



Performance of finger millet varieties under system of crop intensification in ragi

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Abstract

A field study was conducted during the kharif seasons of 2023 and 2024 at the Zonal Agricultural Research Station, University of Agricultural Sciences, Bengaluru, to evaluate the performance of finger millet varieties under different planting geometries following the system of crop intensification (SCI) (guli method). The experiment was conducted in a factorial randomised complete block design (RCBD) with three replications, comprising six varieties, viz., Unde ragi, Picchakaddi ragi, Jagalur ragi, GPU 48, GPU 66 and MR 6 and three planting geometries, viz., 30 × 10 cm, 25 × 25 cm and 30 × 30 cm. The varieties, planting geometries and their interaction significantly influenced the major growth and yield attributes of finger millet. Among varieties, MR 6 recorded the highest plant height (110.73 cm), number of tillers hill⁻¹ (9.39), dry matter production (71.22 g hill⁻¹) and grain yield (3427 kg ha⁻¹) and which on par with GPU 66. Among planting geometries, 30 × 30 cm recorded the higher number of tillers hill⁻¹ (9.06), dry matter production (68.14 g hill⁻¹), grain yield (3279 kg ha⁻¹) and straw yield (4479 kg ha⁻¹). Significant variety × planting geometry interaction was observed for grain and straw yields. The MR 6 with 30 × 30 cm combination recorded the highest grain yield (4231 kg ha⁻¹) and straw yield (5431 kg ha⁻¹) and which was on par with GPU 66 planted at 30 × 30 cm. Thus, MR 6 and GPU 66 planted at 30 × 30 cm under the SCI method were identified as promising combinations for enhancing sustainable and efficient finger millet production under rainfed conditions.

Keywords: finger millet; grain yield; planting geometry; rainfed condition; varieties

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1. Introduction

Finger millet (*Eleusine coracana* L.), commonly known as ragi, is an important small millet cultivated widely in the semi-arid and tropical regions of Asia and Africa (1). Its drought tolerance, adaptability to diverse agro-climatic conditions and low input requirements make it important for food and nutritional security. Recognised as a “nutri-cereal,” finger millet is rich in carbohydrates, protein, dietary fibre, minerals and essential amino acids, with notably high calcium (Ca) and appreciable iron (Fe) and phosphorus (P) contents (2–3). India is the leading producer of ragi in the world with an area of approximately 1.18 million ha, with a production of about 1.8 million t and an average productivity of 1600 kg ha⁻¹ whereas Karnataka accounts for approximately 60 % the area under finger millet cultivation and contributes maximum share of the country's production (4). Despite its nutritional and agronomic importance, finger millet

productivity in India remains below its potential due to moisture stress, erratic rainfall, poor soil fertility, imbalanced nutrient management, pests and diseases and limited adoption of improved technologies (5–6).

The development and adoption of improved varieties are important strategy for enhancing finger millet productivity. Varieties differ in their yield potential, stress tolerance, nutrient-use efficiency, root characteristics, photosynthetic efficiency and biomass partitioning (7). However, the performance of varieties varies across environments, necessitating the identification of cultivars that can efficiently utilise available resources under changing climatic conditions (8). Varieties differ in plant architecture, tillering ability, root characteristics and resource-use patterns, resulting in differential responses to plant density (9).

Plant spacing is another important factor governing the efficient utilisation of light, moisture,

nutrients and growing space. Optimum spacing minimises inter-plant competition while maintaining an adequate plant population and promoting better crop establishment and resource utilisation (10). The guli or guni or system of crop intensification (SCI) method, which involves transplanting two seedlings at predetermined spacings in small pits, has also gained attention for improving root development, moisture conservation, nutrient utilisation and intercultural operations (11–12).

The investigation of genotype $\times$ planting geometry interaction under the guli planting method is important because finger millet genotypes differ considerably in their growth habit, tillering ability, canopy architecture, root development and resource-use pattern. Planting geometry determines the spatial availability of soil moisture, nutrients, light interception and above-ground growing space and these factors may influence different genotypes differently. Under rainfed conditions, such differential responses can be particularly important because the effectiveness of a particular geometry depends not only on plant population but also on the ability of a genotype to exploit available soil moisture and other resources. Although the guli method provides a favourable spatial arrangement for crop establishment and resource utilisation, the optimum geometry may vary among genotypes. Therefore, evaluating genotype $\times$ planting geometry interaction is necessary to identify whether specific finger millet genotypes perform consistently across geometries or whether particular genotype–geometry combinations provide advantages in grain and straw productivity under rainfed conditions. Such information can help refine the guli planting method from a generalised recommendation to a more genotype-specific production strategy.

However, the response of different finger millet varieties to spacing under the guli method remains insufficiently studied. Thus, a common spacing may not be optimal for all varieties. Identifying suitable variety-spacing combinations is therefore essential for efficient resource utilisation and stable production. Hence, the present study was undertaken to evaluate the response of different finger millet varieties to varying planting spacings under the guli method and to identify suitable combinations for improved crop performance under the prevailing agro-climatic conditions.

