PLANT SCIENCE TODAY
ISSN 2348-1900 (online)
Vol 11(sp4): 01–12
https://doi.org/10.14719/pst.5075

HORIZON
e-Publishing Group
HePG

RESEARCH ARTICLE

Effect of sowing methods, spacings and fertilizer levels on quantitative and qualitative traits and economics of brown top millet (*Brachiaria ramosa* L.) under different cropping seasons

Dokka Abhigna[1]*, Rengabashyam Kalpana[1]*, Padmanaban Geetha[2], Ponnusamy Janaki[3], Sengodan Radhamani[1] & Veerasamy Ravichandran[4]

[1]Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore 641 003, India

[2]Department of Centre for Post-Harvest Technology, Tamil Nadu Agricultural University, Coimbatore 641 003, India

[3]Department of Nammazhvar Organic Farming Research Centre, Tamil Nadu Agricultural University, Coimbatore 641 003, India

[4]Department of Crop Physiology, Tamil Nadu Agricultural University, Coimbatore 641 003, India

*Email: abhiabhigna001@gmail.com, kalpana@tnau.ac.in

OPEN ACCESS

ARTICLE HISTORY
Received: 01 September 2024
Accepted: 02 October 2024
Available online
Version 1.0 : 28 October 2024
Version 2.0 : 24 February 2025

Check for updates

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

CITE THIS ARTICLE
Abhigna D, Kalpana R, Geetha P, Janaki P, Radhamani S, Ravichandran V. Effect of sowing methods, spacings and fertilizer levels on quantitative and qualitative traits and economics of brown top millet (*Brachiaria ramosa* L.) under different cropping seasons. Plant Science Today.2024;11(sp4):01-12. https:/doi.org/10.14719/pst.5075

Abstract

A field study was conducted during the summer, kharif and rabi seasons of 2023-2024 to evaluate brown top millet under two sowing methods (direct sowing and transplantation), three spacing configurations (20 x 10, 30 x 10 and 45 x 10 cm) and three fertilizer doses (75% of the recommended dose of fertilizer (RDF) (45:20:15 kg ha^{-1}), 100% RDF (60:30:20 kg ha^{-1}) and 125% RDF (75:40:25 kg ha^{-1})). The study was designed as a factorial randomized complete block design assessing growth, yield, thiamine content and economics. The results indicated that the summer season was more favorable for growth than the kharif and rabi seasons. Direct sown crops (E_1) exhibited significantly higher growth attributes, yield and economics than transplanted crops (E_2). The spacing configuration of 45 x 10 cm (S_3) recorded significantly superior growth and yield parameters compared to 20 x 10 cm (S_1). Applying 125% RDF (N_3) resulted in significantly enhanced growth, yield, quality and economic return compared to 75% RDF. Among the interactions, the combination of direct sown with narrow spacing and 125% RDF (E_1 x S_1 x N_3) led to significantly higher growth parameters. In comparison, the combination of direct sowing with wider spacing and 125% RDF (E_1 x S_3 x N_3) resulted in higher grain yields (2005, 1759, 1548 kg ha^{-1}) and benefit-cost ratios (2.64, 2.58 and 2.58) across the same seasons. However, the differences in grain yield among the treatment combinations were statistically non-significant. These findings provide a valuable foundation for future research and agricultural practices aimed at maximizing the potential of brown top millet.

Keywords

benefit; brown top millet; cost; growth; quality; yield

Introduction

The challenges of the 21st century, including climate change, drought, population growth, rising food inflation and various socio-economic factors, pose significant threats to agri-food systems. Consequently, it is essential to identify alternative food sources capable of addressing these challenges. One promising crop is brown top millet, which originated in Southeast Asia (1). In 2020, India accounted for nearly 41% of global millet production and 79.36% of Asia's millet output (2). Brown top millet is a drought-resistant and stressadaptive cereal (3), traditionally cultivated as a rainfed crop for food and forage production (4) in Karnataka and Andhra Pradesh. Distinct among all millet species, it demonstrates shade tolerance (1). This annual crop typically grows 3 to 5 feet tall and features fibrous roots that can penetrate up to 60 cm deep. It thrives in sandy loam soils with a slightly acidic pH. The recommended seed rate is approximately 4 to 5 kg per hectare for row planting and 11 to 12 kg per hectare for broadcasting. Brown top millet can be cultivated as a single crop or intercrop (1). With a short growth cycle of 75 to 90 days and robust biomass production, it is well-suited for cultivation as a catch, cover, or nurse crop (4). Nutritionally, brown top millet is comparable to other millets and cereals, offering high energy levels, carbohydrates, fiber and protein (1, 5). Incorporating this short-duration crop into cropping systems helps mitigate the impact of climate change and combats malnutrition due to its exceptional nutritional profile (6). Despite these benefits, the production and consumption of brown top millet in India remain low, primarily due to its lower productivity and limited financial returns.

To unlock the full potential of brown top millet to unlock the full potential of brown top millet, the adoption of good agronomic practices is essential. Poor implementation of these practices can create unfavourable conditions during critical growth stages, ultimately reducing yield and quality. Lodging also poses a significant challenge for this crop. Determining the suitable sowing technique and spacing is essential, as these elements affect crop growth, yield and nutritional quality (7, 8). Variations in sowing timing can affect plant-environment interactions, impacting physiological processes and overall crop yield (9). Fertilizer application plays a vital role in enhancing the productivity of brown top millet, making it essential to determine optimal nutrient levels to achieve the crop's genetic yield potential (10). Agronomists possess extensive knowledge of how to optimize inputs for millet cultivation. Considering the scarce information available on agronomic practices for brown top millet in Tamil Nadu, where rainfall primarily takes place during the North-East monsoon, unlike other regions in India (11), this study sought to identify the optimal crop establishment techniques, spacing and nutrient levels for the cropping seasons in Tamil Nadu. The study aimed to optimize the growth, yield attributes, yield, quality and economics of brown top millet cultivation.

Materials and Methods

Experimental site

The trial was conducted during the summer (March-June), kharif (July-October) and rabi season (October–March) seasons of 2023-24 in field number 37 of the Eastern Block farm at Tamil Nadu Agricultural University (TNAU), Coimbatore. The aim was to assess the influence of different cropping seasons, establishment techniques, crop spacings and fertilizer doses on the plant growth, yield attributes, yield and vitamin content of brown top millet. The experimental site is located at a latitude of 11° N and a longitude of 77° E, with an altitude of 426.7 meters above mean sea level, in the western agro-climatic zone of Tamil Nadu. Weather conditions during the trial were recorded at the Meteorological Observatory, TNAU, Coimbatore and are given in Table 1. Composite soil samples were randomly collected from 0 to 30 cm depth in the experimental area before the field trials for all three seasons. These samples were pooled and a portion was obtained using the quartering method. The standard procedures and physicochemical properties of the initial soil samples from the three seasons trials are detailed in Table 2.

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

Weather parameters		Summer season (March-June)	Kharif season (July-October)	Rabi season (October-January)
Maximum temperature (˚C)		34.8	30.2	28.6
Minimum temperature (˚C)		23.2	21.5	20.0
Rainfall (mm)		264.5	552.6	720.0
Bright sunshine (hours)		6.6	5.1	4.2
Relative humidity (%)	07:22 hours	82.4	82.2	83.0
	14:22 hours	50.6	56.6	46.0
Mean pan evaporation (mm)		6.2	5.2	4.4

Table 2. Physico-chemical characteristics of the initial soil sample from the experimental site

S.No.	Particulars	Field experiment			Methods
		I. Physical properties			
1.	Clay (%)		29.11		Robinson's International Pipette method (34)
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 (35)
7.	Electrical conductivity (dS m^{-1})	0.17	0.15	0.14	1: 2.5 soil: water suspension (35)
8.	Organic carbon (g kg^{-1})	0.82	0.70	0.52	Wet chromic acid digestion method (36)
9.	Available nitrogen (kg ha^{-1})	248.2	242.4	231.4	Alkaline permanganate method (37)
10.	Available phosphorus (kg ha^{-1})	29.8	22.1	23.2	Olsen's method (38)
11.	Available potassium (kg ha^{-1})	586.0	602.4	598.2	Neutral normal ammonium acetate method (35)

Treatment details and experimental setup

The field study used a factorial randomized complete block design (FRCBD) with three factors and three replications. Details of the treatments are provided in Table 3. RDF used was 60N:30P:20K kg ha^{-1} consisting of nitrogen (N) (from urea), phosphorus (P) (from diammonium phosphate) and potassium (K) (from muriate of potash). Full doses of P, K and half of the N were applied at sowing, while the remaining Nitrogen was applied 30 days after sowing (DAS). The brown top millet variety tested was GPUBT-6, developed by the University of Agricultural Sciences, Gandhi Krishi Vigyana Kendra (GKVK), Bengaluru, through selective breeding from IC 613561.

