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RESEARCH ARTICLE

Influence of various establishment techniques, spacings and fertilizer levels on leaf traits, yield and nutrient dynamics of brown top millet (*Brachiaria ramosa* L.) under different cropping seasons of Tamil Nadu

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Abstract

A field trial was carried out during the Summer 2023, Kharif 2023 and Rabi 2023-2024 seasons to assess the performance of brown top millet under two sowing methods (direct sowing and transplanting), three plant spacings (20 x 10 cm, 30 x 10 cm and 45 x 10 cm), and three fertilizer doses (75% of the recommended dose (RDF) at 45N:20P:15K kg ha^{-1}, 100% RDF at 60N:30P:20K kg ha^{-1} and 125% RDF at 75N:40P:25K kg ha^{-1}) using a factorial randomized block design. The study examined leaf morphological and physiological traits, yield, nutrient content and uptake by straw. The results indicated that the summer season was more favorable compared to the Kharif and Rabi seasons. The direct sown crop (E_1) exhibited significantly higher total chlorophyll content (7.5%, 9.3%, and 8.8%) and grain yield (8.6%, 6.5% and 9.2%) during the Summer, Kharif and Rabi seasons, respectively, over the transplanted crop (E_2). 45 x 10 cm spacing (S_3) registered its superiority in total chlorophyll content (21.2%, 26% and 31%) and grain yield (21.3%, 24.7% and 25% across the same seasons) over 20 x 10 cm spacing (S_1). Application of 125% RDF (N_3) recorded significantly higher chlorophyll content (41.7%, 46% and 51%) and grain yield (33.6%, 35.2% and 41%) compared to 75% RDF (N_1). In terms of interactions, the combination of direct sowing, wider spacing and 125% RDF (E_1 x S_3 x N_3) showed elevated leaf traits, chlorophyll content, grain yield and nutrient dynamics, though the differences in parameters among these treatment combinations were statistically non-significant. These findings provide a strong foundation for future research and for optimizing agricultural practices to maximize the potential of brown top millet.

Keywords

brown top millet; chlorophyll; leaf; yield

Introduction

Millets have been recognized for their high nutritional value and were domesticated even before wheat and rice (1). However, the Green Revolution in India shifted the focus to rice and wheat, leading to a decline in millet cultivation to enhance food production and security (2). In 2020, India accounted for nearly 41% of global millet production and 79.36% of Asia's millet output (3). This shift resulted in reduced crop diversity and a decline in the overall diet quality (4). Recently, consumer preferences have shifted towards nutrition-rich foods rather than merely hunger-satisfying foods, creating a growing need to explore crops that can address nutritional deficiencies and hidden hunger. Brown top millet (*Brachiaria ramosa* L.), belonging to the family Poaceae, that originated in Southeast Asia, is a hardy, drought-resistant species that offers a sustainable solution for food security in arid regions (5). It was traditionally grown as a rainfed crop for both food and forage. It thrives in border regions of Karnataka and Andhra Pradesh. Notably, brown top millet is unique among millets for its ability to tolerate shade (3). This annual crop grows 3-5 feet tall and has fibrous roots that can penetrate up to 60 cm deep. It thrives in sandy loam soils with acidic pH (6). For row planting, the seed rate recommended is 4-5 kg per hectare, while broadcasting requires 11-12 kg per hectare. It can be grown as either a sole crop or an intercrop (5). Its short growth cycle (75-90 days) and substantial biomass production make it an excellent option for use as a catch, cover, or nurse crop (7). Nutritionally, brown top millet is comparable to other millets and cereals, providing a rich source of essential nutrients (6, 5). Regular consumption can help manage non-communicable and lifestyle-related diseases (8).

Despite these advantages, brown top millet production and consumption in India remain limited. Factors such as low soil fertility, inadequate research and a lack of awareness regarding its nutritional benefits, coupled with insufficient post-harvest technologies, have hindered its productivity and reduced economic returns for farmers. Leaf traits such as leaf morphology and physiology play a crucial role in plant ontogeny (9). Optimal leaf morphology and chlorophyll production enhance light absorption, leading to improved photosynthesis and greater grain yield potential (10). Consequently, effective agronomic practices are essential for enhancing these physiological traits. Nitrogen (N), phosphorus (P) and potassium (K) are important macronutrients that significantly enhance these traits in plants, promoting processes such as photosynthesis, root development and water regulation, thereby improving overall growth and resilience against environmental stresses (11). One major challenge in cultivating brown top millet is lodging, highlighting the need for optimal sowing methods and appropriate plant density (12, 13). Additionally, sowing timing significantly affects plant-environment interactions, which in turn impact plant yield and quality (14). While fertilizer application can boost productivity, identifying the appropriate nutrient levels is crucial (15). Although agronomists possess extensive knowledge about optimizing inputs for millet cultivation, information specific to agronomic practices for brown top millet in Tamil Nadu is limited, particularly as this region receives rainfall mainly during the Northeast monsoon (16). This study aims to identify effective crop establishment techniques, spacing and nutrient levels tailored to the cropping seasons of Tamil Nadu with a primary objective to investigate how these agronomic practices influence leaf traits, grain yield and nutrient uptake of brown top millet.

Materials and Methods

Experimental site

The trial was conducted during the summer (March-June), Kharif (July-October) and Rabi (October-March) seasons of 2023-24 at field number 37 of the Eastern Block farm, Tamil Nadu Agricultural University (TNAU), Coimbatore. The study aimed to evaluate the impact of various cropping seasons, establishment techniques, crop spacings and fertilizer doses on the leaf traits, yield and nutrient uptake of brown top millet. The experimental site is situated at a latitude of 11° N and a longitude of 77° E, with an altitude of 426.7 meters above mean sea level, located in the western agro-climatic zone of Tamil Nadu. Weather data during the trial were recorded at the Meteorological Observatory, TNAU, Coimbatore and are presented in Table 1. Composite soil samples were collected randomly from a depth of 0 to 30 cm in the experimental area before the field trials in all three seasons. These samples were pooled and a representative portion was obtained using the quartering method. The standard procedures and physicochemical properties of the initial soil samples from the three seasonal trials are detailed in Table 2.

Treatment details and experimental setup

The field study utilized a factorial randomized complete block design (FRCBD) with three factors and three replications, where treatment plots were randomly assigned within each block to minimize bias and account for variability in soil and environmental conditions across the field. Treatment details are provided in Table 3. The recommended dose of fertilizers (RDF) used was 60N:30P:20K kg ha^{-1}, which included nitrogen (as urea), phosphorus (as diammonium phosphate) and potassium (as muriate of potash). Full doses of phosphorus and potassium, along with half of the nitrogen, were applied at the time of sowing, while the remaining nitrogen was applied 30 days after sowing. The brown top millet variety tested in the study was GPUBT-6, developed by the University of Agricultural Sciences, Gandhi Krishi Vigyana Kendra (GKVK) in Bengaluru, through selective breeding from IC 613561.

Nursery bed and main field preparation

A nursery covering an area of 500 m^2 was established for transplanting into one hectare of the main field. The land was ploughed twice using a tractor-drawn cultivator, followed by tilling with a tractor-drawn rotavator. For nursery bed preparation, six raised beds, each measuring 3 m x 1.5 m, were manually created with 30 cm spacing to facilitate irrigation. Seeds were sown on the beds at a rate of 2-3 kg per hectare of the main field using the line sowing technique, with the sowing dates for the nursery outlined in Table 4. In the main field, flat beds and irrigation channels were formed. A total of 54 plots, each covering an area of 18 m^2 (for a total area of 1200 m^2), were prepared for the 18 treatments, each replicated three

Table 1. Average weather conditions at the experimental site (March 2023 - January 2024)

Weather parameters		Summer season-2023	Kharif season-2023	Rabi season-2023-24
Maximum temperature (˚C)		34.5	32.2	29
Minimum temperature (˚C)		23.5	23.5	21
Rainfall (mm)		35.3	56	331
Bright sunshine (hours)		7.9	5.4	5.8
Relative humidity (%)	07:22 hours	83	83	85
	14:22 hours	44	53	52
Mean pan evaporation (mm)		6.5	5.8	4.4

Table 2. Physicochemical properties of the initial soil from experimental site

S.No.	Particular	Field Experiment			Methods
		I. Physical properties			
1.	Clay (%)	29.11			Robinson's International Pipette method (38)
2.	Silt (%)	16.91			
3.	Fine sand (%)	32.00			
4.	Coarse sand (%)	21.67			
5.	Texture	Sandy clay loam			
		II. Chemical properties			
6	pH	8.52	8.34	8.16	1: 2.5 soil: water suspension (39)
7.	Electrical conductivity (dS m^{-1})	0.17	0.15	0.14	1: 2.5 soil: water suspension (39)
8.	Organic carbon (g kg^{-1})	0.82	0.76	0.70	Wet chromic acid digestion method (40)
9.	Available nitrogen (kg ha^{-1})	248.2	240.4	231.4	Alkaline permanganate method (41)
10.	Available phosphorus (kg ha^{-1})	29.8	23.1	20.2	Olsen's method (42)
11.	Available potassium (kg ha^{-1})	586.0	564.4	532.2	Neutral normal ammonium acetate method (39)

Table 3. Details of treatments

		Factor 1: Establishment methods (E)
E_1	:	Direct sowing
E_2	:	Transplanting (18-20 days old seedlings)
		Factor 2: Spacings (S)
S_1	:	20 x 10 cm
S_2	:	30 x 10 cm
S_3	:	45 x 10 cm
		Factor 3: Fertilizer Levels (N)
N_1	:	75% RDF
N_2	:	100% RDF
N_3	:	125% RDF

times. The seed rate for brown top millet using the line sowing method was set at 2 kg ha^{-1}.

Direct sowing and Transplantation

Sowings were carried out in all three seasons with the dates of sowing and transplanting detailed in Table 4. Irrigation was provided as required. The crops were harvested after achieving physiological maturity, with the dates of harvesting also provided in Table 4.