2. Materials and Methods

Experimental site characteristics

The field experiment was conducted during the kharif seasons of 2023 and 2024, between the first fortnight of June and the first fortnight of October at Zonal Agricultural Research Station (ZARS), University of Agricultural Sciences (UAS), Gandhi Krishi Vigyan Kendra (GKVK), Bengaluru. The experimental site is located in the Eastern dry zone (Zone-V) of Karnataka and is located between 12°51' N latitude and 77° 35' E longitude at an altitude of 930 m above mean sea level

(MSL). The experiment was conducted under rainfed conditions.

The experimental soil was red sandy clay loam, deep and well drained. A composite soil sample collected from 0–15 cm depth was analysed for its physical and chemical properties. The soil was neutral in reaction (pH 6.60) with an electrical conductivity of 0.35 dS m⁻¹ and organic carbon content of 0.43 %. The soil contained medium levels of available nitrogen (N) (296.08 kg ha⁻¹), Phosphorus (P) (48.60 kg ha⁻¹) and potassium (K) (142.34 kg ha⁻¹).

Treatment details

The experiment was conducted in a factorial randomised complete block design (RCBD) with 3 replications. Factor A consisted of six varieties (V₁: Unde ragi, V₂: Picchakaddi ragi, V₃: Jagalur ragi, V₄: GPU 48, V₅: GPU 66 and V₆: MR 6) and the factor B consisted of three spacing levels [S₁: 30 x 10 cm (333333 plants ha⁻¹), S₂: 25 x 25 cm (160000 plants ha⁻¹) and S₃: 30 x 30 cm (111111 plants ha⁻¹)]. The gross plot size: 4.5 x 4.5 m with a net plot size: 3.3 m x 4.1 m (30 x 10 cm), 3.5 x 3.5 m (25 x 25 cm) and 3.3 x 3.3 m (30 x 30 cm). Treatments were randomly allotted to the plots within each block.

Crop establishment and management

Healthy and uniform finger millet seedlings of 20 days' age were carefully uprooted from the nursery and transplanted into the prepared pits following the guni method (square planting) as per the specified spacing treatments, with two seedlings per pit to maintain uniform plant population. Light irrigation was provided immediately after transplanting to ensure proper establishment of seedlings.

At the time of transplanting, 100 g of farmyard manure (FYM) was applied to each pit before planting the finger millet seedlings. The recommended dose of fertilisers (N: Phosphorus pentoxide (P₂O₅): potassium oxide (K₂O) at 50: 40: 37.5 kg ha⁻¹) was applied to the crop. Fifty per cent of N and the full dose of P and K were applied as a basal dose at the time of transplanting, while the remaining 50 % N was top-dressed during the vegetative phase, 30 days after transplanting (DAT).

Intercultivation and weeding was carried out simultaneously using a blade hoe with a bullock pair at 25 and 50 DAT during kharif 2023 and kharif 2024. All recommended agronomic practices were followed to ensure optimum crop growth.

Observations recorded

The biometric observations included plant height, tillers hill⁻¹, dry matter production, days to 50 % flowering and maturity. At maturity, ear heads and straw were harvested separately, sun-dried, weighed and expressed as kg ha⁻¹.

The leaf area was measured by collected green leaves from five hills were passed through a leaf area meter INC/LI-COR Ltd., Nebraska, USA to measure the leaf area at 30, 60, 90 DAT and at harvest.



Harvest index was calculated by using formula as the ratio of grain yield to total above-ground biological yield (grain yield + straw yield), expressed as a percentage.

Statistical analysis

The data recorded for different growth, yield and yield-attributing parameters were subjected to analysis of variance (ANOVA) appropriate for a factorial RCBD following Fisher's method of ANOVA (13) using Microsoft Excel and OPSTAT. The significance of treatment effects was tested at the 5 % probability level. Critical difference (CD) values were calculated for parameters showing significant *f*-values, whereas non-significant effects were denoted as NS.

3. Results and Discussion

Growth parameters

Effect of varieties

The growth parameters of finger millet varieties varied significantly with respect to plant height, number of tillers hill⁻¹, dry matter production and leaf area at harvest (Table 1). Among the varieties, MR 6 (V₆) recorded the highest plant height (110.73 cm), number of tillers hill⁻¹ (9.39) and dry matter production (71.22 g hill⁻¹). This was on par with the GPU 66 (V₅), which recorded 106.89 cm plant height, 8.95 tillers hill⁻¹ and 67.85 g hill⁻¹ dry matter. The lowest values for these parameters were recorded in Unde ragi (V₁) (with 81.80 cm plant height, 6.31 tillers hill⁻¹ and 47.12 g hill⁻¹ dry matter).

The superior growth of MR 6 could be attributed to its inherent genetic potential for vigorous vegetative growth, greater tillering ability and efficient biomass accumulation. The larger leaf area observed in MR 6 increased the photosynthetic surface, thereby facilitating greater assimilate production and dry matter accumulation. Similar varietal differences in plant height and dry matter production have been reported in finger millet, indicating that growth attributes are strongly governed by genotype (14–16).

Effect of planting geometry

Planting geometry significantly influenced all the major growth parameters (Table 1). Among the three geometries, S₁ recorded the maximum pooled plant height (106.81 cm), whereas S₃ recorded the highest number of tillers hill⁻¹ (9.06) and dry matter production (68.14 g hill⁻¹). S₂ recorded intermediate values for all the parameters.