Table 3. Treatment details of field experiment

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

Nursery bed and main field preparation

A nursery covering an area of 500 m^2 was established for transplanting into a hectare of the main field. The soil was plowed twice using a tractor-drawn cultivator, followed by a tractor-drawn rotavator. Six raised beds measuring 3 m x 1.5 m were manually created with a 30 cm spacing for nursery bed preparation to facilitate irrigation. Seeds were sown on the bed at 2-3 kg per hectare for the main field, employing the line sowing technique. The nursery sowing dates are presented in Table 4. In the main field, flat beds and irrigation channels were formed. A total of 54 plots (area of 1200 m^2), each covering an area of 18 m^2, were prepared for the 18 treatments, with three replications. The seed rate of brown top millet used for line sowing was 2 kg ha^{-1}.

Direct sowing and transplantation

Sowing was carried out during all three seasons, with the dates of sowing and transplanting presented in Table 4. Irrigation was provided as needed. The crops in each season were harvested after reaching physiological maturity and the harvesting dates are also listed in Table 4.

Biometric data and yield analysis

Five randomly selected plants from each plot were tagged as representative samples to record biometric observations. The plant height (PH) was measured for these plants and averages were calculated for each parameter. The soil plant analysis development (SPAD) chlorophyll meter values were measured at 60 using a Manitol SPAD Chlorophyll meter (Model 502: Minolta Co., Japan). Measurements were taken from the top, middle and base of the top young leaves and average values were recorded.

To calculate the leaf area index (LAI), leaves from five sampled plants in the border rows were collected destructively 60 DAS. The leaf area was evaluated using a leaf area meter (Li-COR model, LT-300):

$$\text{LAI} = \frac{\text{Leaf area (cm}^2\text{)}}{\text{Spacing (cm}^2\text{)}} \quad \text{(Eqn. 1)}$$

For dry matter production (DMP), five representative plant samples, including shoots, leaves and roots, were harvested at maturity from each treatment plot, evenly distributed across the gross plot area. These samples were shade-dried and then oven-dried at 60 ± 5 °C until a stable weight was achieved. The dry weight of the final sample was recorded and expressed in kg ha^{-1}.

After harvesting, the following parameters were recorded: number of tillers $plant^{-1}$(NT), number of panicles $plant^{-1}$(NP), panicle length (PL) (cm) and panicle weight (PW) (g). These measurements were taken using standard procedures and averaged accordingly. All plants from the designated net plot of each treatment in three replications were harvested, sun-dried, threshed, cleaned and weighed to determine grain weight (GW) $plot^{-1}$, which was then converted to grain yield (GY) in kg ha^{-1}. Additionally, the above-ground biomass (excluding panicles) from the same plot area was collected, sun-dried and weighed to determine straw yield (SY) in kg ha^{-1}. The total cost of cultivation (COC) for brown top millet for each treatment was estimated based on the cost of inputs used during the experiment. Gross returns (GR) (₹) were calculated for the corresponding treatments by multiplying the economic yield by the prevailing market price of brown top millet. Net returns (NR) (₹) for each treatment were estimated by deducting the COC from the gross returns. The benefit-to-cost ratio (B: C) was determined using the following formula:

$$\text{Benefit: cost ratio} = \frac{\text{Gross returns (₹ ha}^{-1}\text{)}}{\text{Cost of cultivation (₹ ha}^{-1}\text{)}} \quad \text{(Eqn. 2)}$$

Table 4. Dates of sowing/transplanting and harvesting 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

Vitamin analysis

The thiamine (vitamin B_1) content in grain samples from three replications was estimated using high-performance liquid chromatography (HPLC), following the guidelines set by the American Association of Cereal Chemists (12).

Statistical analysis

The data relating to growth, yield attributes and vitamin content across eighteen treatments and three replications were analyzed using analysis of variance (ANOVA) within a factorial complete randomized block design, employing AGRES software on a Windows platform. The statistical procedures followed by (13) were used to evaluate both main effects establishment methods (E), crop geometries (S), nutrient levels (N) and 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 showed no significant differences were denoted as NS. Additionally, a correlation heat map was generated using SPSS version 21.

Results and Discussion

Growth attributes

PH, SPAD values, LAI and DMP of brown top millet were significantly influenced by various cropping seasons, crop establishment techniques, plant densities and nutrient levels, as detailed in Tables 5 and 6. Among the different crop establishment methods, direct sown brown top millet (E_1) recorded significantly higher PH (124.4, 118.6 and 111 cm), SPAD values (47.9, 44.3 and 39.9), LAI (2.36, 2.28 and 2.21) and DMP (6463, 5754 and 4968 kg ha^{-1}) during the summer, kharif and rabi seasons, respectively, compared to the transplanted brown top millet (E_2). This improvement can be attributed to the robust root system of the direct sown brown top millet, which enhanced growth conditions by facilitating efficient photosynthesis and nutrient utilization from the soil, leading to superior vegetative growth and chlorophyll content in the leaves. In contrast, the transplanted crop may have experienced root disturbances during transplantation, impairing root development and overall plant performance. A study noted that transplanted maize exhibited poor performance due to transplant shock and a limited capacity for root replacement (14). Similarly, it was also found that wheat genotypes with rapid initial root growth developed deeper roots, while seedlings with slower early root growth generally formed shallower roots (15). These findings are consistent with the observations of brown top millet. Another study reported that normal drilling at the recommended sowing date resulted in greater PH (178.69 cm), LAI (2.60) and DMP (95.96 g plant-1) compared to transplanted pearl millet (16). The height of the plant demonstrated a strong correlation with LAI and DMP, with coefficients of 0.95 and 0.93, respectively, indicating that taller plants generally have larger leaf areas and higher dry matter content (Fig. 2).

Among the different crop geometries, the 20 x 10 cm spacing (S_1) recorded significantly higher PH (126.8, 120.7 and 113.5 cm), LAI (2.40, 2.32 and 2.25) and DMP (6635, 5910 and 5140 kg ha^{-1}) across the summer, kharif and rabi seasons, respectively, compared to other spacings. This can be attributed to the increased plant density, which led to mutual shading and reduced light availability, particularly for the lower leaves. As a result, individual plants tend to grow taller to reach the available light under higher plant density.

These findings align with reports from (17, 18), who observed significantly greater vegetative growth under narrow spacings than wider ones. Moreover, It was reported a 7.6% increase in sorghum growth when using a 30 cm spacing compared to a 60 cm spacing (19). Modifying planting patterns to reduce spacing could improve plant leaf area and biomass (20). The minimum PH, LAI and DMP were observed with the 45 x 10 cm (S_3) spacing. Notably, the higher SPAD values (50.4, 46.5 and 42.3) were recorded at the 45 x 10 cm spacing, while S_1 (20 x 10 cm) exhibited lower SPAD values. This may be attributed to the wider plant spacing, which likely provided better access to nutrients for plant metabolism, ultimately leading to increased chlorophyll production compared to narrower plant spacing. These results are consistent with (21, 22), who reported higher SPAD values under wider crop geometries.

The fertilizer dose of 125% RDF (N_3) resulted in significantly superior PH (131.6, 125.4 and 118.3 cm), SPAD values (52.2, 48.0 and 44.2), LAI (2.47, 2.40 and 2.33) and DMP (6927, 6204 and 5432 kg ha^{-1}) in brown top millet during the three seasons, compared to 100% RDF (N_2) and 75% RDF (N_1). The lower growth attributes were observed with 75% RDF (N_1). This could be attributed to elevated nutrient levels, which enhanced nutrient availability and translocation from the stem to the leaves. As a result, improved chlorophyll production and photosynthesis likely supported the overall growth of brown top millet. It was reported that a 50:25:00 kg NPK ha^{-1} fertilizer dose in brown top millet yielded significantly higher growth attributes than other fertilizer levels (23). Similarly, a study found that 125 % RDF resulted in a higher plant population per quadrat (7.81) and greater PH (165.8 cm) compared to 75% RDF and 100 % RDF in barnyard millet (24). These findings are consistent with the observations made in brown top millet.