Biometric data and yield analysis

To record biometric observations, five plants from each plot were selected randomly and tagged as representative samples. Leaf length (LL) and leaf breadth (LB) were taken from these plants, and the averages were calculated for each parameter. The soil plant analysis development chlorophyll meter values (SPAD) were measured from tagged plants 60 days after sowing (DAS) by using a Manitol SPAD Chlorophyll meter (502: Minolta Co., Japan) in the top, middle and base of the top young leaves and the average values were recorded. For calculating the Leaf Area Index (LAI), leaves from five sampled plants from the border rows were collected destructively at 60 DAS. The leaf area was evaluated using a leaf area meter (Li-COR model, LT-300):

$$\text{LAI} = \frac{\text{Leaf area (cm}^2)}{\text{Spacing (cm}^2)}$$

For extracting the chlorophyll pigments, the fully mature leaves were collected from the plants at 60 DAS. In the spectrophotometer, chlorophyll 'a', chlorophyll 'b' and total chlorophyll content were measured at various wavelengths. The following formulae were given by (17) for chlorophyll 'a' (CA), chlorophyll 'b' (CB) and total chlorophyll content (TCA) estimation. It was expressed in mg g^{-1}.

$$\text{Chlorophyll 'a'} = \frac{(12.7 \times \text{O.D at } 663) - (2.69 \times \text{O.D at } 645)}{W} \times V$$

$$\text{Chlorophyll 'b'} = \frac{(22.9 \times \text{O.D at } 645) - (4.68 \times \text{O.D at } 663)}{W} \times V$$

$$\text{Total Chlorophyll} = \frac{(20.2 \times \text{O.D at } 645) + (8.02 \times \text{O.D at } 663)}{W} \times V$$

Where, W: weight of the leaf sample, V: volume of the supernatant solution and O.D: optical density

All the plants from the designated net plot of each treatment of three replications were harvested, sun-dried, threshed, cleaned and weighed to determine grain weight plot $^{-1}$ and converted to grain yield (GY) in kg ha^{-1}. Additionally, the above-ground biomass (excluding panicles) from the same plot area was also collected, sun-dried and weighed to determine straw yield (SY) in kg ha^{-1}. Five representative plant samples of the net plot area of each treatment plot across three replications were collected at the harvest stage by uprooting and were dried at 60°C in a hot air oven, powdered using a grinder fitted with stainless steel blades. Then the nitrogen content (NC) in brown top millet straw was determined using the micro-Kjeldahl method, as described by (18). This involves digesting the sample with sulfuric acid to convert organic nitrogen to ammonium sulphate, followed by distillation and titration to quantify total nitrogen accurately. Phosphorus content (PC) was assessed through triple acid digestion, followed by colorimetric estimation as outlined by (19). The sample was digested with sulfuric, nitric and hydrochloric acids and phosphorus was quantified by measuring the intensity of a blue-colored complex formed with a molybdate reagent using a spectrophotometer. Potassium content (KC) was determined similarly through triple acid digestion, with subsequent analysis

Table 4. Dates of sowings and harvestings of brown top millet

	Summer season	Kharif season	Rabi season
Date of direct sowing	31th March 2023	20th July 2023	31th October 2023
Date of nursery sowing	10th March 2023	29th June 2023	12th October 2023
Date of transplanting	31th March 2023	20th July 2023	31th October 2023
Harvesting date of direct sown crop	19th June 2023	11th October 2023	26th January 2024
Harvesting date of transplanted crop	1th June 2023	22th September 2023	8th January 2024

using flame photometry (19). The sample was introduced into a flame, where potassium ions emit light at a specific wavelength, allowing for quantification based on standard solutions. The straw uptake (U) of nitrogen, phosphorus and potassium at harvest was calculated as follows:

$$\text{Nutrient uptake (kg ha}^{-1}) = \frac{\text{(Straw yield (kg ha}^{-1}) \times \text{(nutrient content (\%)}}{100}$$

Statistical analysis

The data concerning leaf traits, yield, NPK content, and uptake in straw across the eighteen treatments and three replications were analyzed using analysis of variance (ANOVA) within a factorial complete randomized block design, utilizing AGRES software version 7.0. on a Windows platform. Statistical procedures, as outlined by (20), were employed to evaluate both main effects (E, S, N) and their interactions (E x S, E x N, S x N, E x S x N), with significant variations and critical differences assessed at the 5% level (P=0.05). Treatments that did not show significant differences were marked as NS. Additionally, Pearson's correlation was performed to study the relationships among parameters by using SPSS version 21.

Results and Discussion

Leaf morphological traits

Among crop establishment methods, E_1 recorded significantly higher LL (18.2, 17.8 and 17.4 cm), LB (2.66, 2.64 and 2.50 cm) and LAI (2.36, 2.28 and 2.21) during Summer, Kharif, Rabi seasons, respectively, compared to the E_2at 60 DAS (Table 5). This could be attributed to the sturdy root system in E_1, which facilitated efficient translocation of nutrients and water, that supported the elongation and expansion of leaves. In contrast, E_2 hindered by root disturbances, produced shorter and narrow leaves due to limited nutrient uptake and slower growth. These results are consistent with (21), who observed a higher LAI (2.60) in direct sown pearl millet compared to transplanted pearl millet (2.27). Similarly, (22) found that direct-seeded rice developed greater leaf area during the vegetative stage than transplanted rice, which suffered from transplanting shock which delayed crop establishment, tillering and leaf area development. (23) found that direct-seeded rice had superior leaf growth and area compared to transplanted rice, owing to the absence of transplant shock, allowing for uninterrupted root development and nutrient uptake.

Among crop geometry, S_3 showed significantly higher LL (18.7, 18.3 and 17.9 cm) and LB (2.73, 2.70 and 2.57 cm) across three seasons, respectively, when compared to S_2 and S_1 (Table 5). This could be achieved to reduce competition for water, nutrients and light. With more available space for lateral growth, plants had better access to resources, allowing them to develop more robust foliage. Additionally, the lower competition for light in wider spacing allowed the plants to focus on expanding leaf size rather than competing for vertical growth, resulting in increased leaf length and breadth when compared to narrower spacings. A similar result of higher LL and LB of brown top millet under wider spacing when compared to narrow spacing was in alignment with (24). The higher LAI (2.40, 2.32 and 2.25) was recorded with S_1. However, the spacing of S_1 was found at par with S_2 during all three seasons. This might be attributed to the elevated plant population per unit area, which resulted in a higher accumulation of leaves, which resulted in enhanced LAI. Although individual plants in wider spacing (S_3) developed larger leaves, the overall leaf surface area per unit area is greater in denser planting S_1. These results of higher LAI in narrower spacings conformed with (25, 26). The lower LAI was recorded with S_3.

Significantly higher LL (19.1, 18.8 and 18.3 cm), LB (2.80, 2.77 and 2.63 cm) and LAI (2.47, 2.40 and 2.33) were recorded with N_3 during three seasons, respectively (Table 5). The lower values were observed with N_1. This could be attributed to the boosted nutrient supply, which enhanced leaf primordia development through improved cell division and enlargement. Consequently, this led to a greater number of healthy, robust tillers with larger leaves. Similar findings were reported by (25- 27).

Interaction effect

No significant differences were observed among the two-way and three-way interactions between establishment methods (E), spacings (S) and nutrient levels (N) for LL, LB and LAI across three seasons (Table 5).

Leaf physiological traits

E_1 recorded significantly higher SPAD values (48, 44 and 40), CA (1.62, 1.44 and 1.39 mg g^{-1}), CB (0.95, 0.90 and 0.83 mg g^{-1}) and TCA (2.57, 2.34 and 2.22 mg g^{-1}) during summer, Kharif and Rabi seasons, respectively, over E_2 which recorded lower values (Table 6). The uninterrupted root growth in direct sown crops might have facilitated efficient nitrogen uptake, which is essential for chlorophyll synthesis. CA plays a primary role in converting light energy into chemical energy during photosynthesis. CB plays a crucial role in capturing light and transferring energy to CA for photosynthesis. The rise in TCA was attributed to higher concentrations of both CA and CB, resulting in an overall enhancement of the total chlorophyll level. (28) reported that direct seeded rice with 20 cm row to row recorded higher CA (38.1), CB (3.74) and TCA (3.81) when compared to aerobic conventional rectangular transplanting at 20 x 10 cm spacing with 2-3 seedlings hill^{-1}. (29) reported a similar finding, with significantly higher SPAD chlorophyll values observed in the direct-sown oilseed rape (43.1) compared to the transplanted oilseed rape (41.9) at 120 DAS.

The wider spacing in S_3 recorded significantly greater SPAD (50, 47 and 42), CA (1.69, 1.52 and 1.49 mg g^{-1}), CB (1.0, 0.95 and 0.88 mg g^{-1}) and TCA (2.69, 2.47 and 2.51 mg g^{-1}) during three seasons, respectively, over other spacings S_2 and S_1. This could be due to the sparse population under S_3 where plants experienced less competition for vital resources like nitrogen. This favourable condition likely promoted enhanced chlorophyll production. These results conform with (23). The lower SPAD, CA, CB and TCA were recorded with S_1 (Table 6).

N_3 recorded significant maximum SPAD (52, 48 and 44), CA (1.77, 1.60 and 1.56 mg g^{-1}), CB (1.05, 1.0 and 0.94 mg g^{-1}) and TCA (2.82, 2.60 and 2.51 mg g^{-1}) across three seasons, respectively (Table 6). However, the lower values were observed with N_1. This could be linked to the increased nutrient supply, particularly N, which enhanced chlorophyll synthesis and imparted a darker green colour to the leaves, leading to higher SPAD readings that reflect the improved photosynthetic activity. These results conformed with (23).