The superiority of wider spacing may be attributed to reduced inter-plant competition for light, moisture, nutrients and physical space, which favoured individual plant growth and tiller production.

Greater availability of resources per plant under wider geometry might have promoted canopy development and dry matter accumulation (17). The different responses for hill spacing might be due to the fact that the wider spacing allowed more light, space for producing higher number of effective tillers (18–19).

Interaction effect of varieties × planting geometry

The interaction between variety and planting geometry significantly influenced the growth attributes of finger millet (Table 2). V₆S₁ (MR 6 with 30 × 10 cm) recorded the highest pooled plant height (119.20 cm), while V₆S₃ (MR 6 with 30 × 30 cm) recorded the highest pooled number of tillers (11.22 hill⁻¹) and dry matter production (82.37 g hill⁻¹), which was on par with that of V₅S₃ (GPU 66 × 30 cm × 30 cm). In contrast, V₁S₃ recorded the lowest plant height (70.25 cm) and V₁S₁ (Unde ragi with 30 × 10 cm) recorded the lowest number of tillers (5.71 hill⁻¹) and dry matter production (42.54 g hill⁻¹).

The better performance of MR 6 under wider spacing suggests a favourable interaction between genotype and available growing space. The vigorous genotype was able to exploit the additional resources available under wider spacing, resulting in greater tillering, leaf development and biomass accumulation. The interaction therefore demonstrates that the optimum planting geometry may depend on the growth habit and competitive ability of the genotype (5, 20).

Days to 50 % flowering and maturity

Effect of varieties

Significant differences were observed among the finger millet varieties for days to 50 % flowering and days to maturity (Table 3). The pooled data revealed that MR 6 (V₆) was the latest to attain 50 % flowering (62.71 days) and maturity (119.70 days), which was on par with the GPU 66 (V₅) with 58.26 and 109.21 days, respectively. Unde ragi (V₁) was the earliest, recording 43.29 days to 50 % flowering and 86.78 days to maturity. The differences among varieties indicate considerable genetic variation in crop duration (21–23).

Effect of planting geometry

Planting geometry significantly influenced both flowering and maturity (Table 3). Among the spacing treatments, S₃ (30 × 30 cm) recorded the maximum days to 50 % flowering (56.87 days) and maturity (107.17 days), whereas S₁ (30 × 10 cm) recorded the minimum values (49.54 and 94.34 days, respectively). The delayed flowering and maturity under wider spacing may be attributed to reduced inter-plant competition for light, moisture, nutrients and growing space, which favoured prolonged crop growth and delayed reproductive development (18).



Table 1. Plant height, number of tillers and dry matter production of finger millet varieties as influenced by different planting geometry

Treatments	Plant height (cm)			Number of tillers hill ⁻¹			Dry matter production (g hill ⁻¹)		
	At harvest			At harvest			At harvest		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Varieties (V)									
V ₁	75.26	88.33	81.80	6.18	6.43	6.31	45.05	49.19	47.12
V ₂	81.93	94.49	88.21	6.77	7.00	6.88	48.98	54.49	51.74
V ₃	87.64	101.18	94.41	7.15	7.42	7.28	51.38	59.13	55.26
V ₄	97.54	111.20	104.37	8.31	8.66	8.49	57.52	72.01	64.76
V ₅	101.04	112.74	106.89	8.76	9.13	8.95	60.33	75.37	67.85
V ₆	104.35	117.11	110.73	9.12	9.65	9.39	64.22	78.23	71.22
S.Em. ±	3.38	4.16	2.58	0.31	0.31	0.26	1.94	2.92	2.04
C.D at 5 %	9.70	11.96	7.25	0.88	0.89	0.73	5.57	8.38	5.73
Planting geometry (S)									
S ₁	100.79	112.83	106.81	6.77	7.00	6.88	48.00	55.12	51.56
S ₂	91.77	104.97	98.37	7.54	7.86	7.70	54.01	64.53	59.27
S ₃	81.33	94.72	88.02	8.84	9.29	9.06	61.73	74.55	68.14
S.Em. ±	2.39	2.94	1.82	0.22	0.22	0.18	1.37	2.06	1.44
C.D at 5 %	6.86	8.45	5.12	0.62	0.63	0.52	3.94	5.92	4.05

V₁: Unde ragi; V₂: Picchakaddi ragi; V₃: Jagalur ragi; V₄: GPU 48; V₅: GPU 66; V₆: MR 6; S₁: 30 x 10 cm; S₂: 25 x 25 cm; S₃: 30 x 30 cm; GPU 48 and 66: germplasm utilisation 48 and 66; MR-6: Mandya ragi-6; NS: non-significant; S.Em. ±: standard error of mean; C.D ($p = 0.05$): critical difference at the 5 % level of significance.