Among the interactions, the treatment combination of E_1 x N_3 (138.5, 132.9 and 125.2 cm) and S_1 x N_3 (140.5, 134.4 and 127.2 cm) recorded significantly elevated PH at harvest in all three seasons. However, the treatment combination of S_1 x N_3 was comparable to that of S_2 x N_3 and S_1 x N_2. The lower PH was observed in the treatment interaction of E_2 x N_1 and S_3 x N_1. No significant difference was found in the brown top millet's PH under E x S and E x S x N interactions. The treatment combinations of E_1x S_3 (49.8), E_1x N_3 (51.3), S_3 x N_3 (52.9) and E_1 x S_3 x N_3 (57.7) recorded significantly higher SPAD values at 60 DAS during the kharif season whereas, the treatment combination of E_1 x N_3 (47.1 at 60 DAS) and S_3 x N_3 (49.3 at 60 DAS) recorded significantly higher SPAD values over other treatment combinations during rabi season. Similarly, the treatment combination S_3 x N_3 (56.5) recorded significantly higher values during summer than the other treatments. The lower SPAD values were noted in the treatment combination of E_2 x S_1, E_2 x N_1, S_1 x N_1 and E_2 x S_1 x

N_1. No two-way or three-way interaction was observed for the LAI for 60 DAS and DMP at the harvest stage. These results align with the findings of a study which states that early-sown crops benefited from longer photoperiods during their vegetative stage, achieving maximum growth compared to those sown later (25). In contrast, excessive rainfall during the monsoon (kharif) season may have led to waterlogging, negatively impacting millet yield. Additionally, during the winter (rabi) season, cooler temperatures and reduced light intensity could limit plant growth and development. Another study similarly observed that late-sown foxtail millet varieties grown under shorter photoperiods exhibited reduced biomass (26).

Yield attributes, yield and thiamine content

E_1 recorded significantly higher numbers of NT plant^{-1} (10.36, 10.16 and 10.02), NP plant^{-1} (9.49, 9.33 and 9.24), GW plot^{-1} (3.19, 2.91 and 2.55 kg), GY (1525, 1312 and 1189), SY (4603, 4117 and 3653 kg ha^{-1}), test weight (TW) (3.34, 3.32 and 3.31 g) and thiamine content (0.78, 0.75 and 0.68 mg) during the summer, kharif and rabi seasons, respectively compared to E_2 (Table 6, 7). However, the differences in TW were statistically non-significant (Fig. 1). The higher yield attributes and overall yield can be attributed to the robust root system that likely created optimal conditions for efficient nutrient uptake, resulting in maximum productivity. In contrast, the transplanted crop may have suffered from transplant shock, which could have impeded root and crop development. These findings are consistent with the findings of one investigation which stated that the direct drilling of pearl millet resulted in significantly greater effective tillers (5.0), ear head length (21 cm), ear head circumference (10 cm), GY (36 q ha^{-1}), SY (92 q ha^{-1}) and TW (9.0 g) compared to transplanted crop (16). Furthermore, E_1 recorded significantly higher vitamin content than E_2 (Fig. 1). This could be due to stress caused by weeds in direct sown crops, which likely triggered increased thiamine production in brown top millet. Thiamine plays a role in activating plant defense mechanisms and enhancing stress tolerance (27). It was further noted that elevated thiamine levels are associated with improved stress response and resilience (28). Grain weight per plot exhibited strong correlations with SPAD, DMP and GY, suggesting that heavier grains are associated with higher chlorophyll content, increased DMP and greater yields (Fig. 2).

The wider spacing of 45 x 10 cm (S_3) resulted in significantly higher NT plant^{-1} (10.53, 10.37 and 10.23), NP plant^{-1} (9.77, 9.60 and 9.57), GW plot^{-1} (3.35, 3.04 and 2.66 kg), GY (1597, 1408 and 1251 kg ha^{-1}), TW (3.37, 3.35 and 3.34 g) and thiamine content (0.79, 0.76 and 0.69 mg) during the summer, kharif and rabi seasons, respectively, compared to narrower spacings (S_1 and S_2) (Tables 6 and 7). However, the differences in TW were recorded as non-significant (Fig. 1). The wider spacing (S_3) likely provided a more favorable microclimate that improved each plant's efficient use of light, moisture and nutrients. This optimized resource utilization probably enhanced yield characteristics, productivity and quality. In contrast, the denser plant spacing may have impaired air circulation, hindering gas exchange essential for photosynthesis, which could negatively affect yield and quality (29). Another study reported a 60% increase in pearl millet grain yield when spacing was adjusted from 60 × 10 cm to 120 × 5 cm (30). Similarly, it was also found that a wider crop geometry of 60 cm contributed to maximum GY (1303 kg ha^{-1}) compared to narrower spacings in brown top millet (23). Comparable findings for brown top millet were also reported by (17). In contrast, the spacing of 20 x 10 cm (S_1) recorded significantly higher SY (4718, 4238 and 3768 kg ha^{-1}) across all three seasons compared to wider spacing (S_3) (Table 7). This could be due to the closer arrangement of plants, which likely resulted in higher plant density and intensified competition for essential resources such as space, moisture and nutrients. This increased competition likely prompted the development of larger, more extensive root systems and improved photosynthetic efficiency per unit area, ultimately leading to a superior accumulation of photosynthates and enhanced overall SY. Similar results of higher SY in narrow spacing were also reported (18, 23).

Among the different nutrient levels tested, N_3 (125% RDF) recorded significantly elevated NT plant^{-1} (11.13, 10.83 and 10.73), NP plant^{-1} (10.03, 9.9 and 9.8), GW plot^{-1} (3.50, 3.15 and 2.83 kg), GY (1672, 1457 and 1329), TW (3.38, 3.36 and 3.35 g) and thiamine content (0.81, 0.78 and 0.71 mg) during the three seasons compared to N_1 and N_2; however, lower yield attributes and yield were recorded with N_1 (Table 6 and 7). This could be attributed to the higher fertilizer dose, which optimized the availability and movement of nutrients to the reproductive organs, leading to enhanced yield and quality in brown top millet. These outcomes are consistent with the findings of other studies, which indicated that applying higher NPK fertilizer dosages produced greater millet crop yield than lower doses of NPK fertilizer (31, 32).

Among the interactions, E_1xN_3 (1533 and 1396 kg ha^{-1} during kharif and rabi seasons) and S_3xN_3 (1843, 1622 and 1447 kg ha^{-1} during summer, kharif and rabi seasons) registered significantly greater GY compared to other treatment combinations. The lower GY was observed with E_2xN_1 and S_1xN_1. Similarly, GW per plot was significantly higher with S_3xN_3 (3.77 and 3.05 kg plot^{-1}) during the summer and rabi seasons. (Table 6, 7, Fig. 1 and 2). Among the various cropping seasons in Tamil Nadu, brown top millet showed superior yield attributes, yield and quality during summer compared to the kharif and rabi seasons. This improvement is likely due to the favorable temperatures and adequate photoperiods, which enhanced metabolic activity by boosting photosynthesis and, consequently, the overall performance of brown top millet. Similar results of higher performance were reported by when pearl millet was sown on February 15 compared to other planting dates (33) .

