interest rate of 6%, with no loan repayment required in the first year of the project. Several private institutions also contribute to the installation of solar projects, including Intraco Solar Power Ltd., SOLshare, Joules Power Limited, Global Renewable Energy, Bengal Solar, and Pacific BD, among others.

Environmental Protection

The use of solar power plays an important role in environmental protection. It helps reduce carbon emissions, conserve natural resources, decrease air and water pollution, and preserve biodiversity. Additionally, it enhances energy security and paves the way for sustainable development.

Estimated Costs for Installation and Operation of Solar Power Systems in the Tea Industry of Bangladesh

It has been observed that a solar plant with a capacity of approximately 500 kW is generally suitable for a tea estate that produces around 1 million kilograms of tea annually. The estimated cost of constructing such a plant is approximately BDT 28 million. A 500 kW solar plant typically produces around 700000 units of electricity per year. With occasional maintenance, this type of plant can provide electricity for about 20-25 years.

Currently, the cost of grid electricity for industrial use is around BDT 11.63 per unit. According to IDCOL (Infrastructure Development Company Limited), the cost of producing solar electricity on rooftops is about BDT 5.0-5.5 per unit, and the cost of a 1 MW solar power project capable of production is approximately BDT 60 million. The majority of this cost comes from solar panels and inverters. The lifetime of a solar panel is about 20 years, and the lifetime of an inverter is around 10 years, with the project timeline being considered for 20 years overall.

Challenges and Recommendations for Solar Power System Implementation in the Tea Industry of Bangladesh

Initial Investment

The installation of solar panels and other technologies requires a significant initial investment, which can be challenging for small tea estates. Therefore, government and private financing and investment need to be ensured in this sector.

Space Issues

Solar panels need ample open space to function effectively with direct sunlight. Although the roofs of tea estate factories and other buildings can be used for this purpose, they may often be insufficient compared to the required space. Additionally, the shade from trees in tea plantations may hinder the effectiveness of solar panels. However, modern solar panels available today are capable of generating power even in low light conditions. Moreover, semi-transparent solar panels, which help mitigate shading problems, have also been developed. The efficiency of these panels should be assessed.

Technical Expertise

Trained personnel are needed for managing and maintaining solar energy systems. Therefore, training programs on solar technology should be arranged for the workers involved in the tea industry.

Research and Development

Detailed research is required to ensure the optimal use of solar energy in the tea industry. Emphasis should be placed on research and development, and solar energy could be tested experimentally in a few tea factories initially to observe the results.

Dependence on Weather

Solar power production depends largely on sunlight. Production may decrease on cloudy or rainy days. Therefore, energy storage systems should be improved to store excess energy generated by solar panels, which can be used when needed. Additionally, hybrid systems should be considered. In this system, solar energy is combined with other energy sources, such as wind energy or diesel generators, to ensure an uninterrupted power supply.

Conclusion

The review demonstrates that harnessing solar energy in the tea industry of Bangladesh is both a necessary and feasible pathway toward sustainable development. The sector's heavy reliance on conventional energy sources, such as diesel and coal, has resulted in escalating production costs, frequent power disruptions, and significant environmental impacts. Given the country's declining natural gas reserves and increasing energy demand, the urgency to transition to renewable alternatives is clear.

Bangladesh's favorable solar radiation, along with the underutilized rooftops and unused land in tea estates, makes a strong case for the integration of solar power. Experiences from other major tea-producing countries, such as India, China, and Sri Lanka, further validate the technical and economic viability of solar energy adoption in this sector. Implementing solar power systems can ensure uninterrupted production, reduce operational costs, and significantly lower the carbon footprint of tea processing. While high initial investment and space constraints remain notable challenges, these can be addressed through targeted pilot projects, government incentives, and public-private partnerships.

In summary, transitioning to solar energy presents a valuable opportunity for Bangladesh's tea industry to boost its competitiveness, strengthen resilience, and promote environmental sustainability. Realizing this potential will require ongoing research, effective policies, and strong collaboration among stakeholders to ensure a sustainable future for the sector.

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TEA JOURNAL OF BANGLADESH

Volume 51, 2025

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