Table 2. Plant height, number of tillers and dry matter production of finger millet varieties interaction with different planting geometry

Treatments	Plant height (cm)			Number of tillers hill ⁻¹			Dry matter production (g hill ⁻¹)		
	At harvest			At harvest			At harvest		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Interaction (V × S)									
V ₁ S ₁	87.10	98.69	92.90	5.59	5.82	5.71	40.09	44.98	42.54
V ₁ S ₂	71.24	93.25	82.25	6.11	6.34	6.23	44.95	47.97	46.46
V ₁ S ₃	67.45	73.04	70.25	6.85	7.12	6.99	50.10	54.61	52.36
V ₂ S ₁	91.46	106.67	99.07	5.82	6.06	5.94	41.12	46.12	43.62
V ₂ S ₂	86.40	97.34	91.87	6.81	7.06	6.94	49.87	52.89	51.38
V ₂ S ₃	67.93	79.46	73.70	7.68	7.87	7.78	55.95	64.46	60.21
V ₃ S ₁	97.81	110.09	103.95	6.64	6.76	6.70	45.51	49.87	47.69
V ₃ S ₂	87.25	99.54	93.40	6.88	7.23	7.06	50.63	57.33	53.98
V ₃ S ₃	77.87	93.90	85.89	7.92	8.27	8.10	58.00	70.20	64.10
V ₄ S ₁	104.09	116.59	110.34	7.18	7.57	7.38	52.01	59.72	55.87
V ₄ S ₂	100.82	111.06	105.94	8.17	8.45	8.31	58.46	73.82	66.14
V ₄ S ₃	87.71	105.95	96.83	9.58	9.97	9.78	62.08	82.48	72.28
V ₅ S ₁	112.02	118.78	115.40	7.51	7.76	7.64	52.79	63.18	57.99

V ₅ S ₂	100.99	112.91	106.95	8.53	8.81	8.67	59.19	76.88	68.04
V ₅ S ₃	90.10	106.52	98.31	10.25	10.83	10.54	69.02	86.04	77.53
V ₆ S ₁	112.23	126.16	119.20	7.85	8.02	7.94	56.46	66.86	61.66
V ₆ S ₂	103.89	115.74	109.82	8.73	9.29	9.01	60.97	78.31	69.64
V ₆ S ₃	96.93	109.42	103.18	10.78	11.65	11.22	75.22	89.52	82.37
S.Em. ±	5.85	7.20	4.47	0.53	0.54	0.45	31.13	5.05	3.53
C.D at 5 %	16.80	20.71	12.55	1.53	1.54	1.27	32.02	14.51	9.93

V₁: Unde ragi; V₂: Picchakaddi ragi; V₃: Jagalur ragi; V₄: GPU 48; V₅: GPU 66; V₆: MR 6; S₁: 30 x 10 cm; S₂: 25 x 25cm; S₃: 30 x 30 cm; GPU 48 and 66: germplasm utilisation 48 and 66; MR-6: Mandya ragi-6; NS: non-significant; S.Em. ±: standard error of mean; C.D ($\rho = 0.05$): critical difference at the 5 % level of significance.

Table 3. Days to 50 % flowering and day to maturity of finger millet varieties as influenced by different planting geometry

Treatments	Days to 50 % flowering			Days to maturity		
	2023	2024	Pooled	2023	2024	Pooled
Varieties (V)						
V ₁	41.71	44.86	43.29	85.58	87.98	86.78
V ₂	44.45	47.81	46.13	88.02	90.27	89.15
V ₃	48.54	52.57	50.56	92.79	94.71	93.75
V ₄	55.51	59.06	57.29	103.70	107.72	105.71
V ₅	56.06	60.46	58.26	107.33	111.09	109.21
V ₆	60.68	64.73	62.71	118.57	120.82	119.70
S.Em. ±	2.61	2.75	2.68	3.89	3.90	3.90
C.D at 5 %	7.50	7.90	7.70	10.31	10.63	10.47
Planting geometry (S)						
S ₁	47.79	51.28	49.54	93.42	95.26	94.34
S ₂	50.90	54.52	52.71	98.86	102.41	100.63
S ₃	54.79	58.95	56.87	105.72	108.63	107.17
S.Em. ±	1.84	1.95	1.90	3.66	3.68	3.67
C.D at 5 %	5.30	5.59	5.45	10.52	10.59	10.56

V₁: Unde ragi; V₂: Picchakaddi ragi; V₃: Jagalur ragi; V₄: GPU 48; V₅: GPU 66; V₆: MR 6; S₁: 30 x 10 cm; S₂: 25 x 25 cm; S₃: 30 x 30 cm; GPU 48 and 66: germplasm utilisation 48 and 66; MR-6: Mandya ragi-6; NS: non-significant; S.Em. ±: standard error of mean; C.D ($\rho = 0.05$): critical difference at the 5 % level of significance.

Interaction effect of varieties × planting geometry

The interaction between variety and planting geometry showed marked variation in crop duration (Table 4). The pooled data indicated that V₆S₃ (MR 6 with 30 × 30 cm) recorded the maximum days to 50 % flowering (65.30 days) and maturity (124.70 days), followed by V₅S₃ (GPU 66 with 30 × 30 cm) with 63.47 and 121.79 days, respectively. In contrast, V₁S₁ (Unde ragi with 30 × 10 cm) is the earliest combination, recording 38.02 days to 50 % flowering and 81.43 days to maturity. The differential response may be attributed to inherent varietal differences in

growth duration coupled with the influence of plant density on resource availability and crop development (9, 18). Thus, MR 6 under wider spacing exhibited a longer crop duration, whereas Unde ragi under closer spacing was the earliest to flower and mature.