Economics

The treatment combination of transplanted brown top millet sown with a spacing of 20 x 10 cm and 125% RDF (E_2xS_1xN_3) recorded the highest total COC of Rs. 60188, 53888 and 48488 during the summer, kharif and rabi seasons, respectively (Table 8). This can be attributed to the transplanting method (E_2), which requires additional labor for raising seedlings in a nursery and transferring them to

Table 5. Impact of different cropping seasons, crop establishment methods, crop geometry and nutrient levels on plant height, leaf area index and dry matter production of brown top millet

	Plant height (cm)			Leaf area index			Dry matter production (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: Direct sowing	124.4	118.6	111.1	2.36	2.28	2.21	6463	5754	4968
E_2: Transplanting	115.4	109.2	102.2	2.25	2.16	2.09	6137	5388	4642
SEm±	1.39	1.34	1.40	0.03	0.03	0.03	77.54	85.74	76.01
CD (p=0.05)	4.00	3.84	4.01	0.08	0.08	0.08	222.84	246.43	218.45
Crop geometry (S)									
S_1: 20x10cm	126.8	120.7	113.5	2.40	2.32	2.25	6635	5910	5140
S_2: 30x10cm	123.6	117.7	110.4	2.35	2.27	2.20	6497	5767	5002
S_3: 45x10cm	109.3	103.4	96.0	2.17	2.07	2.00	5767	5036	4272
SEm±	1.71	1.64	1.71	0.03	0.03	0.04	94.96	105.01	93.09
CD (p=0.05)	4.90	4.70	4.91	0.10	0.10	0.10	272.92	301.81	267.54
Nutrient levels (N)									
N_1:75%RDF	104.6	99.1	91.4	2.04	1.92	1.86	5389	4695	3894
N_2:100% RDF	123.5	117.2	110.2	2.41	2.33	2.26	6583	5813	5088
N_3:125%RDF	131.6	125.4	118.3	2.47	2.40	2.33	6927	6204	5432
SEm±	1.71	1.64	1.71	0.03	0.03	0.04	94.96	105.01	93.09
CD (p=0.05)	4.90	4.70	4.91	0.10	0.10	0.10	272.92	301.81	267.54
Crop establishment (E) x Crop geometry (S)									
SEm±	2.41	2.31	2.42	0.05	0.05	0.05	134.50	148.51	131.65
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop establishment (E) x Nutrient levels (N)									
E_1N_1	105.6	100.0	92.3	2.07	1.96	1.90	5479	4782	3984
E_1N_2	129.0	123.0	115.8	2.47	2.41	2.34	6719	5980	5224
E_1N_3	138.5	132.9	125.2	2.54	2.48	2.41	7190	6500	5695
E_2N_1	103.7	98.1	90.4	2.00	1.88	1.83	5300	4608	3805
E_2N_2	117.9	111.5	104.6	2.35	2.26	2.18	6446	5647	4951
E_2N_3	124.7	118.0	111.5	2.41	2.33	2.25	6665	5907	5170
SEm±	2.41	2.31	2.42	0.05	0.05	0.05	134.50	148.51	131.65
CD (p=0.05)	6.94	6.65	6.95	NS	NS	NS	NS	NS	NS
Crop geometry (S) x Nutrient levels (N)									
S_1N_1	107.5	101.7	94.2	2.14	2.03	1.95	5694	4988	4199
S_1N_2	132.5	126.0	119.2	2.51	2.45	2.37	6937	6147	5442
S_1N_3	140.5	134.4	127.2	2.55	2.49	2.42	7274	6594	5779
S_2N_1	105.1	99.6	91.1	2.03	1.92	1.87	5456	4753	3961
S_2N_2	128.4	122.2	115.1	2.49	2.42	2.36	6844	6065	5349
S_2N_3	137.5	131.3	124.0	2.53	2.47	2.39	7190	6483	5695
S_3N_1	101.4	95.9	88.1	1.94	1.82	1.78	5017	4345	3522
S_3N_2	109.5	103.6	96.2	2.24	2.14	2.05	5967	5227	4472
S_3N_3	117.0	110.6	103.7	2.34	2.26	2.18	6318	5534	4823
SEm±	2.96	2.83	3.0	0.06	0.06	0.06	164.48	181.89	161.24
CD (p=0.05)	8.50	8.14	8.51	NS	NS	NS	NS	NS	NS
Crop establishment (E) x Crop geometry (S) x Nutrient levels (N)									
SEm±	4.18	4.01	4.19	0.08	0.08	0.09	232.61	257.23	228.02
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS: Non-significant, CD: Critical difference, SEm±: Standard error means

Table 6. Impact of different cropping seasons, crop establishment methods, crop geometry and nutrient levels on SPAD, number of tillers and number of panicles of brown top millet

	SPAD			Number of tillers plant^{-1}			Number of panicles plant^{-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: Direct sowing	47.9	44.3	39.9	10.36	10.16	10.02	9.49	9.33	9.24
E_2: Transplanting	45.4	40.2	36.4	9.62	9.36	9.24	9.00	8.87	8.84
SEm±	0.6	0.5	0.6	0.20	0.22	0.21	0.16	0.16	0.14
CD (p=0.05)	1.6	1.5	1.7	0.57	0.62	0.59	0.46	0.47	0.40
Crop geometry (S)									
S_1: 20x10cm	41.8	37.1	32.8	9.27	9.03	8.90	8.70	8.50	8.47
S_2: 30x10cm	47.8	43.0	39.2	10.17	9.87	9.77	9.27	9.20	9.10
S_3: 45x10cm	50.4	46.5	42.3	10.53	10.37	10.23	9.77	9.60	9.57
SEm±	0.7	0.6	0.7	0.24	0.27	0.25	0.20	0.20	0.17
CD (p=0.05)	2.0	1.8	2.0	0.69	0.76	0.72	0.56	0.57	0.49
Nutrient levels (N)									
N_1:75%RDF	39.5	34.9	30.5	8.63	8.53	8.40	8.23	8.07	8.03
N_2:100% RDF	48.3	43.8	39.7	10.20	9.90	9.77	9.47	9.33	9.30
N_3:125%RDF	52.2	48.0	44.2	11.13	10.83	10.73	10.03	9.90	9.80
SEm±	0.7	0.6	0.7	0.24	0.27	0.25	0.20	0.20	0.17
CD (p=0.05)	2.0	1.8	2.0	0.69	0.76	0.72	0.56	0.57	0.49
Crop establishment (E) x Crop geometry (S)									
E_1S_1	42.7	38.0	33.7	9.47	9.27	9.13	8.87	8.67	8.60
E_1S_2	49.1	45.0	41.1	10.47	10.20	10.13	9.53	9.47	9.33
E_1S_3	52.0	49.8	44.9	11.13	11.00	10.80	10.07	9.87	9.80
E_2S_1	41.0	36.3	32.0	9.07	8.80	8.67	8.53	8.33	8.33
E_2S_2	46.4	41.1	37.4	9.87	9.53	9.40	9.00	8.93	8.87
E_2S_3	48.8	43.2	39.8	9.93	9.73	9.67	9.47	9.33	9.33
SEm±	1.0	0.9	1.0	0.34	0.38	0.36	0.28	0.28	0.24
CD (p=0.05)	NS	2.6	NS	NS	NS	NS	NS	NS	NS
Crop establishment (E) x Nutrient levels (N)									
E_1N_1	39.9	35.2	30.9	8.80	8.73	8.60	8.40	8.27	8.20
E_1N_2	49.9	46.3	41.7	10.67	10.40	10.27	9.67	9.53	9.47
E_1N_3	54.0	51.3	47.1	11.60	11.33	11.20	10.40	10.20	10.07
E_2N_1	39.1	34.6	30.1	8.47	8.33	8.20	8.07	7.87	7.87
E_2N_2	46.7	41.4	37.7	9.73	9.40	9.27	9.27	9.13	9.13
E_2N_3	50.4	44.6	41.4	10.67	10.33	10.27	9.67	9.60	9.53
SEm±	1.0	0.9	1.0	0.34	0.38	0.36	0.28	0.28	0.24
CD (p=0.05)	NS	2.6	2.9	NS	NS	NS	NS	NS	NS
Crop geometry (S) x Nutrient levels (N)									
S_1N_1	38.6	34.2	29.6	8.10	8.10	7.90	7.80	7.60	7.70
S_1N_2	42.2	37.4	33.2	9.60	9.30	9.20	9.00	8.80	8.70
S_1N_3	44.8	39.9	35.8	10.10	9.70	9.60	9.30	9.10	9.00
S_2N_1	39.4	34.7	30.4	8.60	8.50	8.40	8.20	8.10	8.00
S_2N_2	48.7	43.4	39.7	10.50	10.00	9.90	9.40	9.40	9.30
S_2N_3	55.3	51.1	47.7	11.40	11.10	11.00	10.20	10.10	10.00
S_3N_1	40.5	35.9	31.5	9.20	9.00	8.90	8.70	8.50	8.40
S_3N_2	54.1	50.8	46.2	10.50	10.40	10.20	10.00	9.80	9.90
S_3N_3	56.5	52.9	49.3	11.90	11.70	11.60	10.60	10.50	10.40
SEm±	1.2	1.1	1.2	0.42	0.46	0.44	0.34	0.35	0.29
CD (p=0.05)	3.5	3.2	3.5	NS	NS	NS	NS	NS	NS
Crop establishment (E) x Crop geometry (S) x Nutrient levels (N)									
$E_1S_1N_1$	38.9	34.4	29.9	8.20	8.40	8.20	8.00	7.80	7.80
$E_1S_1N_2$	43.1	38.2	34.1	9.80	9.40	9.40	9.20	9.00	8.80
$E_1S_1N_3$	46.1	41.3	37.1	10.40	10.00	9.80	9.40	9.20	9.20
$E_1S_2N_1$	39.7	34.7	30.7	8.80	8.60	8.60	8.40	8.40	8.20
$E_1S_2N_2$	50.5	45.2	41.5	10.60	10.20	10.00	9.40	9.40	9.40
$E_1S_2N_3$	57.3	55.0	51.1	12.00	11.80	11.80	10.80	10.60	10.40
$E_1S_3N_1$	41.1	36.4	32.1	9.40	9.20	9.00	8.80	8.60	8.60
$E_1S_3N_2$	56.2	55.5	49.5	11.60	11.60	11.40	10.40	10.20	10.20
$E_1S_3N_3$	58.6	57.7	53.3	12.40	12.20	12.00	11.00	10.80	10.60
$E_2S_1N_1$	38.3	33.9	29.3	8.00	7.80	7.60	7.60	7.40	7.60
$E_2S_1N_2$	41.3	36.6	32.3	9.40	9.20	9.00	8.80	8.60	8.60
$E_2S_1N_3$	43.5	38.5	34.5	9.80	9.40	9.40	9.20	9.00	8.80
$E_2S_2N_1$	39.1	34.6	30.1	8.40	8.40	8.20	8.00	7.80	7.80
$E_2S_2N_2$	46.9	41.5	37.9	10.40	9.80	9.80	9.40	9.40	9.20
$E_2S_2N_3$	53.3	47.2	44.3	10.80	10.40	10.20	9.60	9.60	9.60
$E_2S_3N_1$	40.0	35.4	31.0	9.00	8.80	8.80	8.60	8.40	8.20
$E_2S_3N_2$	52.0	46.0	43.0	9.40	9.20	9.00	9.60	9.40	9.60
$E_2S_3N_3$	54.4	48.2	45.4	11.40	11.20	11.20	10.20	10.20	10.20
SEm±	1.7	1.6	1.7	0.59	0.65	0.62	0.48	0.49	0.41
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS: Non-significant, CD: Critical difference, SEm±: Standard error means