Table 5. Impact of agronomic practices on leaf length, breadth and LAI at 60 DAS of brown top millet

	Leaf length (cm)			Leaf breadth (cm)			Leaf Area Index		
	summer	*Kharif*	*Rabi*	summer	*Kharif*	*Rabi*	summer	*Kharif*	*Rabi*
Crop Establishment (E)									
E_1	18.2	17.8	17.4	2.66	2.64	2.50	2.36	2.28	2.21
E_2	17.1	16.7	16.3	2.56	2.53	2.41	2.25	2.16	2.09
SEm±	0.21	0.23	0.20	0.03	0.03	0.03	0.03	0.03	0.03
CD (P=0.05)	0.6	0.6	0.6	0.09	0.09	0.09	0.08	0.08	0.08
Crop Geometry (S)									
S_1	16.5	16.1	15.7	2.46	2.44	2.32	2.40	2.32	2.25
S_2	17.6	17.4	17.0	2.64	2.62	2.48	2.35	2.27	2.20
S_3	18.7	18.3	17.9	2.73	2.70	2.57	2.17	2.07	2.00
SEm±	0.25	0.28	0.25	0.04	0.04	0.04	0.03	0.03	0.04
CD (P=0.05)	0.7	0.8	0.7	0.11	0.11	0.11	0.10	0.10	0.10
Nutrient levels (N)									
N_1	15.6	15.3	14.8	2.36	2.33	2.20	2.04	1.92	1.86
N_2	18.2	17.8	17.4	2.67	2.66	2.54	2.41	2.33	2.26
N_3	19.1	18.8	18.3	2.80	2.77	2.63	2.47	2.40	2.33
SEm±	0.25	0.28	0.25	0.04	0.04	0.04	0.03	0.03	0.04
CD (P=0.05)	0.7	0.8	0.7	0.11	0.11	0.11	0.10	0.10	0.10
Crop Establishment (E) x Crop Geometry (S)									
E_1S_1	16.7	16.3	15.9	2.49	2.48	2.36	2.46	2.39	2.32
E_1S_2	18.3	17.9	17.5	2.69	2.67	2.53	2.42	2.34	2.28
E_1S_3	19.6	19.3	18.8	2.80	2.76	2.62	2.20	2.11	2.05
E_2S_1	16.2	15.9	15.4	2.43	2.41	2.27	2.33	2.25	2.17
E_2S_2	17.2	16.9	16.4	2.59	2.56	2.43	2.28	2.20	2.13
E_2S_3	17.8	17.4	16.9	2.65	2.63	2.51	2.14	2.02	1.95
SEm±	0.36	0.39	0.35	0.05	0.05	0.05	0.05	0.05	0.05
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop Establishment (E) x Nutrient levels (N)									
E_1N_1	15.9	15.5	15.0	2.38	2.37	2.24	2.07	1.96	1.90
E_1N_2	18.6	18.3	17.9	2.73	2.72	2.58	2.47	2.41	2.34
E_1N_3	20.1	19.8	19.3	2.87	2.82	2.68	2.54	2.48	2.41
E_2N_1	15.4	15.1	14.6	2.33	2.30	2.16	2.00	1.88	1.83
E_2N_2	17.8	17.3	16.8	2.61	2.59	2.49	2.35	2.26	2.18
E_2N_3	18.1	17.8	17.3	2.73	2.71	2.57	2.41	2.33	2.25
SEm±	0.36	0.39	0.35	0.05	0.05	0.05	0.05	0.05	0.05
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop Geometry (S) x Nutrient levels (N)									
S_1N_1	14.9	14.7	14.2	2.28	2.26	2.10	2.14	2.03	1.95
S_1N_2	17.0	16.6	16.2	2.52	2.50	2.38	2.51	2.45	2.37
S_1N_3	17.5	17.1	16.7	2.59	2.58	2.47	2.55	2.49	2.42
S_2N_1	15.7	15.3	14.8	2.36	2.34	2.21	2.03	1.92	1.87
S_2N_2	18.2	17.8	17.3	2.68	2.66	2.56	2.49	2.42	2.36
S_2N_3	19.4	19.3	18.8	2.88	2.86	2.69	2.53	2.47	2.39
S_3N_1	16.3	16.0	15.5	2.43	2.41	2.30	1.94	1.82	1.78
S_3N_2	19.4	19.1	18.7	2.82	2.82	2.67	2.24	2.14	2.05
S_3N_3	20.3	20.0	19.6	2.93	2.87	2.73	2.34	2.26	2.18
SEm±	0.44	0.48	0.43	0.07	0.07	0.07	0.06	0.06	0.06
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop Establishment (E) x Crop Geometry (S) x Nutrient levels (N)									
$E_1S_1N_1$	15.2	14.9	14.4	2.30	2.29	2.15	2.18	2.07	1.98
$E_1S_1N_2$	17.0	16.7	16.3	2.56	2.54	2.42	2.58	2.53	2.46
$E_1S_1N_3$	17.8	17.4	17.0	2.61	2.60	2.50	2.63	2.58	2.52
$E_1S_2N_1$	15.9	15.5	15.0	2.39	2.37	2.25	2.08	1.96	1.90
$E_1S_2N_2$	18.3	17.9	17.4	2.72	2.70	2.60	2.56	2.50	2.45
$E_1S_2N_3$	20.6	20.4	20.0	2.96	2.93	2.75	2.61	2.55	2.48
$E_1S_3N_1$	16.5	16.1	15.6	2.46	2.44	2.33	1.95	1.85	1.81
$E_1S_3N_2$	20.4	20.2	19.9	2.90	2.91	2.72	2.28	2.19	2.10
$E_1S_3N_3$	21.8	21.5	21.0	3.04	2.94	2.80	2.38	2.30	2.23
$E_2S_1N_1$	14.6	14.4	14.0	2.25	2.22	2.05	2.10	1.98	1.92
$E_2S_1N_2$	16.9	16.5	16.0	2.48	2.45	2.34	2.43	2.36	2.28
$E_2S_1N_3$	17.2	16.8	16.3	2.57	2.55	2.43	2.47	2.40	2.32
$E_2S_2N_1$	15.4	15.1	14.6	2.33	2.30	2.16	1.98	1.87	1.83
$E_2S_2N_2$	18.0	17.6	17.1	2.63	2.61	2.51	2.41	2.34	2.26
$E_2S_2N_3$	18.2	18.1	17.6	2.80	2.78	2.63	2.45	2.38	2.30
$E_2S_3N_1$	16.1	15.8	15.3	2.40	2.38	2.27	1.92	1.78	1.74
$E_2S_3N_2$	18.4	17.9	17.4	2.73	2.72	2.62	2.20	2.08	2.00
$E_2S_3N_3$	18.8	18.4	18.1	2.82	2.80	2.65	2.30	2.21	2.12
SEm±	0.62	0.68	0.61	0.09	0.09	0.09	0.08	0.08	0.09
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

E_1: Direct sowing; E_2: Transplanting; S_1: 20 x 10 cm; S_2: 30 x 10 cm; S_3: 45 x 10 cm; N_1: 75% RDF; N_2: 100% RDF; N_3: 125% RDF

Interaction effect

SPAD values

The treatment combination of E_1 x S_3 (direct sown brown top millet with 45 x 10 cm spacing) recorded a significantly higher SPAD value of 49.8 during the *Kharif* season. The lower SPAD values of 36.3 were recorded with transplanted millet with 20 x 10 cm spacing (E_2 x S_1) across the same season. During the *Kharif* and *Rabi* seasons, E_1 x N_3 (direct sown brown top millet with 125% RDF) recorded higher SPAD values of 51.3 and 47.1, respectively. The lower SPAD values of 34.6 and 30.1 were recorded with E_2 x N_1 (transplanted millet sown with 75% RDF) at 60 DAS. S_3 x N_3 (brown top millet sown with 45 x 10 cm and 125% RDF) recorded higher SPAD values of 56.5, 52.9 and 49.3 during the summer, Kharif and Rabi seasons respectively when compared to other treatment combinations. However, it was found to be at par with S_2 x N_3(brown top millet sown with 30 x 10 cm and 125% RDF) and S_3 x N_2(brown top millet sown with 45 x 10 cm and 100% RDF) during *Kharif* and *Rabi* seasons. The lower SPAD values of 38.6, 34.2 and 29.6 were recorded with S_1 x N_1(brown top millet sown with 20 x 10 cm and 75% RDF). There was no significant difference in SPAD values among three -way interaction between establishment methods x crop geometry x nutrient levels irrespective of the crop growth stages and seasons (Table 6).

Chlorophyll 'a'

Direct sown brown top millet with 45 x 10 cm spacing (E_1 x S_3) recorded significantly higher CA value during the Rabi season (1.58 mg g^{-1}at 60 DAS) when compared to other treatment combinations whereas, the lowest CA was recorded with E_2 x S_1 (transplanted brown top millet with 20 x 10 cm spacing) (Table 6). E_1 x N_3 (direct sown brown top millet with 125% RDF) recorded higher CA of 1.72 and 1.67 mg g^{-1}during the Kharif and Rabi seasons, respectively whereas, the lower values were recorded with E_2x N_1 (transplanted brown top millet with 75% RDF). The combination S_3 x N_3 (brown top millet sown with 45 x 10 cm spacing and 125% RDF) recorded higher CA (1.92, 1.78 and 1.76 mg g^{-1}at 60 DAS) during Summer, *Kharif* and *Rabi* seasons, respectively. However, it was found at par with S_2 x N_3 (brown top millet sown with 30 x 10 cm and 125% RDF) and S_3 x N_2 (brown top millet sown with 45 x 10 cm spacing with 100% RDF). There were no significant differences recorded among three-way interactions.