Yield and harvest index

Effect of varieties

Varieties differed significantly for grain yield and straw yield, while the differences in harvest index were statistically non-significant (Table 5). MR 6 (V₆) recorded the highest pooled grain yield (3427 kg ha⁻¹) and straw yield (4627 kg ha⁻¹) and was statistically on

par with GPU 66 (V_5). The higher grain yield of MR 6 can therefore be attributed to its superior plant height, tillering, leaf area, dry matter production and grain weight earhead⁻¹. Similar associations between plant growth, yield components and grain yield have been reported in finger millet (24–25). This indicates that the superior grain yield of MR 6 was associated with better assimilate partitioning towards reproductive sinks rather than excessive vegetative biomass (14, 15, 18).

Effect of planting geometry

Planting geometry significantly influenced grain yield and straw yield, while the differences in harvest index were statistically non-significant (Table 5). Among the planting geometries, 30×30 cm (S_3) recorded the highest pooled grain yield (3279 kg ha⁻¹) and straw yield (4479 kg ha⁻¹), followed by S_2 (2828 and 4028 kg ha⁻¹), while 30×10 cm (S_1) recorded the lowest values (2447 and 3647 kg ha⁻¹).

The higher grain yield under S_3 was due to the markedly superior growth and yield attributes per plant, particularly greater tillering, dry matter production, leaf area and grain weight earhead⁻¹. The greater harvest index under S_3 further indicates more efficient partitioning of biomass towards grain. Wider spacing, especially in square planting, reduced inter-row competition for resources, while a higher number of effective tillers and healthy grains per unit area resulted in an increased yield (17, 26–28).

Interaction effect of varieties $\times$ planting geometry

A significant interaction between variety and planting geometry was observed for grain yield and straw yield (Table 6). V_6S_3 (MR 6 with 30×30 cm) recorded the highest pooled grain yield (4231 kg ha⁻¹) and straw

yield (5431 kg ha⁻¹) and was statistically at par with V_5S_3 (GPU 66 with 30×30 cm), which recorded 3734 kg grain ha⁻¹ and a straw yield of 4934 kg ha⁻¹. The lowest pooled grain yield (1843 kg ha⁻¹) and straw yield (3043 kg ha⁻¹) were recorded for V_1S_1 (Unde ragi with 30×10 cm). The harvest index was not significantly influenced by the $V \times S$ interaction. The numerically highest harvest index (0.44) was recorded with V_6S_3 , whereas the lowest (0.38) was observed in V_1S_1 . The superior yield performance of V_6S_3 was associated with its greater growth, tillering and dry matter production observed under the wider guli planting geometry. Similar differential responses of finger millet varieties to planting geometry have been reported, indicating that genotype and plant density can interact to influence crop productivity (9).

The higher performance of V_6S_3 suggests that MR 6 responded particularly well to wider spacing, allowing greater expression of its genetic potential through improved plant growth, biomass accumulation and grain formation. Wider spacing can reduce inter-plant competition for light, moisture and nutrients and provide greater growing space per plant, thereby favouring better growth and dry matter production (17, 18). The combination of a vigorous genotype with adequate inter-plant space probably enhanced interception and utilisation of available growth resources, resulting in greater assimilate production and translocation towards the reproductive organs. Consequently, higher grain production relative to total biomass resulted in greater grain yield and harvest index. The significant variety $\times$ planting geometry interaction further indicates that the response of grain productivity to plant arrangement was genotype dependent.

Table 4. Days to 50 % flowering and day to maturity of finger millet varieties interaction with different planting geometry

Treatments	Days to 50 % flowering			Days to maturity		
	2023	2024	Pooled	2023	2024	Pooled
Interaction ($V \times S$)						
V_1S_1	36.52	39.51	38.02	80.46	82.39	81.43
V_1S_2	41.26	43.17	42.22	85.80	87.45	86.63
V_1S_3	47.34	51.91	49.63	90.47	94.10	92.29
V_2S_1	39.73	42.90	41.32	82.25	85.18	83.72
V_2S_2	44.28	47.04	45.66	87.28	89.71	88.50
V_2S_3	49.34	53.48	51.41	94.54	95.92	95.23
V_3S_1	46.62	50.17	48.40	89.80	91.28	90.54
V_3S_2	48.28	53.04	50.66	92.78	95.78	94.28
V_3S_3	50.73	54.50	52.62	95.80	97.08	96.44
V_4S_1	52.98	56.87	54.93	97.89	98.82	98.36
V_4S_2	54.71	58.69	56.70	100.14	106.42	103.28
V_4S_3	58.85	61.63	60.24	113.08	117.92	115.50
V_5S_1	53.26	57.16	55.21	98.73	100.10	99.42
V_5S_2	55.53	59.56	57.55	106.48	112.19	109.34