Table 7. Impact of different cropping seasons, crop establishment methods, crop geometry and nutrient levels on grain weight per plot, grain and straw yield of brown top millet

	Grain weight plot^{-1} (kg)			Grain yield (kg ha^{-1})			Straw yield (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: Direct sowing	3.19	2.91	2.55	1525	1312	1189	4603	4117	3653
E_2: Transplanting	2.99	2.75	2.35	1401	1226	1089	4366	3880	3416
SEm±	0.05	0.04	0.04	27	21	19	74	70	72
CD (p=0.05)	0.13	0.12	0.11	79	59	55	212	201	208
Crop geometry (S)									
S_1: 20x10cm	2.77	2.56	2.17	1314	1134	1001	4718	4232	3768
S_2: 30x10cm	3.15	2.89	2.51	1480	1265	1165	4516	4030	3566
S_3: 45x10cm	3.35	3.04	2.66	1594	1408	1251	4219	3733	3269
SEm±	0.06	0.05	0.05	34	25	24	91	85	89
CD (p=0.05)	0.16	0.15	0.14	97	73	68	260	246	255
Nutrient levels (N)									
N_1:75%RDF	2.54	2.38	1.91	1252	1083	877	4109	3623	3159
N_2:100% RDF	3.23	2.95	2.60	1465	1266	1210	4587	4101	3637
N_3:125%RDF	3.50	3.15	2.83	1672	1457	1329	4757	4271	3807
SEm±	0.06	0.05	0.05	34	25	24	91	85	89
CD (p=0.05)	0.16	0.15	0.14	97	73	68	260	246	255
Crop establishment (E) x Crop geometry (S)									
E_1S_1	2.83	2.62	2.24	1327	1139	1028	4931	4445	3981
E_1S_2	3.26	2.95	2.59	1547	1310	1216	4632	4146	3682
E_1S_3	3.50	3.15	2.81	1701	1486	1323	4245	3759	3295
E_2S_1	2.72	2.50	2.11	1301	1129	973	4504	4018	3554
E_2S_2	3.05	2.82	2.42	1414	1219	1114	4400	3914	3450
E_2S_3	3.19	2.93	2.52	1488	1329	1179	4193	3707	3243
SEm±	0.08	0.07	0.07	48	36	33	128	121	125
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Crop establishment (E) x Nutrient levels (N)									
E_1N_1	2.57	2.43	1.94	1265	1073	892	4152	3666	3202
E_1N_2	3.36	3.03	2.72	1526	1329	1279	4706	4220	3756
E_1N_3	3.66	3.26	2.98	1784	1533	1396	4949	4463	3999
E_2N_1	2.51	2.33	1.89	1240	1093	863	4065	3579	3115
E_2N_2	3.10	2.87	2.48	1404	1203	1141	4468	3982	3518
E_2N_3	3.35	3.04	2.68	1559	1382	1262	4565	4079	3615
SEm±	0.08	0.07	0.07	48	36	33	128	121	125
CD (p=0.05)	NS	NS	NS	NS	103	96	NS	NS	NS
Crop geometry (S) x Nutrient levels (N)									
S_1N_1	2.41	2.21	1.80	1214	1008	821	4251	3765	3301
S_1N_2	2.86	2.67	2.26	1320	1154	1050	4788	4302	3838
S_1N_3	3.05	2.80	2.46	1409	1240	1132	5115	4629	4165
S_2N_1	2.53	2.40	1.93	1253	1076	884	4106	3620	3156
S_2N_2	3.24	2.96	2.62	1426	1210	1202	4668	4182	3718
S_2N_3	3.68	3.29	2.98	1763	1509	1409	4775	4289	3825
S_3N_1	2.68	2.53	2.01	1291	1165	927	3971	3485	3021
S_3N_2	3.59	3.23	2.92	1649	1435	1380	4305	3819	3355
S_3N_3	3.77	3.36	3.05	1843	1622	1447	4382	3896	3432
SEm±	0.10	0.09	0.08	58	44	41	157	148	153
CD (p=0.05)	0.28	NS	0.24	167	126	117	NS	NS	NS
Crop establishment (E) x Crop geometry (S) x Nutrient levels (N)									
$E_1S_1N_1$	2.42	2.28	1.82	1224	1014	832	4266	3780	3316
$E_1S_1N_2$	2.94	2.71	2.39	1334	1153	1114	5001	4515	4051
$E_1S_1N_3$	3.12	2.86	2.51	1424	1250	1138	5527	5041	4577
$E_1S_2N_1$	2.56	2.43	1.95	1274	1080	895	4168	3682	3218
$E_1S_2N_2$	3.32	3.02	2.66	1444	1262	1250	4808	4322	3858
$E_1S_2N_3$	3.89	3.42	3.16	1924	1589	1502	4919	4433	3969
$E_1S_3N_1$	2.72	2.57	2.06	1295	1125	948	4023	3537	3073
$E_1S_3N_2$	3.81	3.37	3.11	1801	1573	1474	4309	3823	3359
$E_1S_3N_3$	3.96	3.50	3.26	2005	1759	1548	4402	3916	3452
$E_2S_1N_1$	2.40	2.14	1.78	1203	1002	810	4235	3749	3285
$E_2S_1N_2$	2.77	2.62	2.13	1306	1155	985	4575	4089	3625
$E_2S_1N_3$	2.99	2.75	2.41	1394	1231	1125	4703	4217	3753
$E_2S_2N_1$	2.50	2.37	1.90	1231	1072	872	4043	3557	3093
$E_2S_2N_2$	3.16	2.91	2.57	1409	1158	1154	4528	4042	3578
$E_2S_2N_3$	3.48	3.16	2.79	1602	1429	1316	4630	4144	3680
$E_2S_3N_1$	2.63	2.48	1.97	1287	1206	906	3918	3432	2968
$E_2S_3N_2$	3.38	3.08	2.73	1497	1297	1285	4300	3814	3350
$E_2S_3N_3$	3.57	3.22	2.85	1681	1485	1346	4362	3876	3412
SEm±	0.14	0.13	0.12	82	62	58	222	209	217
CD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