Chlorophyll 'b'

Irrespective of the seasons, the differences in **CB under** E x S (establishment methods x crop geometry), E x N (establishment methods x nutrient levels) and E x S x N (establishment methods x crop geometry x nutrient levels) interactions **were found statistically non-significant** (Table 6)**.** However, S_3 x N_3 (brown top millet sown with 45 x 10 cm and 125% RDF) recorded significantly higher CB during *Kharif* season (1.08 mg g^{-1}) and *Rabi* season (1.03 mg g^{-1}) and was found statistically comparable with S_3 x N_3 (brown top millet sown with 45 x 10 cm and 100% RDF) and S_3 x N_2(brown top millet sown with 45 x 10 cm and 100% RDF). The lower **CB** was recorded in a treatment combination of S_1 x N_1(brown top millet sown with 20 x 10 cm and 75% RDF). There were no significant differences in CB under S x N (crop geometry x nutrient levels) during the summer season.

Total chlorophyll content

The differences in TCC **under** E x S (establishment methods x crop geometry) and E x S x N (establishment methods x crop geometry x nutrient levels) interactions **were found statistically non-significant during all the seasons** (Table 7)**.** However, E_1x N_3 (direct sown brown top millet with 125% RDF) recorded significantly higher TCC during *Kharif* (2.76 mg g^{-1}) and *Rabi* season (2.67 mg g^{-1}) when compared to other treatment combinations. The lower TCC **was recorded with** E_2x N_1 (transplanted brown top millet crop sown with 75% RDF). S_3 x N_3 (brown top millet sown with 45 x 10 cm and 125% RDF) recorded higher TCC (3.04, 2.86 and 2.79 mg g^{-1}), during summer, Kharif and Rabi seasons, respectively and was found at par with S_3 x N_3 (brown top millet sown with 45 x 10 cm and 125% RDF) and S_3 x N_2 (brown top millet sown with 45 x 10 cm and 100% RDF). The lower TCC was recorded in a treatment combination of E_2x N_1 (transplanted brown top millet sown with 75% RDF) and S_1 x N_1 (brown top millet sown with 20 x 10 cm and 75% RDF).

Yield

E_1 recorded significantly higher GY (1.52, 1.31, and 1.19 t ha^{-1}) and SY (4.6, 4.12 and 3.65 t ha^{-1}) during Summer, Kharif and Rabi seasons over E_2 which recorded lower yield across same seasons (Table 7). The uninterrupted growth in E_1 likely promoted better tiller development, leading to a higher number of productive tillers. Since each panicle serves as a potential grain source, an increased panicle number directly enhances GY. Additionally, the larger leaf area, higher tiller count and more robust plant growth observed in E_1 contributed to an increased straw yield. The stronger physiological development in E_1 also supported the plant's ability to efficiently fill grains, resulting in greater grain mass. In contrast, transplanted plants often experience stress from transplanting, which could negatively affect nutrient allocation and grain filling, leading to lower GY. These outcomes are in accordance with (21), who noticed that the direct drilling of pearl millet resulted in significantly greater GY (36 q ha^{-1}) and SY (92 q ha^{-1}) over the transplanted crop.

The wider spacing of S_3 recorded significantly greater GY (1.59, 1.41 and 1.25 t ha^{-1}) during three seasons respectively, over other spacings S_2 and S_1. The lower GY was recorded with S_1. The wider spacing could have allowed plants to maximize their yield potential by producing more and larger grains due to reduced competition. This could have contributed to higher overall grain yield. In closer spacings, the increased competition for resources could have limited the plant's ability to produce a high number of grains, leading to a lower grain weight per plant. Similar results of higher grain yield in brown top millet under greater inter-row spacing were reported by (30 -33). Significantly greater SY (4.72, 4.23 and 3.77 t ha^{-1}) was recorded with S_1 across three seasons respectively, whereas the lower SY was recorded with S_3(Table 7). This could be attributed to the increased plant population density, which led to a greater cumulative vegetative biomass. In S_1, the presence of more plants per square meter competes intensely for essential resources, causing plants to elongate their stems (etiolation) and focus energy on vegetative growth. This competition for light could have promoted increased stem biomass, contributing to the higher SY. Additionally, the denser

Table 6. Impact of agronomic practices on SPAD, Chlorophyll ‘a’, ‘b’ at 60 DAS of brown top millet

	SPAD			Chlorophyll ‘a’ (mg g^{-1})			Chlorophyll ‘b’ (mg g^{-1})		
	summer	***Kharif***	***Rabi***	**summer**	***Kharif***	***Rabi***	**summer**	***Kharif***	***Rabi***
Crop Establishment (E)									
E_1	47.9	44.3	39.9	1.62	1.44	1.39	0.95	0.90	0.83
E_2	45.4	40.2	36.4	1.50	1.30	1.27	0.89	0.84	0.76
SEm±	0.57	0.52	0.58	0.02	0.02	0.02	0.01	0.01	0.01
CD (P=0.05)	1.6	1.5	1.7	0.06	0.05	0.05	0.03	0.03	0.03
Crop Geometry (S)									
S_1	41.8	37.1	32.8	1.40	1.19	1.15	0.82	0.77	0.69
S_2	47.8	43.0	39.2	1.59	1.41	1.37	0.94	0.89	0.82
S_3	50.4	46.5	42.3	1.69	1.52	1.49	1.00	0.95	0.88
SEm±	0.70	0.63	0.71	0.02	0.02	0.02	0.01	0.01	0.01
CD (P=0.05)	2.0	1.8	2.0	0.07	0.06	0.06	0.04	0.04	0.04
Nutrient levels (N)									
N_1	39.5	34.9	30.5	1.26	1.09	1.06	0.73	0.69	0.60
N_2	48.3	43.8	39.7	1.64	1.43	1.37	0.98	0.92	0.85
N_3	52.2	48.0	44.2	1.77	1.60	1.56	1.05	1.00	0.94
SEm±	0.70	0.63	0.71	0.02	0.02	0.02	0.01	0.01	0.01
CD (P=0.05)	2.0	1.8	2.0	0.07	0.06	0.06	0.04	0.04	0.04
Crop Establishment (E) x Crop Geometry (S)									
E_1S_1	42.7	38.0	33.7	1.43	1.22	1.17	0.84	0.79	0.71
E_1S_2	49.1	45.0	41.1	1.65	1.47	1.42	0.97	0.92	0.84
E_1S_3	52.0	49.8	44.9	1.78	1.62	1.58	1.04	0.99	0.93
E_2S_1	41.0	36.3	32.0	1.37	1.16	1.13	0.80	0.75	0.67
E_2S_2	46.4	41.1	37.4	1.54	1.34	1.31	0.91	0.86	0.79
E_2S_3	48.8	43.2	39.8	1.60	1.41	1.39	0.97	0.91	0.83
SEm±	0.99	0.90	1.00	0.03	0.03	0.03	0.02	0.02	0.02
CD(P=0.05)	NS	2.6	NS	NS	NS	0.09	NS	NS	NS
Crop Establishment (E) x Nutrient levels (N)									
E_1N_1	39.9	35.2	30.9	1.29	1.11	1.08	0.75	0.70	0.61
E_1N_2	49.9	46.3	41.7	1.70	1.49	1.43	1.01	0.96	0.88
E_1N_3	54.0	51.3	47.1	1.87	1.72	1.67	1.08	1.04	1.00
E_2N_1	39.1	34.6	30.1	1.24	1.08	1.05	0.71	0.67	0.58
E_2N_2	46.7	41.4	37.7	1.59	1.36	1.32	0.95	0.88	0.81
E_2N_3	50.4	44.6	41.4	1.68	1.47	1.45	1.01	0.96	0.89
SEm±	0.99	0.90	1.00	0.03	0.03	0.03	0.02	0.02	0.02
CD(P=0.05)	NS	2.6	2.9	NS	0.09	0.09	NS	NS	NS
Crop Geometry (S) x Nutrient levels (N)									
S_1N_1	38.6	34.2	29.6	1.20	1.05	1.01	0.67	0.64	0.56
S_1N_2	42.2	37.4	33.2	1.45	1.21	1.16	0.87	0.80	0.72
S_1N_3	44.8	39.9	35.8	1.54	1.32	1.27	0.93	0.87	0.80
S_2N_1	39.4	34.7	30.4	1.25	1.09	1.07	0.73	0.68	0.59
S_2N_2	48.7	43.4	39.7	1.67	1.44	1.37	0.99	0.93	0.85
S_2N_3	55.3	51.1	47.7	1.86	1.69	1.66	1.10	1.06	1.01
S_3N_1	40.5	35.9	31.5	1.34	1.14	1.11	0.80	0.74	0.64
S_3N_2	54.1	50.8	46.2	1.82	1.63	1.59	1.09	1.04	0.98
S_3N_3	56.5	52.9	49.3	1.92	1.78	1.76	1.12	1.08	1.03
SEm±	1.21	1.10	1.22	0.04	0.04	0.04	0.02	0.03	0.02
CD(P=0.05)	3.5	3.2	3.5	0.12	0.11	0.10	NS	0.07	0.07
Crop Establishment (E) x Crop Geometry (S) x Nutrient levels (N)									
$E_1S_1N_1$	38.9	34.4	29.9	1.21	1.06	1.02	0.68	0.65	0.57
$E_1S_1N_2$	43.1	38.2	34.1	1.49	1.25	1.20	0.89	0.82	0.75
$E_1S_1N_3$	46.1	41.3	37.1	1.58	1.35	1.29	0.95	0.89	0.82
$E_1S_2N_1$	39.7	34.7	30.7	1.27	1.10	1.10	0.75	0.70	0.60
$E_1S_2N_2$	50.5	45.2	41.5	1.71	1.50	1.39	1.02	0.96	0.86
$E_1S_2N_3$	57.3	55.0	51.1	1.96	1.82	1.79	1.14	1.11	1.07
$E_1S_3N_1$	41.1	36.4	32.1	1.38	1.16	1.12	0.82	0.75	0.66
$E_1S_3N_2$	56.2	55.5	49.5	1.90	1.73	1.69	1.13	1.09	1.03
$E_1S_3N_3$	58.6	57.7	53.3	2.06	1.98	1.94	1.16	1.13	1.10
$E_2S_1N_1$	38.3	33.9	29.3	1.19	1.04	1.00	0.66	0.63	0.55
$E_2S_1N_2$	41.3	36.6	32.3	1.41	1.17	1.12	0.84	0.77	0.68
$E_2S_1N_3$	43.5	38.5	34.5	1.50	1.28	1.25	0.90	0.84	0.77
$E_2S_2N_1$	39.1	34.6	30.1	1.23	1.08	1.05	0.70	0.66	0.58
$E_2S_2N_2$	46.9	41.5	37.9	1.62	1.38	1.34	0.96	0.90	0.84
$E_2S_2N_3$	53.3	47.2	44.3	1.76	1.56	1.53	1.06	1.01	0.94
$E_2S_3N_1$	40.0	35.4	31.0	1.29	1.12	1.11	0.77	0.73	0.62
$E_2S_3N_2$	52.0	46.0	43.0	1.73	1.53	1.49	1.05	0.98	0.92
$E_2S_3N_3$	54.4	48.2	45.4	1.78	1.58	1.57	1.08	1.03	0.96
SEm±	1.72	1.56	1.73	0.06	0.06	0.05	0.03	0.04	0.03
CD(P=0.05)	NS	4.5	NS	NS	NS	NS	NS	NS	NS