V ₅ S ₃	59.39	64.67	62.03	116.78	120.98	118.88
V ₆ S ₁	57.64	61.06	59.35	111.40	113.80	112.60
V ₆ S ₂	61.32	65.62	63.47	120.67	122.90	121.79
V ₆ S ₃	63.08	67.52	65.30	123.64	125.76	124.70
S.Em. ±	4.52	4.76	4.08	8.79	9.03	7.91
C.D at 5 %	12.98	13.69	11.46	25.33	25.94	22.23

V₁: Unde ragi; V₂: Picchakaddi ragi; V₃: Jagalur ragi; V₄: GPU 48; V₅: GPU 66; V₆: MR 6; S₁: 30 x 10 cm; S₂: 25 x 25 cm; S₃: 30 x 30 cm; GPU 48 and 66: germplasm utilisation 48 and 66; MR-6: Mandya ragi-6; NS: non-significant; S.Em. ±: standard error of mean; C.D ($p = 0.05$): critical difference at the 5 % level of significance.

Table 5. Grain yield, straw yield and harvest index of finger millet varieties as influenced by different planting geometry

Treatments	Grain yield (kg ha ⁻¹)			Straw yield (kg ha ⁻¹)			Harvest index		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Varieties (V)									
V ₁	2288	2237	2263	3488	3437	3463	0.39	0.39	0.39
V ₂	2475	2441	2458	3675	3641	3658	0.40	0.40	0.40
V ₃	2717	2706	2712	3917	3906	3912	0.41	0.41	0.41
V ₄	3020	3036	3028	4220	4236	4228	0.42	0.42	0.42
V ₅	3203	3236	3220	4403	4436	4420	0.42	0.42	0.42
V ₆	3433	3421	3427	4633	4621	4627	0.42	0.42	0.42
S.Em. ±	134.66	141.77	120.98	161.59	170.12	163.46	0.00	0.00	0.00
C.D ($p = 0.05$)	387.03	407.44	340.00	464.44	488.90	475.42	NS	NS	NS
Planting geometry (S)									
S ₁	2464	2430	2447	3664	3630	3647	0.40	0.40	0.40
S ₂	2829	2828	2828	4029	4028	4028	0.41	0.41	0.41
S ₃	3275	3282	3279	4475	4482	4479	0.42	0.42	0.42
S.Em. ±	95.22	100.24	85.54	114.24	120.34	117.24	0.00	0.00	0.00
C.D ($p = 0.05$)	273.67	288.10	240.42	328.41	345.82	337.04	NS	NS	NS

V₁: Unde ragi; V₂: Picchakaddi ragi; V₃: Jagalur ragi; V₄: GPU 48; V₅: GPU 66; V₆: MR 6; S₁: 30 x 10 cm; S₂: 25 x 25 cm; S₃: 30 x 30 cm; GPU 48 and 66: germplasm utilisation 48 and 66; MR-6: Mandya ragi-6; NS: non-significant; S.Em. ±: standard error of mean; C.D ($p = 0.05$): critical difference at the 5 % level of significance.

Table 6. Grain yield, straw yield and harvest index of finger millet varieties interaction with different planting geometry

Treatments	Grain yield (kg ha ⁻¹)			Straw yield (kg ha ⁻¹)			Harvest index		
	2023	2024	Pooled	2023	2024	Pooled	2023	2024	Pooled
Interaction (V × S)									
V ₁ S ₁	1886	1799	1843	3086	2999	3043	0.38	0.37	0.38
V ₁ S ₂	2408	2368	2388	3608	3568	3588	0.40	0.40	0.40
V ₁ S ₃	2570	2545	2558	3770	3745	3758	0.41	0.40	0.40
V ₂ S ₁	2052	1979	2016	3252	3179	3216	0.39	0.38	0.39
V ₂ S ₂	2548	2521	2535	3748	3721	3735	0.40	0.40	0.40
V ₂ S ₃	2825	2824	2825	4025	4024	4025	0.41	0.41	0.41

V ₃ S ₁	2493	2461	2477	3693	3661	3677	0.40	0.40	0.40
V ₃ S ₂	2620	2599	2610	3820	3799	3810	0.41	0.41	0.41
V ₃ S ₃	3039	3057	3048	4239	4257	4248	0.42	0.42	0.42
V ₄ S ₁	2735	2726	2731	3935	3926	3931	0.41	0.41	0.41
V ₄ S ₂	3067	3087	3077	4267	4287	4277	0.42	0.42	0.42
V ₄ S ₃	3257	3296	3277	4457	4496	4477	0.42	0.42	0.42
V ₅ S ₁	2750	2742	2746	3950	3942	3946	0.41	0.41	0.41
V ₅ S ₂	3164	3194	3179	4364	4394	4379	0.42	0.42	0.42
V ₅ S ₃	3695	3773	3734	4895	4973	4934	0.43	0.43	0.43
V ₆ S ₁	2867	2870	2869	4067	4070	4069	0.41	0.41	0.41
V ₆ S ₂	3166	3196	3181	4366	4396	4381	0.42	0.42	0.42
V ₆ S ₃	4266	4196	4231	5466	5396	5431	0.44	0.44	0.44
S.Em. ±	233.25	245.55	209.54	280.19	294.64	287.24	0.01	0.01	0.01
C. D ($p = 0.05$)	670.36	705.71	588.90	804.53	846.82	825.62	NS	NS	NS

V₁: Unde ragi; V₂: Picchakaddi ragi; V₃: Jagalur ragi; V₄: GPU 48; V₅: GPU 66; V₆: MR 6; S₁: 30 × 10 cm; S₂: 25 × 25 cm; S₃: 30 × 30 cm; GPU 48 and 66: germplasm utilisation 48 and 66; MR-6: Mandya ragi-6; NS: non-significant; S.Em. ±: standard error of mean; C.D ($p = 0.05$): critical difference at the 5 % level of significance.