NS: Non-significant, CD: Critical difference, SEm±: Standard error means

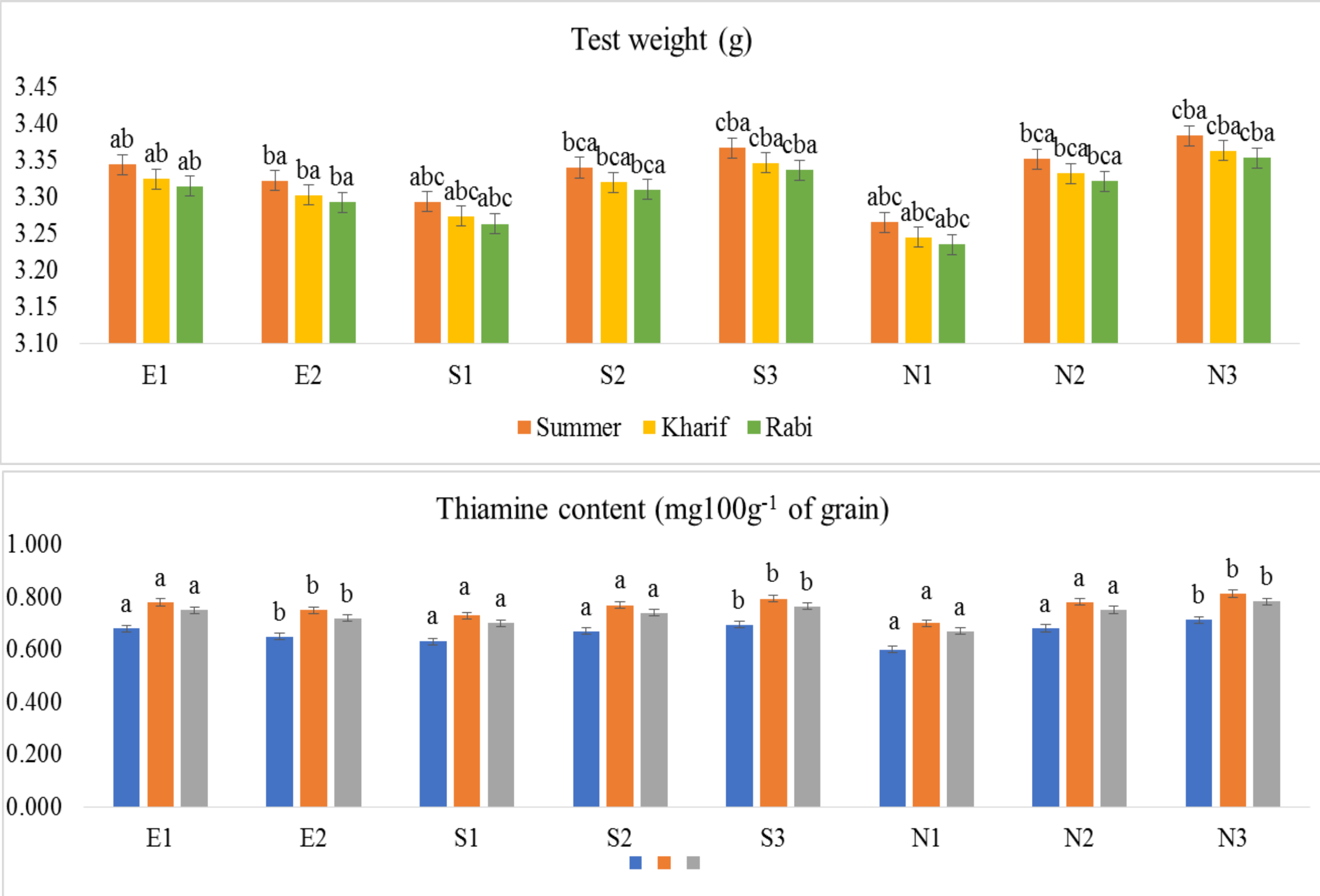

Fig. 1. Effect of different cropping seasons, crop establishment methods, crop geometry and nutrient levels on test weight and thiamine content of brown top millet. Error bars indicate the standard errors (SE) of the means. Treatments sharing the same letter are not significantly different ($p < 0.05$). E_1-direct sown brown top millet, E_2-transplanted brown top millet, S_1- 20 x 10cm, S_2-30 x 10 cm, S_3- 45 x 10 cm, N_1-75% RDF, N_2-100% RDF, N_3-125% RDF**.**

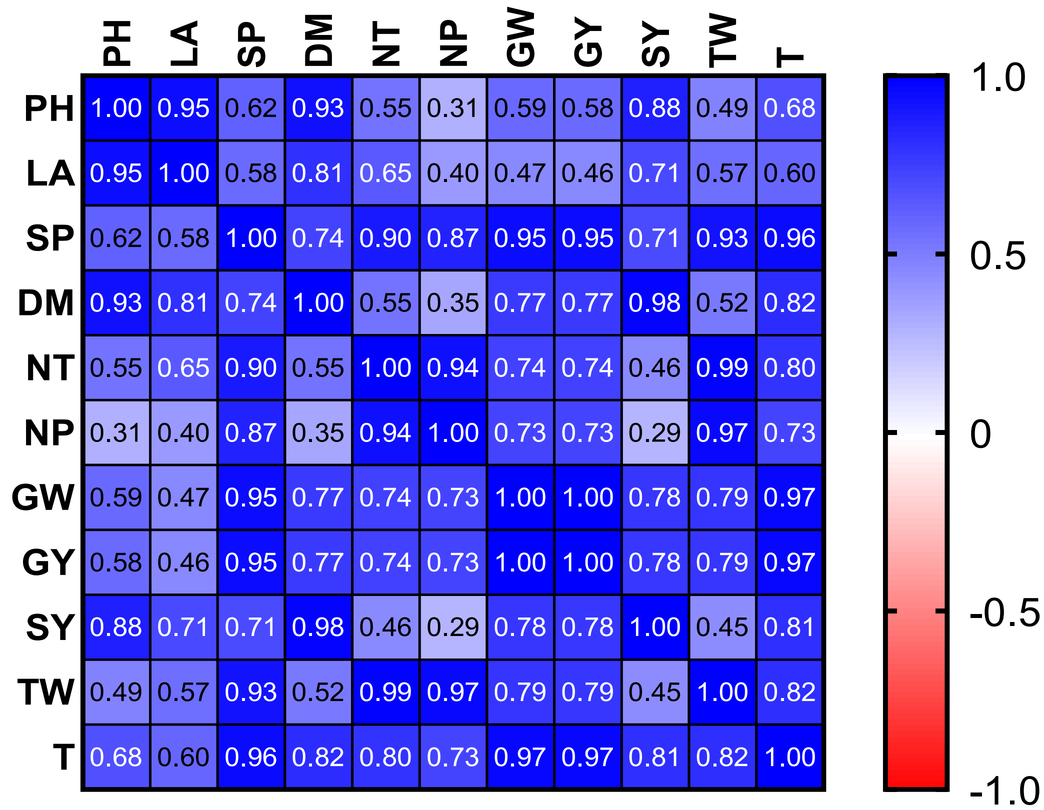

Fig. 2. Heat map depicting the relationship among growth, yield attributes, yield and vitamin contents of brown top millet. PH-plant height, LA-leaf area index, SP-SPAD, DM-dry matter production, NT-number of tillers per plant, NP-number of panicles per plant, GW-grain weight per plot, GY-grain yield, SY-straw yield, TW-test weight, T-thiamine.

the field, thereby increasing labor and management costs. The 20 x 10 cm spacing (S_1) necessitates more seedlings per unit area, leading to higher seedling production and planting costs, whereas the wider spacing of 45 x 10 cm (S_3) reduces seed requirements. Applying 125% RDF (N_3) also incurs higher input costs for fertilizers such as urea, DAP and MOP, unlike the 75% RDF treatment (N_1), which lowers fertilizer expenses. Thus, the combination of labor-intensive transplanting, closer spacing and increased fertilizer application contributed to the higher COC. In contrast, the lower total COC of Rs. 49277, 43877 and 38477 was recorded in a treatment combination of direct-sown brown top millet sown with a spacing of 45 x 10 cm and 75% RDF ($E_1xS_3xN_1$) across the same seasons.