E_1: Direct sowing; E_2: Transplanting; S_1: 20 x 10 cm; S_2: 30 x 10 cm; S_3: 45 x 10 cm; N_1: 75% RDF; N_2: 100% RDF; N_3: 125% RDF

planting in S_1 ensured that a larger portion of the available field space was utilized for biomass production, even though individual plants might be smaller. In contrast, in wider spacing, the reduced competition allowed for more resources to be allocated to reproductive growth (grain development) rather than vegetative growth, resulting in higher GY and lower SY in those treatments. These results of higher SY under narrower spacing in brown top millet were reported by (23, 30).

N_3 recorded significantly maximum GY (1.67, 1.46 and 1.33 t ha^{-1}) and SY (4.76, 4.27 and 3.81 t ha^{-1}) across three seasons respectively (Table 7). However, the lower values were observed with N_1. This could be attributed to the abundant availability of nitrogen, phosphorus and potassium, which might have supported robust plant growth and a higher allocation of resources towards reproductive structures, resulting in higher yields. Similar findings of superior GY and SY with application of 125% RDF were reported by (24, 30, 33, 34).

Interaction effect

Grain yield

No significant interaction effects on GY were found between crop establishment methods and crop geometry (E x S) and crop establishment methods, crop geometry and nutrient levels (E x S x N) during any of the seasons.

Higher GY of 1.53 and 1.40 t ha^{-1} during the Kharif and Rabi seasons were recorded with direct sown brown top millet sown with 125% RDF (E_1 x N_3) when compared to other treatment combinations. The lower GY of 1.09 and 0.86 t ha^{-1} was recorded with transplanted brown top millet sown with 75% RDF (E_2 x N_1) across the same seasons. Brown top millet sown with 45 x 10 cm spacing and 125% RDF (S_3 x N_3) recorded higher GY of 1.84, 1.62 and 1.44 t ha^{-1} during the summer, *Kharif*, and *Rabi* seasons, respectively, compared to other crop geometry and nutrient level combinations (S x N). However, it was statistically on par with brown top millet sown at 30 x 10 cm with 125% RDF (S_2 x N_3) during the summer and *Kharif* season. During *Rabi* season, it was found to be comparable to both brown top millet crop sown at 30 x 10 cm with 125% RDF (S_2 x N_3) and brown top millet sown with 45 x 10 cm with 100% RDF (S_3 x N_2). The lowest GY of 1.21, 1.00 and 0.82 t ha^{-1} were observed with brown top millet sown with 20 x 10 cm and 75% RDF (S_1 x N_1) across the same seasons (Table 7).

Straw yield

There were no significant interaction effects on SY between crop establishment methods and crop geometry (E x S), crop establishment methods and nutrient levels (E x N) and crop geometry and nutrient levels (S x N) or the combined interaction of all three factors (E x S x N) during any of the seasons (Table 7).

Nutrient content and uptake by straw

E_1 recorded notably higher NC (1.03, 0.97 and 0.80 %), PC (0.33, 0.29 and 0.25%), KC (1.62, 1.55 and 1.50%), NU (47.9, 40.3 and 29.5 kg ha^{-1}), PU (15.1, 12.1 and 9.3 kg ha^{-1}) and KU (74.8, 64.0 and 55.0 kg ha^{-1}) during Summer, Kharif and Rabi seasons respectively compared to the E_2 (Table 8 and 9). This is likely attributed to enhanced root systems in E_1 which allowed for more efficient nutrient absorption, especially during the critical growth phases when nutrient demand is highest. The larger leaf area and improved canopy structure contributed to more vigorous photosynthesis, boosting metabolic processes that depend on nutrient availability. This efficient absorption and assimilation of nutrients, particularly in direct sown crops, translated into higher nutrient content and uptake, as reflected in both grain yield and straw quality. In contrast, E_2 faced early growth stress, which could impair root establishment and reduce nutrient absorption capacity, limiting biomass accumulation. This stress response might have triggered hormonal changes, such as increased abscisic acid (ABA), which is known to reduce nutrient uptake by restricting root growth and stomatal conductance, thereby limiting the plant's ability to efficiently transport and absorb nutrients. Consequently, the total content and uptake in E_2 were lower, which was reflected in both lower grain yield and reduced straw quality. Similar findings were reported by (35) who registered a higher NPK content and uptake in direct sown when compared to transplanted crops.

Among crop geometry, S_3 recorded higher NC (1.08, 1.01 and 0.86 %), PC (0.34, 0.31 and 0.27%), KC (1.66, 1.58 and 1.54%) during three seasons, respectively over other spacings (Table 8). S_2 showed significantly higher NU (47.0, 39.1 and 28.7 kg ha^{-1}), PU (14.4, 12.0 and 9.1 kg ha^{-1}), and KU (72.9, 62.2 and 53.4 kg ha^{-1}) across three seasons respectively when compared to S_3 and S_1 (Table 9). However, the spacing of S_2 was found at par with S_3 during all three seasons. This could be attributed to reduced inter-plant competition in wider spacing which could have allowed each plant to have better access to available N, P and K in the soil. This led to more robust root development and more efficient nutrient uptake, especially under wider spacing where nutrient availability per plant was enhanced. The lower NPK contents and uptakes were recorded with S_1 due to the presence of higher plant densities with increased competition for nutrients which resulted in reduced overall nutrient availability per plant and ultimately limited the ability of each plant for uptake, leading to lower NPK content and uptakes in straw. Similar results of higher NPK dynamics in brown top millet were reported by (23, 30).

Significantly higher NC (1.13, 1.07 and 0.90%), PC (0.36, 0.34 and 0.29%), KC (1.69, 1.61 and 1.57%), NU (53.7, 45.5 and 34.3 kg ha^{-1}), PU (17.0, 14.4 and 11.2 kg ha^{-1}) and KU (80.6, 68.7 and 60.0 kg ha^{-1}) were recorded with N_3 during three seasons, respectively (Table 8,9). This could be due to increased nutrient availability from the higher fertilizer application in N_3. The lower values were observed with N_1. Similar results of higher nutrient uptake in straw under higher fertilizer doses were reported by (5, 30, 31, 32, 33).

Interaction effect

Nutrient content

There were no significant interaction effects in NPK content in straw between crop establishment methods and crop geometry (E x S), crop establishment methods and nutrient levels (E x N) and crop geometry and nutrient levels (S x N) or the combined interaction of all three factors (E x S x N) during any of the seasons (Table 8).

Nutrient uptake by straw

Significantly higher NU (49.5 and 37.1 kg ha^{-1}during Kharif and Rabi seasons), PU (18.4, 161 and 12.5 kg ha^{-1}during Summer, Kharif, Rabi seasons) and KU (85.6 and 64.6 kg ha^{-1} during

Table 7. Impact of agronomic practices on total chlorophyll at 60 DAS and yield of brown top millet