Heat map

The consistently higher leaf area (Fig. 1) under 30 × 30 cm spacing (S₃) suggests that wider spacing provided greater availability of light, moisture, nutrients and growing space, thereby promoting leaf expansion. Among varieties, MR 6 (V₆) showed superior leaf development, particularly when combined with wider spacing. The V₆S₃ combination produced the maximum leaf area at all growth stages, indicating a favourable interaction between the genotype and planting geometry.

The sharp increase in leaf area up to 90 DAT indicates active canopy development during the vegetative and reproductive stages. The subsequent reduction at harvest is likely associated with leaf senescence and translocation of assimilates towards grain development.

Overall, the heat map demonstrates that V₆S₃ (MR 6 with 30 × 30 cm) was the most favourable treatment for maintaining a larger photosynthetic canopy, while V₁S₁ (Unde ragi with 30 × 10 cm) consistently recorded the lowest leaf area (Fig. 1).

Correlation

The correlation analysis revealed a very strong positive association between grain yield and all the measured growth parameters of finger millet (Fig. 2).

Grain yield showed a very strong positive correlation with plant height ($r = 0.936$), indicating that taller plants generally were associated with higher grain yield. The number of tillers hill⁻¹ recorded a very strong positive correlation ($r = 0.987$) with grain yield, suggesting that increased tillering contributed substantially to yield improvement by providing more productive tillers and earheads.

Similarly, dry matter production showed the highest positive correlation ($r = 0.987$) with grain yield, indicating that greater biomass accumulation was closely associated with higher grain productivity. Leaf area also exhibited a very strong positive correlation ($r = 0.980$) with grain yield, suggesting that greater leaf area enhanced the photosynthetic capacity of plants and consequently supported greater assimilate production and grain formation.

Overall, the correlation results indicate that dry matter production and number of tillers hill⁻¹ were the most closely associated growth attributes with grain yield, followed by leaf area and plant height. These results demonstrate the importance of vigorous vegetative growth, higher tillering ability and greater assimilatory surface in achieving higher grain yield in finger millet.

4. Conclusion

The study reveals that finger millet growth and productivity were significantly influenced by variety, planting geometry and their interaction under the guli method. Among the varieties, MR 6 recorded the highest growth and yield performance, while 30 × 30 cm spacing generally favoured greater growth, biomass production and grain yield. The combination of MR 6 with 30 × 30 cm spacing recorded the highest grain yield, straw yield and harvest index and was comparable with GPU 66 with 30 × 30 cm spacing. Therefore, MR 6 and GPU 66 with 30 × 30 cm spacing under the guli method can be considered promising options for improving finger millet productivity under rainfed conditions.