The highest GR of Rs. 184852, 162247 and 142772 during the summer, kharif and rabi seasons, respectively, were recorded with the treatment combination of direct-sown brown top millet with a spacing of 45 x 10 cm and 125% RDF ($E_1xS_3xN_3$). This combination likely yielded higher GR due to optimal plant population, effective resource utilization and enhanced nutrient availability from the higher fertilizer dose, leading to increased productivity. Conversely, the lowest GR of Rs. 112505, 93931 and 76185 were recorded with transplanted brown top millet using 20 x 10 cm spacing and 75% RDF ($E_2xS_1xN_1$) across the same seasons. Similar results of higher GR in brown top millet under wider row spacing and higher fertilizer dosage were reported by (17, 23) (Table 8).

The highest NR of Rs. 134133, 116928 and 102853 during the summer, kharif and rabi seasons, respectively, were recorded with the treatment of direct-sown brown top millet using a spacing of 45 x 10 cm and 125% recommended fertilizer level ($E_1xS_3xN_3$). The higher NR in this treatment can be attributed to the balance between optimal spacing, efficient resource utilization and enhanced productivity in the direct-sown crop, which resulted in higher GR and lower production costs. The lowest NR of Rs. 53760, 41487 and 29141 were recorded with transplanted brown top millet sown with 20 x 10 cm crop geometry and a fertilizer dose of 75% RDF ($E_2xS_1xN_1$) across the same seasons (Table 8). These results align with findings by (22, 23) regarding higher NR in brown top millet under wider spacing and higher dosage

The treatment combination of direct-sown brown top millet with a spacing of 45 x 10 cm and 125% RDF ($E_1xS_3xN_3$) recorded superior B:C ratios of 2.64, 2.58, 2.58 during summer, kharif and rabi seasons, respectively (Table 8). This indicates that the higher fertilizer dose, combined with optimal spacing and direct sowing, led to significantly increased returns relative to the COC, maximizing profitability. In contrast, the lower B:C ratios of 0.92, 0.79 and 0.62 were recorded with transplanted brown top millet sown using 20 x 10 cm spacing and 75% RDF ($E_2xS_1xN_1$) across the same seasons. These results are consistent with the findings of (17, 22, 23).

Conclusion

This study reveals key insights into the response of brown top millet to various agronomic practices. Among the establishment methods tested, direct-sown brown top millet demonstrated significantly superior growth, yield and quality compared to the transplanted crop. A closer plant spacing of 20 x 10 cm resulted in greater growth metrics and straw yield. In contrast, the wider spacing of 45 x 10 cm led to significantly better yield attributes, overall yield and quality. Applying 150% RDF produced markedly better outcomes than other nutrient levels.

Table 8. Impact of different cropping seasons, crop establishment methods, crop geometry and nutrient levels on the economics of brown top millet

	Total cost of cultivation (₹ ha^{-1})			Gross returns (₹ ha^{-1})			Net returns (₹ ha^{-1})			B:C ratio (₹ ha^{-1})		
	Summer	**Kharif**	**Rabi**	**Summer**	**Kharif**	**Rabi**	**Summer**	**Kharif**	**Rabi**	**Summer**	**Kharif**	**Rabi**
Crop establishment (E) x Crop geometry (S) x Nutrient levels (N)												
$E_1S_1N_1$	52077	46677	41277	114434	95042	78196	62357	48365	36920	1.20	1.04	0.89
$E_1S_1N_2$	52798	47398	41998	125028	108302	104311	72230	60904	62313	1.37	1.28	1.48
$E_1S_1N_3$	53520	48120	42720	133653	117573	106997	80133	69453	64278	1.50	1.44	1.50
$E_1S_2N_1$	51127	45727	40327	118866	100869	83768	67740	55142	43442	1.32	1.21	1.08
$E_1S_2N_2$	51848	46448	41048	134738	117864	116358	82890	71416	75310	1.60	1.54	1.83
$E_1S_2N_3$	52570	47170	41770	178057	147413	139149	125488	100244	97380	2.39	2.13	2.33
$E_1S_3N_1$	49277	43877	38477	120611	104755	88393	71334	60878	49917	1.45	1.39	1.30
$E_1S_3N_2$	49998	44598	39198	166431	145409	136019	116433	100811	96821	2.33	2.26	2.47
$E_1S_3N_3$	50720	45320	39920	184852	162247	142772	134133	116928	102853	2.64	2.58	2.58
$E_2S_1N_1$	58745	52445	47045	112505	93931	76185	53760	41487	29141	0.92	0.79	0.62
$E_2S_1N_2$	59467	53166	47766	122120	108056	92275	62654	54890	44509	1.05	1.03	0.93
$E_2S_1N_3$	60188	53888	48488	130201	114971	105003	70013	61084	56516	1.16	1.13	1.17
$E_2S_2N_1$	57795	51945	46095	114803	100001	81573	57009	48057	35479	0.99	0.93	0.77
$E_2S_2N_2$	58516	52666	46816	131333	108252	107438	72817	55586	60622	1.24	1.06	1.29
$E_2S_2N_3$	59238	53388	47538	148765	132726	122120	89528	79338	74583	1.51	1.49	1.57
$E_2S_3N_1$	55495	49195	43795	119748	111967	84508	64254	62773	40714	1.16	1.28	0.93
$E_2S_3N_2$	56216	49916	44516	139048	120533	119000	82832	70617	74484	1.47	1.41	1.67
$E_2S_3N_3$	56938	50638	45238	155630	137560	124552	98693	86922	79315	1.73	1.72	1.75

E_1-direct sown brown top millet, E_2-transplanted brown top millet, 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. 3. Overall view of the field experiment A) Nursery bed B) Transplantation C) Field view D) Grain filling stage E) Maturity stage.

Furthermore, brown top millet sown in the summer recorded higher mean values for growth and yield parameters than those sown during the kharif and rabi seasons. The treatment combination of direct-sown millet, with a 45 x 10 cm spacing and 150% RDF, achieved significantly higher yield attributes, grain yield, vitamin content, gross returns, net returns and benefit-cost (B) ratio compared to other treatments. Despite numerous studies on the agronomic practices of brown top millet in India, none have specifically examined its cultivation across different seasons and the resulting impacts on growth, yield, vitamin content and economic viability. This research explores brown top millet's response to the transplanting method, offering new insights into its growth patterns. Additionally, this study represents the first attempt to standardize agronomic practices for brown top millet in Tamil Nadu. These findings will serve as a valuable reference for future research and agricultural practices to maximize the crop's potential.

Acknowledgements

Gratitude is extended to the Chairman and advisory members for their insightful opinion and constructive recommendations about the manuscript.

Authors' contributions

DA carried out the experiment, took observations and analyzed the data. RK guided the research by formulating the concept and approved the final manuscript. PG contributed by developing the ideas and reviewing the manuscript. PJ helped edit, summarize and revise the manuscript. SR helped summarize and revise the manuscript. VR helped edit, summarize and revise 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

References

1. Maitra S. Potential horizon of brown-top millet cultivation in drylands: A review. Crop Res. 2020;55:57-63. http://dx.doi.org/10.31830/2454-1761.2020.012
2. Crops and livestock products [Internet]. FAOSTAT. Rome: Food and Agriculture Organization of the United Nations; c2024 [cited 2024 Aug 17]. Available from: https://www.fao.org/faostat/en/#data/QCL
3. Saikishore A, Rekha KB, Hussain SA, Madhavi A. Grain yield, nutrient uptake and post-harvest soil properties of brown top millet under varying sowing windows and nitrogen levels. Int J Bio-Resour Stress Manag. 2021;12(5):541-51. https://doi.org/10.23910/1.2021.2336
4. Bhat S, Ganiger PC, Nandini C, Prabhakar, Thippeswamy V. Brown top millet - A review. Agric Res Technol. 2018;14(5):001-02. http://doi.org/10.19080/ARTOAJ.2018.14.555937
5. Singh S, Suri S, Singh R. Potential and unrealized future possibilities of brown top millet in the food sector. Front Sustain Food Syst. 2022;6. http://doi.org/10.3389/fsufs.2022.974126
6. Reddy A, Prasad KG. Return of the forgotten crop - Brown top millet [Internet]. LEISA India Magazine. 2017 Dec; Issue 19(4) [cited 2024 Aug 17]. Available from: https://www.leisaindia.org/return-of-the-forgotten-crop-brown-top-millet/
7. Prakash G, Kalyana Murty KN, Prathima AS, Rohani NM. Effect of spacing and nutrient levels on growth attributes and yield of finger millet (*Eleusine coracana* L. Gaertn) cultivated under guni planting method in red sandy loamy soil of Karnataka, India. Int J Curr Microbiol Appl Sci. 2018;7(5):1337-43. https://doi.org/10.20546/ijcmas.2018.705.160
8. Sarawale PP, Rajemahadik VA, Shendage GB, Kumhar BL, Mote AD. Effect of different establishment methods and varieties on yield, quality and nutrient uptake of kharif finger millet (*Eleusine coracana* (L.) Gaertn.). Int J Curr Microbiol Appl Sci. 2017;6(4):1285-89. https://doi.org/10.20546/ijcmas.2017.604.157