	Total chlorophyll content (mg g^{-1})			**Grain yield (t ha^{-1})**			**Straw yield (t ha^{-1})**		
	summer	***Kharif***	***Rabi***	**summer**	***Kharif***	***Rabi***	**summer**	***Kharif***	***Rabi***
Crop Establishment (E)									
E_1	2.57	2.34	2.22	1.52	1.31	1.19	4.60	4.12	3.65
E_2	2.39	2.14	2.04	1.40	1.23	1.09	4.37	3.88	3.42
SEm±	0.03	0.03	0.03	0.03	0.02	0.02	0.07	0.07	0.07
CD (P=0.05)	0.09	0.09	0.08	0.08	0.06	0.06	0.21	0.20	0.21
Crop Geometry (S)									
S_1	2.22	1.96	1.84	1.31	1.13	1.00	4.72	4.23	3.77
S_2	2.53	2.30	2.18	1.48	1.26	1.16	4.52	4.03	3.57
S_3	2.69	2.47	2.37	1.59	1.41	1.25	4.22	3.73	3.27
SEm±	0.04	0.04	0.04	0.03	0.03	0.02	0.09	0.09	0.09
CD (P=0.05)	0.11	0.10	0.10	0.10	0.07	0.07	0.26	0.25	0.25
Nutrient levels (N)									
N_1	1.99	1.78	1.66	1.25	1.08	0.88	4.11	3.62	3.16
N_2	2.63	2.35	2.22	1.47	1.27	1.21	4.59	4.10	3.64
N_3	2.82	2.60	2.51	1.67	1.46	1.33	4.76	4.27	3.81
SEm±	0.04	0.04	0.04	0.03	0.03	0.02	0.09	0.09	0.09
CD (P=0.05)	0.11	0.10	0.10	0.10	0.07	0.07	0.26	0.25	0.25
Crop Establishment (E) x Crop Geometry (S)									
E_1S_1	2.27	2.01	1.88	1.33	1.14	1.03	4.93	4.45	3.98
E_1S_2	2.62	2.40	2.27	1.55	1.31	1.22	4.63	4.15	3.68
E_1S_3	2.82	2.61	2.51	1.70	1.49	1.32	4.24	3.76	3.29
E_2S_1	2.17	1.91	1.79	1.30	1.13	0.97	4.50	4.02	3.55
E_2S_2	2.44	2.20	2.09	1.41	1.22	1.11	4.40	3.91	3.45
E_2S_3	2.57	2.32	2.22	1.49	1.33	1.18	4.19	3.71	3.24
SEm±	0.05	0.05	0.05	0.05	0.04	0.03	0.13	0.12	0.13
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop Establishment (E) x Nutrient levels (N)									
E_1N_1	2.04	1.81	1.69	1.26	1.07	0.89	4.15	3.67	3.20
E_1N_2	2.71	2.45	2.31	1.53	1.33	1.28	4.71	4.22	3.76
E_1N_3	2.95	2.76	2.67	1.78	1.53	1.40	4.95	4.46	4.00
E_2N_1	1.95	1.75	1.64	1.24	1.09	0.86	4.07	3.58	3.12
E_2N_2	2.54	2.24	2.13	1.40	1.20	1.14	4.47	3.98	3.52
E_2N_3	2.69	2.43	2.34	1.56	1.38	1.26	4.57	4.08	3.62
SEm±	0.05	0.05	0.05	0.05	0.04	0.03	0.13	0.12	0.13
CD(P=0.05)	NS	0.15	0.14	NS	0.10	0.10	NS	NS	NS
Crop Geometry (S) x Nutrient levels (N)									
S_1N_1	1.87	1.69	1.57	1.21	1.01	0.82	4.25	3.76	3.30
S_1N_2	2.32	2.01	1.87	1.32	1.15	1.05	4.79	4.30	3.84
S_1N_3	2.47	2.18	2.07	1.41	1.24	1.13	5.12	4.63	4.17
S_2N_1	1.98	1.77	1.66	1.25	1.08	0.88	4.11	3.62	3.16
S_2N_2	2.66	2.37	2.22	1.43	1.21	1.20	4.67	4.18	3.72
S_2N_3	2.96	2.75	2.66	1.76	1.51	1.41	4.77	4.29	3.82
S_3N_1	2.13	1.88	1.75	1.29	1.17	0.93	3.97	3.48	3.02
S_3N_2	2.91	2.67	2.57	1.65	1.44	1.38	4.30	3.82	3.35
S_3N_3	3.04	2.86	2.79	1.84	1.62	1.45	4.38	3.90	3.43
SEm±	0.06	0.06	0.06	0.06	0.04	0.04	0.16	0.15	0.15
CD(P=0.05)	0.18	0.18	0.18	0.17	0.13	0.12	NS	NS	NS
Crop Establishment (E) x Crop Geometry (S) x Nutrient levels (N)									
$E_1S_1N_1$	1.89	1.71	1.59	1.22	1.01	0.83	4.27	3.78	3.32
$E_1S_1N_2$	2.38	2.07	1.95	1.33	1.15	1.11	5.00	4.52	4.05
$E_1S_1N_3$	2.53	2.24	2.11	1.42	1.25	1.14	5.53	5.04	4.58
$E_1S_2N_1$	2.02	1.80	1.70	1.27	1.08	0.90	4.17	3.68	3.22
$E_1S_2N_2$	2.73	2.46	2.25	1.44	1.26	1.25	4.81	4.32	3.86
$E_1S_2N_3$	3.10	2.93	2.86	1.92	1.59	1.50	4.92	4.43	3.97
$E_1S_3N_1$	2.20	1.91	1.78	1.30	1.12	0.95	4.02	3.54	3.07
$E_1S_3N_2$	3.03	2.82	2.72	1.80	1.57	1.47	4.31	3.82	3.36
$E_1S_3N_3$	3.22	3.11	3.04	2.01	1.76	1.55	4.40	3.92	3.45
$E_2S_1N_1$	1.85	1.67	1.55	1.20	1.00	0.81	4.24	3.75	3.29
$E_2S_1N_2$	2.25	1.94	1.80	1.31	1.16	0.99	4.58	4.09	3.63
$E_2S_1N_3$	2.40	2.12	2.02	1.39	1.23	1.13	4.70	4.22	3.75
$E_2S_2N_1$	1.93	1.74	1.63	1.23	1.07	0.87	4.04	3.56	3.09
$E_2S_2N_2$	2.58	2.28	2.18	1.41	1.16	1.15	4.53	4.04	3.58
$E_2S_2N_3$	2.82	2.57	2.47	1.60	1.43	1.32	4.63	4.14	3.68
$E_2S_3N_1$	2.06	1.85	1.73	1.29	1.21	0.91	3.92	3.43	2.97
$E_2S_3N_2$	2.78	2.51	2.41	1.50	1.30	1.29	4.30	3.81	3.35
$E_2S_3N_3$	2.86	2.61	2.53	1.68	1.49	1.35	4.36	3.88	3.41
SEm±	0.09	0.09	0.09	0.08	0.06	0.06	0.22	0.21	0.22
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

E_1: Direct sowing; E_2: Transplanting; S_1: 20 x 10 cm; S_2: 30 x 10 cm; S_3: 45 x 10 cm; N_1: 75% RDF; N_2: 100% RDF; N_3: 125% RDF

Table 8. Impact of agronomic practices on nutrient content in straw of brown top millet at maturity stage

	Nitrogen content (%)			**Phosphorus content (%)**			**Potassium content (%)**		
	summer 2023	***Kharif* 2023**	***Rabi* 2023-24**	**summer 2023**	***Kharif* 2023**	***Rabi* 2023-24**	**summer 2023**	***Kharif* 2023**	***Rabi* 2023-24**
Crop Establishment (E)									
E_1	1.03	0.97	0.80	0.33	0.29	0.25	1.62	1.55	1.50
E_2	0.98	0.91	0.75	0.30	0.26	0.22	1.56	1.50	1.44
SEm±	0.01	0.01	0.02	0.01	0.01	0.01	0.02	0.02	0.02
CD (P=0.05)	0.04	0.04	0.04	0.02	0.02	0.02	0.05	0.05	0.05
Crop Geometry (S)									
S_1	0.91	0.85	0.69	0.28	0.23	0.19	1.51	1.46	1.39
S_2	1.03	0.96	0.79	0.32	0.29	0.25	1.61	1.53	1.49
S_3	1.08	1.01	0.86	0.34	0.31	0.27	1.66	1.58	1.54
SEm±	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02
CD (P=0.05)	0.04	0.05	0.05	0.03	0.03	0.03	0.07	0.06	0.06
Nutrient levels (N)									
N_1	0.83	0.77	0.60	0.25	0.19	0.15	1.46	1.42	1.34
N_2	1.06	0.99	0.83	0.33	0.31	0.27	1.63	1.54	1.51
N_3	1.13	1.07	0.90	0.36	0.34	0.29	1.69	1.61	1.57
SEm±	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.02
CD (P=0.05)	0.04	0.05	0.05	0.03	0.03	0.03	0.07	0.06	0.06
Crop Establishment (E) x Crop Geometry (S)									
E_1S_1	0.94	0.88	0.71	0.29	0.25	0.21	1.53	1.47	1.41
E_1S_2	1.05	0.98	0.81	0.33	0.30	0.25	1.63	1.55	1.51
E_1S_3	1.11	1.05	0.89	0.36	0.32	0.28	1.69	1.62	1.57
E_2S_1	0.88	0.82	0.67	0.27	0.21	0.17	1.49	1.44	1.37
E_2S_2	1.01	0.93	0.78	0.30	0.28	0.24	1.58	1.51	1.46
E_2S_3	1.04	0.98	0.82	0.32	0.30	0.25	1.62	1.53	1.50
SEm±	0.02	0.02	0.03	0.01	0.01	0.01	0.03	0.03	0.03
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop Establishment (E) x Nutrient levels (N)									
E_1N_1	0.84	0.78	0.62	0.26	0.20	0.16	1.47	1.42	1.35
E_1N_2	1.08	1.02	0.84	0.34	0.31	0.28	1.65	1.57	1.53
E_1N_3	1.18	1.11	0.94	0.38	0.36	0.31	1.74	1.65	1.62
E_2N_1	0.81	0.75	0.59	0.24	0.18	0.14	1.44	1.41	1.32
E_2N_2	1.04	0.97	0.81	0.32	0.30	0.26	1.60	1.52	1.48
E_2N_3	1.08	1.02	0.87	0.34	0.31	0.27	1.65	1.56	1.53
SEm±	0.02	0.02	0.03	0.01	0.01	0.01	0.03	0.03	0.03
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop Geometry (S) x Nutrient levels (N)									
S_1N_1	0.77	0.72	0.55	0.23	0.17	0.13	1.42	1.39	1.30
S_1N_2	0.94	0.88	0.72	0.30	0.23	0.20	1.54	1.47	1.42
S_1N_3	1.03	0.97	0.79	0.33	0.28	0.25	1.59	1.51	1.47
S_2N_1	0.83	0.76	0.60	0.25	0.19	0.15	1.46	1.42	1.34
S_2N_2	1.09	1.01	0.85	0.34	0.33	0.30	1.64	1.54	1.52
S_2N_3	1.17	1.10	0.93	0.36	0.36	0.30	1.72	1.64	1.60
S_3N_1	0.89	0.82	0.66	0.27	0.22	0.17	1.49	1.44	1.37
S_3N_2	1.16	1.09	0.92	0.36	0.36	0.31	1.71	1.62	1.59
S_3N_3	1.20	1.13	0.99	0.38	0.37	0.33	1.77	1.68	1.65
SEm±	0.03	0.03	0.03	0.02	0.02	0.02	0.04	0.04	0.04
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop Establishment (E) x Crop Geometry (S) x Nutrient levels (N)									
$E_1S_1N_1$	0.78	0.73	0.56	0.23	0.17	0.13	1.43	1.40	1.31
$E_1S_1N_2$	0.95	0.90	0.73	0.31	0.24	0.21	1.56	1.48	1.44
$E_1S_1N_3$	1.08	1.02	0.83	0.34	0.33	0.29	1.61	1.52	1.49
$E_1S_2N_1$	0.85	0.78	0.62	0.26	0.20	0.16	1.47	1.42	1.35
$E_1S_2N_2$	1.10	1.02	0.86	0.34	0.34	0.30	1.65	1.56	1.53
$E_1S_2N_3$	1.21	1.14	0.94	0.37	0.37	0.31	1.76	1.68	1.64
$E_1S_3N_1$	0.90	0.84	0.68	0.28	0.22	0.18	1.50	1.45	1.38
$E_1S_3N_2$	1.20	1.13	0.94	0.38	0.36	0.32	1.74	1.66	1.62
$E_1S_3N_3$	1.24	1.18	1.04	0.41	0.39	0.35	1.84	1.76	1.72
$E_2S_1N_1$	0.76	0.70	0.54	0.22	0.16	0.12	1.40	1.38	1.28
$E_2S_1N_2$	0.92	0.86	0.70	0.28	0.22	0.18	1.51	1.46	1.39
$E_2S_1N_3$	0.97	0.91	0.76	0.32	0.24	0.22	1.57	1.49	1.45
$E_2S_2N_1$	0.81	0.74	0.58	0.23	0.18	0.13	1.45	1.41	1.33
$E_2S_2N_2$	1.08	1.00	0.83	0.34	0.33	0.30	1.62	1.52	1.50
$E_2S_2N_3$	1.13	1.06	0.92	0.35	0.35	0.30	1.68	1.60	1.56
$E_2S_3N_1$	0.87	0.80	0.64	0.26	0.21	0.16	1.48	1.43	1.36
$E_2S_3N_2$	1.11	1.05	0.90	0.35	0.35	0.30	1.67	1.57	1.55
$E_2S_3N_3$	1.15	1.08	0.93	0.35	0.35	0.30	1.70	1.60	1.58
SEm±	0.04	0.04	0.05	0.02	0.03	0.02	0.06	0.05	0.05
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