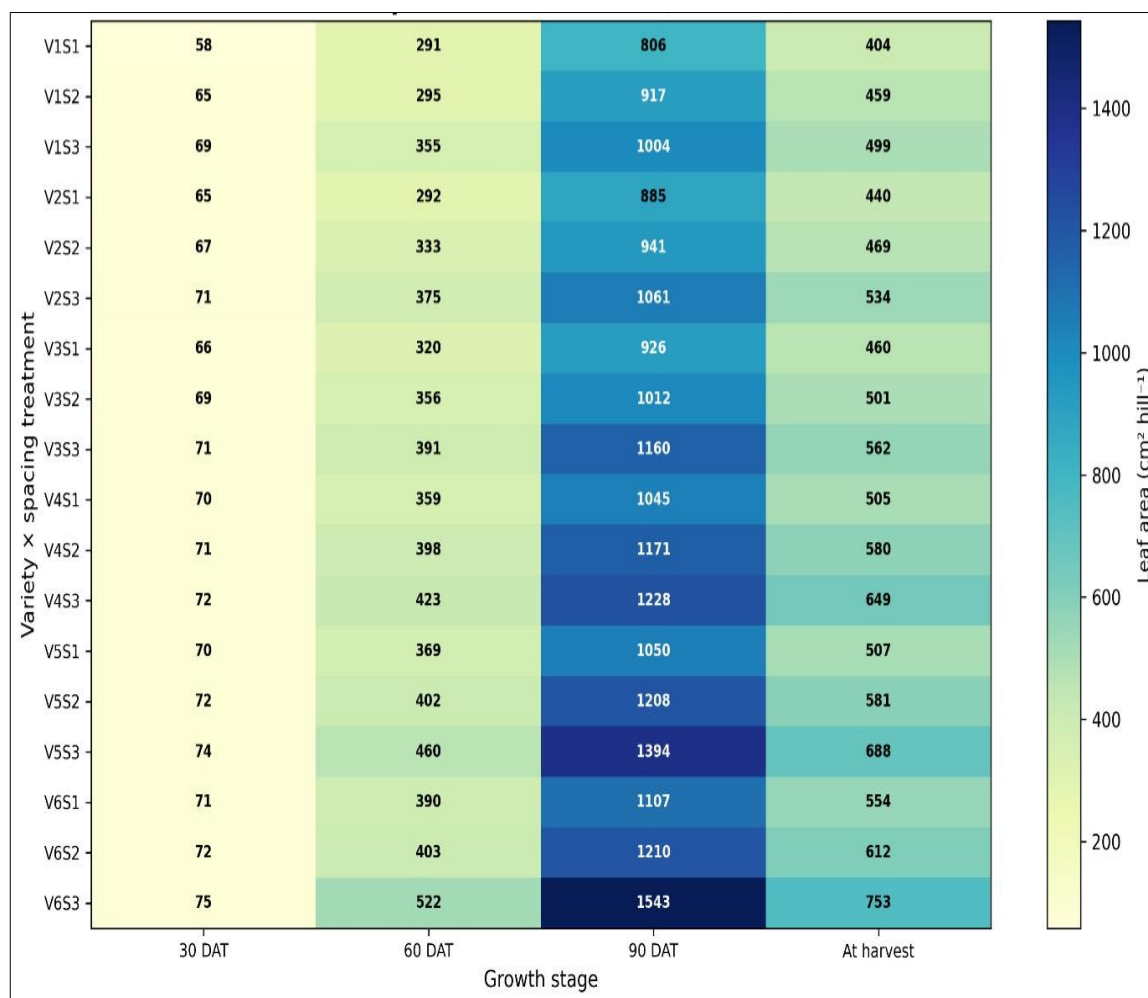


Fig. 1. Leaf area (cm² hill⁻¹) of finger millet varieties as influenced by different planting geometry.

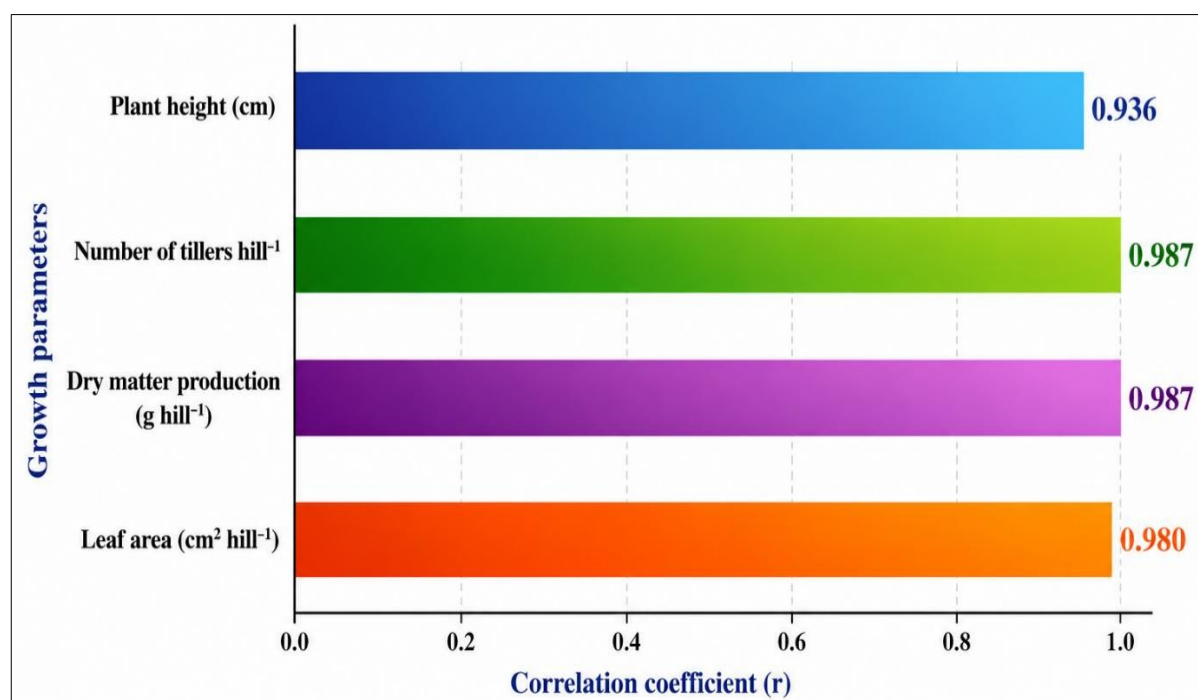


Fig. 2. Correlation of growth parameters with grain yield.

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Authors' contributions

MIK and TSS contributed to the conceptualisation and design of the study, data collection and analysis and preparation of the manuscript. DCH supervised the research work and contributed to manuscript review. NGD, ASP and CC contributed to manuscript preparation and verification of the content. MRA, MS and TJ provided guidance and contributed to manuscript review. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest

Authors do not have any conflict of interests to declare.

Ethical issues

None

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