9. Revathi T, Rekha MS, Lakshmi NV, Lalitha KJ. Growing degree days and heat use efficiency of finger millet varieties at different sowing dates. Andhra Pradesh J Agric Sci. 2017;64(2):289-94.

10. Mahajan G, Pushplatha T, Singh D. Response of kodo millet varieties to different fertility levels under rainfed conditions of Kymore Plateau. Environ Ecol. 2017;35(2B):1018-21.

11. Vaani N, Porchelvan P. Monitoring of agricultural drought using fortnightly variation of vegetation condition index (VCI) for the state of Tamil Nadu, India. Int Arch Photogramm Remote Sens Spatial Inf Sci. 2018;42(4/W9):159–64. https://doi.org/10.5194/isprs-archives-XLII-4-W9-159-2018

12. American Association of Cereal Chemists (AACC). Approved methods of the AACC. St. Paul (MN): The Association; 1983.

13. Gomez KA, Gomez AA. Statistical procedures for agricultural research. 2nd ed. New York: John Wiley and Sons; 1984. p. 680.

14. Andonova SP, Rattin J, Di Benedetto A. Yield increase as influenced by transplanting of sweet maize (*Zea mays* L. saccharata). Am J Exp Agric. 2014;4:1314-29. https://doi.org/10.9734/AJEA/2014/11077

15. Zhao Z, Rebetzke GJ, Zheng B, Chapman SC, Wang E. Modelling impact of early vigour on wheat yield in dryland regions. J Exp Bot. 2019;70(9):2535-48. https://doi.org/10.1093/jxb/erz069

16. Chouhan M, Gudadhe NN, Kumar D, Kumawat AK, Kumar R. Transplanting dates and nitrogen levels influence on growth, yield attributes and yield of summer pearl millet. Bioscan. 2015;10 (3):1295-98.

17. Raghavendra, Hulakund S, Ashoka P, Potdar MP, Rajakumar GR. Optimization of seed rate and planting geometry for genotypes of brown top millet (*Brachiaria ramosa* L.). J Farm Sci. 2022;35(1):52-57.

18. Siddiqui DA, Sharma GK, Chandrakar T, Thakur AK, Pradhan A. Differential levels of fertilizer and row spacing affect growth and yield of brown top millet in Entisols of Bastar Plateau Zone of Chhattisgarh. Int J Curr Microbiol Appl Sci. 2020;9(8):3459-472. https://doi.org/10.20546/ijcmas.2020.908.401

19. Musa M, Gondal MR, Hussain A, Yasin S, Rehman HS. Effect of seed rate and row spacing on grain yield of sorghum. SAARC J Agric. 2017;15(2):81-91. http://doi.org/10.3329/sja.v15i2.35154

20. Bullock DG, Nielsen RL, Nyquist WE. A growth analysis comparison of corn growth in conventional and equidistant plant spacing. Crop Sci. 1988;28:254-58. https://doi.org/10.2135/cropsci1988.0011183X002800020015x

21. Pavankumar N, Hemalatha S, Subramanyam D, Nirmal Kumar AR, Karuna Sagar G. Effect of plant geometry and nitrogen levels on growth and yield of brown top millet (*Brachiaria ramosa* L.) under Southern Agro-climatic zone of Andhra Pradesh. Pharma Innovation. 2021;10(12):207–11.

22. Shubha S, Vivek, Devaranavadagi S, Shivalingappa H. Effect of wide row spacing on growth and yield of pearl millet (*Pennisetum glaucum* L.) under rainfed conditions of northern Karnataka. Pharma Innov J. 2021;10(12):1723-25. https://doi.org/10.22271/tpi.2021.v10.i10y.8401

23. Triveni U, Nagarjuna D, Jogarao P, Rani YS, Anuradha N, Patro TSSK. Influence of fertilizer nutrition and row spacing on productivity and profitability of brown top millet (*Brachiaria ramosa* L.). Andhra Agric J. 2023;70(3):288-95. https://doi.org/10.61657/aaj.2023.44

24. Krishnaveni AS. Effect of method of crop establishment and nutrient management in barnyard millet under sodic soil conditions. Int J Curr Microbiol Appl Sci. 2018;7(12):51-55. https://doi.org/10.20546/ijcmas.2018.712.007

25. Nandini KM, Sridhara S. Response of growth, yield and quality parameters of foxtail millet genotypes to different planting densities. Int J Curr Microbiol Appl Sci. 2019;8(2):1765-73. https://doi.org/10.20546/ijcmas.2019.802.208

26. Pannase S, Bagade SV, Sonawane DA, Sondawale PA. Effect of foxtail millet cultivars on yield and yield attributes under different sowing windows. J Sci Res Rep. 2024;30(6):277-88. https://doi.org/10.9734/jsrr/2024/v30i62043

27. Hamada AM, Fatehi J, Jonsson LMV. Seed treatments with thiamine reduce the performance of generalist and specialist aphids on crop plants. Bull Entomol Res. 2018;108(1):84-92. https://doi.org/10.1017/S0007485317000529

28. Bouhadi M, El Kouali MH, Samir K, Elbouhmadi K, Talbi M, Fougrach H. Exogenous application of thiamine and nicotinic acid improves tolerance and morpho-physiological parameters of *Lens culinaris* under lead (Pb) exposure. J Plant Growth Regul. 2024;1:1-14. https://doi.org/10.1007/s00344-024-11383-y

29. Advenia D, Arifin N. The effect of planting distance on the growth and yield of sweet potato clone Arf-03 on alluvial soil. Braz J Dev. 2024;10(4). https://doi.org/10.34117/bjdv10n4-064

30. Sangeeta, Surakod VS. Influence of pearl millet crop geometry on growth and yield attributes under dryland conditions. J Pharmacogn Phytochem. 2018;7(3):31-33.

31. Kiran HP, Sukanya TS, Salmankhan RM, Chavadi B. Effect of different nutrient levels on yield and economics of brown top millet. Int J Chem Stud. 2020;8(6):2715-16. https://doi.org/10.22271/chemi.2020.v8.i6am.11192

32. Jogarao P, Triveni U, Patro TSSK, Anuradha N. Effect of nutrient management in finger millet in red sandy loam soils of North Coastal Zone. J Pharmacogn Phytochem. 2019;8(5):557-60.

33. Kanjiya HN, Chopada MC, Vaghasiya DR, Savaliya AV. Effect of planting dates on growth and yield of pearl millet (*Pennisetum glaucum* L.). Int J Curr Microbiol Appl Sci. 2021;10(01):287-91. https://doi.org/10.20546/ijcmas.2021.1001.035

34. Piper J. Diffusion of hydrogen in copper-palladium alloys. J Appl Phys. 1966; 37(2):715-21.

35. Jackson ML. Soil chemical analysis. New Delhi: Prentice Hall of India Pvt. Ltd.; 1973. p. 498.

36. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Sci. 1934; 37(1):29-38. https://doi.org/10.1097/00010694-193401000-00003

37. Subbiah BV, Asija GL. A rapid procedure for determination of available nitrogen in soil. Curr Sci. 1956;25:259-260.

38. Olsen SR, Cole CV, Watanabe FS. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. USDA Circular No. 939. Washington (DC): US Government Printing Office; 1954.