E_1: Direct sowing; E_2: Transplanting; S_1: 20 x 10 cm; S_2: 30 x 10 cm; S_3: 45 x 10 cm; N_1: 75% RDF; N_2: 100% RDF; N_3: 125% RDF

Summer and Rabi seasons) were recorded with direct sown brown top millet when applied with 125% RDF (E_1x N_3). The lower uptakes were recorded with transplanted brown top millet with 75% RDF (E_2x N_1) across the same seasons. Brown top millet sown with 30 x 10 cm and 125% RDF (S_2N_3) recorded higher phosphorus uptake in straw (11.6 kg ha^{-1}) during the *Kharif* season when compared to other treatment combinations. However, S_2N_3 was found on par with S_3x N_3 (45 x 10 cm + 125% RDF), S_2x N_2 (30 x 10 cm + 100% RDF), S_1x N_3 (20 x 10 cm + 125% RDF) and S_3x N_2 (45 x 10 cm + 100% RDF). The lower phosphorus uptake in straw (4.2 kg ha^{-1}) was recorded when brown top millet was sown with 20 x 10 cm and 75% RDF (S_1 x N_1) during the same season. The phosphorus uptake in straw during summer and *Rabi* season was found to be non-significant (Table 9).

Effect of seasons variations

The summer season consistently outperformed the Kharif and Rabi seasons in terms of leaf traits, yield and nutrient dynamics of brown top millet. Favourable conditions in summer, including an average maximum temperature of 34.5°C and 7.9 hours of bright sunshine promoted higher chlorophyll content, SPAD values and greater biomass accumulation. These optimal temperatures and light conditions could have supported longer and broader leaves enhancing photosynthesis and overall plant growth. Grain and straw yields were highest in summer, aided by efficient nutrient uptake due to optimal soil aeration. These results are consistent with previous studies by (36) who reported that summer pearl millet had significantly higher yield attributes and grain yield than late planting dates. In contrast, the Kharif and Rabi season recorded lower growth and yield parameters compared to summer, likely due to higher cumulative rainfall (56.1 and 331 mm respectively) and lower sunshine hours (5.4 and 5.8 respectively) (Table 1). Consequently, leaf length, breadth, chlorophyll content, SPAD values, grain yield and straw yield were all reduced. (5) supported these findings by noting that Kharif-sown brown top millet achieved lower growth parameters compared to summer-sown crops. Similar outcomes of shorter photoperiods and reduced sunshine hours impeding growth and yield during Rabi were reported by (37).

Pearson’s correlation

Pearson’s correlation was employed to analyse the relationships between leaf traits, chlorophyll content, yield, and nutrient dynamics of brown top millet, presented in Fig.1. LL showed high positive correlations with LB (0.995), SPAD (0.991) and CA (0.995), indicating that longer leaves are associated with broader leaves, higher TCC and better photosynthesis efficiency (SPAD). LL showed a moderate correlation with GY (0.977), suggesting that leaf length impacts the yield but was not the strongest factor. SPAD has shown very strong correlations with CA (0.995) and CB (0.992), as SPAD is a direct measure of TCC. SPAD also showed a strong correlation with GY (0.979), indicating that higher chlorophyll levels contribute significantly to grain yield. GY showed a strong correlation with SPAD (0.979), CA (0.970), TCC (0.965) and LB (0.978), showing that leaf chlorophyll and breadth contribute significantly to grain yield. GY has shown a moderate correlation with NU (0.868), indicating that nutrient management also plays an important role in productivity. SY displayed a strong correlation with LAI (0.972), indicating that a higher leaf area results in more biomass. NU showed strong correlations with LB (0.921), CA (0.927) and GY (0.868), demonstrating that nitrogen uptake significantly influences leaf properties, chlorophyll production and yield. NU displayed a very strong correlation with PU (0.997) and KU (0.981), indicating that nitrogen availability is closely linked to phosphorus and potassium in the soil. These findings suggest that optimizing chlorophyll levels, leaf characteristics and nutrient uptake are critical strategies for improving crop productivity, with a particular focus on maximizing grain yield and biomass.

Conclusion

This study provides important insights into how brown top millet responds to various agronomic practices. Among establishment methods evaluated, direct-sown brown top millet showed significantly better leaf characteristics, yield, nutrient content and uptake compared to the transplanted crop. 20 x 10 cm recorded a notably greater leaf area index and straw yield, while the 45 x 10 cm spacing significantly improved leaf length, width, SPAD, chlorophyll a, b, total chlorophyll content, grain yield and nutrient content. Meanwhile, the 30 x 10 cm spacing showed higher nutrient uptake. Applying 125% RDF yielded the best results compared to other nutrient levels. Summer sown brown top millet outperformed crops sown in the Kharif and Rabi seasons in terms of overall observations. The treatment combination of direct sown brown top millet with 45 x 10 cm spacing and 125% RDF produced higher values for leaf length, width, SPAD, chlorophyll a, b, total chlorophyll content, grain yield and nutrient content, though differences between treatment combinations were not statistically significant. Similarly, direct sowing with 20 x 10 cm spacing and 125% RDF showed higher leaf area index and straw yield compared to other treatments, with no significant differences between them. Farmers may adopt these practices to improve productivity and policymakers could support this through extension services and input subsidies. While numerous studies have examined agronomic practices for brown top millet in India, none have focused on its cultivation across different seasons and their effects on leaf morphology and physiological traits. This research uniquely investigates the crop's response to transplanting methods, offering new insights into its growth patterns. Moreover, this is the first study to attempt standardizing agronomic practices for brown top millet in Tamil Nadu, providing a useful reference for future research and agricultural strategies to optimize its potential. Future research could explore long-term soil health impacts, multi-location trials across different agro-climatic zones, and intercropping of brown top millet with cereals or legumes for enhancing resource use efficiency.

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Table 9. Impact of agronomic practices on nutrient uptake by straw of brown top millet at maturity

	Nitrogen uptake (kg ha^{-1})			**Phosphorus uptake (kg ha^{-1})**			**Potassium uptake (kg ha^{-1})**		
	summer 2023	***Kharif* 2023**	***Rabi* 2023-24**	**summer 2023**	***Kharif* 2023**	***Rabi* 2023-24**	**summer 2023**	***Kharif* 2023**	***Rabi* 2023-24**
Crop Establishment (E)									
E_1	47.9	40.3	29.5	15.1	12.1	9.3	74.8	64.0	55.0
E_2	42.9	35.6	26.0	13.2	10.4	7.7	68.6	58.3	49.6
SEm±	0.8	0.6	0.4	0.2	0.3	0.2	0.9	0.7	0.7
CD (P=0.05)	2.4	1.6	1.1	0.6	0.9	0.6	2.6	2.1	1.9
Crop Geometry (S)									
S_1	43.4	36.6	26.3	13.6	9.9	7.5	70.3	59.3	50.6
S_2	47.0	39.1	28.7	14.4	12.0	9.1	72.9	62.2	53.4
S_3	45.8	38.1	28.3	14.3	11.8	8.9	71.9	62.0	52.9
SEm±	1.0	0.7	0.5	0.2	0.4	0.2	1.1	0.9	0.8
CD (P=0.05)	2.9	1.9	1.4	0.7	1.1	0.7	2.2	2.6	2.3
Nutrient levels (N)									
N_1	34.0	27.7	19.1	10.2	6.9	4.7	60.0	51.4	42.2
N_2	48.5	40.6	30.0	15.3	12.5	9.7	74.6	63.3	54.7
N_3	53.7	45.5	34.3	17.0	14.4	11.2	80.6	68.7	60.0
SEm±	1.0	0.7	0.5	0.2	0.4	0.2	1.1	0.9	0.8
CD (P=0.05)	2.9	1.9	1.4	0.7	1.1	0.7	2.2	2.6	2.3
Crop Establishment (E) x Crop Geometry (S)									
E_1S_1	46.9	40.0	28.7	14.9	11.4	8.7	76.1	65.7	56.8
E_1S_2	49.3	41.2	30.3	15.3	12.7	9.6	75.9	64.9	56.0
E_1S_3	47.6	39.7	29.5	15.3	12.4	9.5	72.4	61.3	52.4
E_2S_1	40.0	33.3	23.9	12.4	8.5	6.3	67.7	58.3	49.1
E_2S_2	44.7	36.9	27.2	13.6	11.4	8.6	70.0	59.5	50.8
E_2S_3	44.0	36.5	27.0	13.5	11.3	8.4	68.1	57.2	48.8
SEm±	1.4	1.0	0.7	0.3	0.6	0.3	1.6	1.3	1.1
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop Establishment (E) x Nutrient levels (N)									
E_1N_1	35.0	28.7	19.9	10.8	7.2	5.0	61.2	52.3	43.2
E_1N_2	50.8	42.7	31.5	16.2	13.2	10.3	77.6	66.1	57.4
E_1N_3	58.0	49.5	37.1	18.4	16.1	12.5	85.6	73.6	64.6
E_2N_1	33.1	26.7	18.3	9.7	6.6	4.3	58.8	50.5	41.3
E_2N_2	46.3	38.6	28.5	14.3	11.9	9.1	71.5	60.6	52.1
E_2N_3	49.4	41.4	31.4	15.6	12.7	9.9	75.6	63.9	55.4
SEm±	1.4	1.0	0.7	0.3	0.6	0.3	1.6	1.3	1.1
CD (P=0.05)	NS	2.8	2.0	1.0	1.6	1.0	NS	3.7	3.2
Crop Geometry (S) x Nutrient levels (N)									
S_1N_1	32.8	27.0	18.2	9.7	6.3	4.2	60.3	52.5	42.8
S_1N_2	44.8	37.9	27.5	14.2	10.1	7.6	73.7	63.5	54.5
S_1N_3	52.7	45.0	33.2	17.0	13.4	10.7	81.8	69.9	61.4
S_2N_1	34.1	27.6	19.0	10.1	6.9	4.6	60.1	51.4	42.4
S_2N_2	50.9	42.3	31.5	15.9	13.9	11.1	76.5	64.6	56.5
S_2N_3	56.0	47.4	35.7	17.2	15.3	11.6	82.3	70.6	61.4
S_3N_1	35.2	28.6	20.0	10.8	7.5	5.2	59.5	50.2	41.5
S_3N_2	49.8	41.7	31.0	15.7	13.6	10.4	73.5	61.9	53.3
S_3N_3	52.4	44.1	33.9	16.8	14.5	11.2	77.7	65.7	57.1
SEm±	1.7	1.2	0.8	0.4	0.7	0.4	1.9	1.6	1.4
CD (P=0.05)	NS	NS	NS	NS	NS	1.2	NS	NS	NS
Crop Establishment (E) x Crop Geometry (S) x Nutrient levels (N)									
$E_1S_1N_1$	33.3	27.6	18.6	10.1	6.5	4.4	61.1	53.1	43.5
$E_1S_1N_2$	47.6	40.7	29.6	15.6	11.1	8.6	78.1	67.0	58.4
$E_1S_1N_3$	59.7	51.6	37.9	18.9	16.5	13.2	89.1	76.8	68.3
$E_1S_2N_1$	35.5	28.8	20.0	10.9	7.4	5.2	61.4	52.5	43.5
$E_1S_2N_2$	52.9	44.1	33.2	16.6	14.4	11.5	79.5	67.6	59.1
$E_1S_2N_3$	59.6	50.8	37.6	18.4	16.3	12.2	86.7	74.7	65.2
$E_1S_3N_1$	36.3	29.7	20.9	11.3	7.8	5.6	61.0	51.2	42.5
$E_1S_3N_2$	51.8	43.2	31.7	16.4	14.0	10.9	75.1	63.7	54.5
$E_1S_3N_3$	54.7	46.3	35.9	18.0	15.4	12.1	81.1	69.1	60.2
$E_2S_1N_1$	32.2	26.3	17.8	9.4	6.0	4.0	59.4	51.9	42.2
$E_2S_1N_2$	42.1	35.2	25.4	12.9	9.0	6.6	69.2	59.9	50.5
$E_2S_1N_3$	45.7	38.4	28.6	15.1	10.3	8.3	74.5	63.0	54.5
$E_2S_2N_1$	32.8	26.4	18.0	9.3	6.4	4.1	58.7	50.4	41.2
$E_2S_2N_2$	49.0	40.5	29.7	15.3	13.5	10.7	73.5	61.7	53.8
$E_2S_2N_3$	52.4	44.0	33.9	16.1	14.2	11.0	77.9	66.5	57.5
$E_2S_3N_1$	34.1	27.5	19.0	10.2	7.3	4.8	58.1	49.3	40.5
$E_2S_3N_2$	47.8	40.1	30.2	14.9	13.2	10.0	71.9	60.1	52.0
$E_2S_3N_3$	50.2	41.9	31.8	15.5	13.5	10.3	74.3	62.2	54.0
SEm±	2.5	1.7	1.2	0.6	1.0	0.6	2.7	2.2	2.0
CD(P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

E_1: Direct sowing; E_2: Transplanting; S_1: 20 x 10 cm; S_2: 30 x 10 cm; S_3: 45 x 10 cm; N_1: 75% RDF; N_2: 100% RDF; N_3: 125% RDF

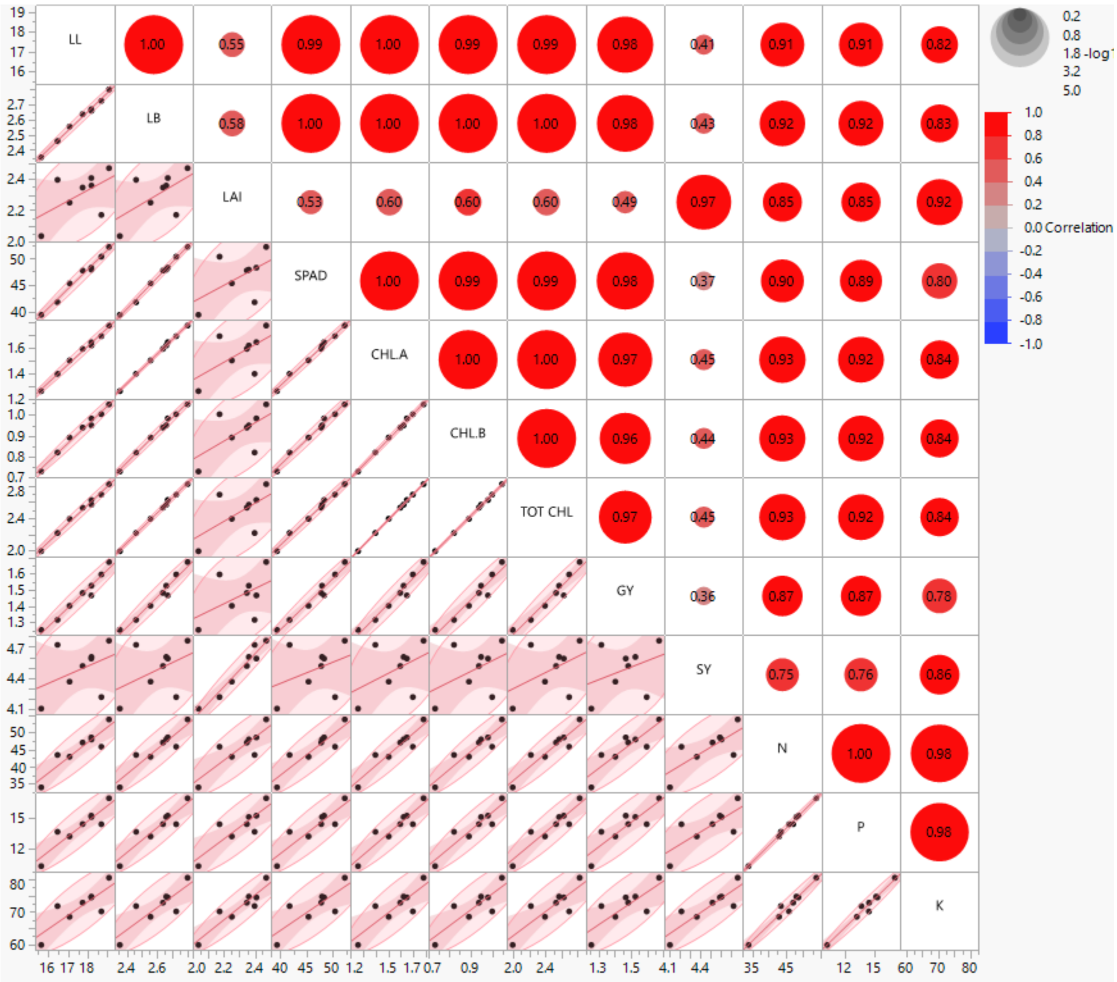

Fig 1. Pearson's correlation depicting relationship among the leaf traits, yield and nutrient dynamics of brown top millet. LL-leaf length, LB-leaf breadth, LAI-leaf area index, SPAD-SPAD chlorophyll values, CHL.A-chlorophyll 'a', CHL.B- Chlorophyll 'b', TOT CHL-total chlorophyll content, GY-grain yield, SY-straw yield, N-nitrogen uptake, P-phosphorus uptake, K- potassium uptake

Fig. 2 Overall view of field experiment A) Nursery B) Transplantation C) Field view D) Grain filling stage E) Maturity stage

Authors' contributions

DA carried out the experiment, took observations and analysed the data. RK guided the research by formulating the research concept and approved the final manuscript. PJ contributed by developing the ideas and reviewing the manuscript. PG helped in editing, summarizing and revising the manuscript. SR helped in summarizing and revising the manuscript. VR helped in editing, summarizing and revising the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

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