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SCREENING OF FOXTAIL MILLET (*SETARIA ITALICA* L.) VARIETIES FOR WATER USE EFFICIENCY TRAITS AND YIELD POTENTIAL UNDER RAINFED SITUATION

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ABSTRACT

A field experiment was conducted during the kharif 2015 season to evaluate foxtail millet varieties for water use efficiency (WUE) traits and yield potential under rainfed conditions. The study was conducted in a randomized block design with three replications, involving nine varieties (Krishnadevaraya, Narasimharaya, Prasad, Sri Lakshmi, SiA 3085, SiA 3156, Suryanandi, SiA 3221, and SiA 3223). Significant genotypic differences were observed in growth parameters, including plant height, leaf area, and dry matter production, at various stages. SiA 3156 exhibited the highest plant height, leaf area, and leaf area index at 30 and 60 DAS, while Suryanandi recorded the highest dry matter production across stages. Considerable variation was also noted in WUE-related traits, including relative water content (RWC), specific leaf area (SLA), and SPAD chlorophyll meter readings (SCMR). SiA 3221 showed higher SLA (161.2 cm^2) and SPAD values (49.4), whereas Narasimharaya recorded the highest RWC at 30 and 45 DAS. For yield attributes, Krishnadevaraya produced the maximum tillers per plant (5.44), SiA 3085 recorded the highest test weight (3.20 g), and Suryanandi achieved the highest grain yield (3111 kg ha^{-1}), followed by SiA 3085 (2874 kg ha^{-1}) and Krishnadevaraya (2824 kg ha^{-1}). The lowest grain yield was observed in SiA 3221 (353 kg ha^{-1}). Krishnadevaraya produced the highest straw yield (6395 kg ha^{-1}), while SiA 3156 registered the highest harvest index (64.67%). The results highlight significant variability among foxtail millet varieties, indicating scope for identifying superior genotypes for rainfed cultivation with improved WUE and yield potential.

Keywords: Foxtail millet, Water use efficiency, SPAD, RWC, Yield, Leaf area

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INTRODUCTION

Foxtail millet (*Setaria italica L.*), one of the world's oldest domesticated cereals, is an important small millet cultivated in semi-arid regions for food and fodder. It is valued for its short duration, nutritional quality, and resilience to environmental stress (Zhao *et al.,* 2023). Despite these advantages, yields remain low in rainfed ecosystems due to erratic rainfall and limited availability of drought-adapted varieties. Improving yield stability under moisture-limited conditions requires understanding genotypic differences in growth and physiological traits. Traits such as chlorophyll content, relative water content (RWC), and specific leaf area (SLA) influence photosynthetic efficiency and water-use dynamics (Zhang *et al.,* 2022; Gao *et al.,* 2023). Likewise, dry matter production and harvest index (HI) are important determinants of yield stability under stress (Srivastava *et al.,* 2022).

Identifying varieties with superior combinations of these traits is crucial for breeding drought-tolerant cultivars. This study aimed to evaluate growth, physiological traits, and yield parameters of foxtail millet varieties under rainfed conditions and to identify superior genotypes for cultivation and breeding programs.

MATERIALS AND METHODS

The field experiment was conducted during *Kharif*, 2015 at Regional Agricultural Research Station, Nandyal of Andhra Pradesh. The experiment was laid out in a randomized block design with three replications. The treatments consisted of nine varieties *viz.,* T1: Krishnadevaraya, T2: Narasimharaya, T3: Prasad, T4: Srilakshmi, T5: SiA 3085, T6: SiA 3156, T7: Suryanandi and T8: SiA 3221 and T9: SiA 3223. The individual plots were laid out according to the layout plan. Sowing was taken up as per the treatments.

The seeds were sown by dibbling in furrows at a depth of 3 cm. Thinning was done at 15 DAS retaining one healthy seedling $hill^{-1}$. The recommended dose of 40 and 20 kg ha^{-1} of N and P_2O_5 was applied at the time of sowing through urea and single super phosphate respectively. Thinning and gap filling was done wherever necessary, weeding and hoeing were taken up depending on the intensity of weeds at critical stages of crop weed competition.

At harvest five plants were randomly selected from each treatment for recording growth parameters such as plant height, number of tillers and panicles per plant, panicle length, panicle weight per plant, threshing percent, and test weight. At harvest in each treatment grain and straw yield from plot (4.5 m x 3 m) was recorded and expressed in kg ha^{-1}. Sowing of the crop was done on 23.07.2025 and the crop suffered the moisture stress conditions due to the failure of the monsoons. The moisture percent of the soil data was taken and represented in the Table.6.

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RESULTS AND DISCUSSION

Significant variation was observed among foxtail millet varieties for growth, physiological efficiency, and yield traits under rainfed conditions.

Plant height

Varietal differences in plant height were non-significant at 30 and 45 DAS, while significant differences were observed from 60 DAS onwards (CD = 11.98 cm at 60 DAS, 10.76 cm at 75 DAS, and 5.60 cm at harvest, P=0.05). At 60 DAS, SiA 3223 (127.78 cm) and Srilakshmi (124.22 cm) attained the maximum height, whereas SiA 3221 (96.42 cm) remained the shortest. Similar trends continued at 75 DAS and at harvest, with SiA 3223 recording the tallest plants (133.17 cm), followed by Narashimaraya (128.17 cm) and Srilakshmi (126.13 cm). The lowest plant height at harvest was observed in SiA 3221 (98.13 cm).

Leaf area

Differences in leaf area were significant from 45 DAS onwards (CD = 106.33 cm^2 at 45 DAS, 93.73 cm^2 at 60 DAS, 92.24 cm^2 at 75 DAS, and 65.22 cm^2 at harvest, P=0.05). At 45 DAS, SiA 3221 (570.67 cm^2) and SiA 3223 (561.67 cm^2) recorded the maximum leaf area, whereas SiA 3156 (384.67 cm^2) had the lowest. At 60 DAS, Prasad (468.67 cm^2) and SiA 3223 (452.00 cm^2) recorded higher values, while SiA 3085 (324.67 cm^2) was the lowest. At 75 DAS, Prasad (474.60 cm^2) and Suryanandi (470.33 cm^2) maintained the highest leaf area. At harvest, SiA 3223 (496.60 cm^2) and Prasad (487.65 cm^2) were superior, while Srilakshmi (395.47 cm^2) recorded the lowest.

Dry matter production

Varieties showed significant variation in dry matter accumulation at 75 DAS and harvest (CD = 12.40 g at 75 DAS and 4.95 g at harvest, P=0.05), while differences were non-significant at 30, 45, and 60 DAS. At 60 DAS, Suryanandi (40.50 g) and Prasad (40.17 g) recorded the highest dry matter, while Srilakshmi (23.67 g) was the lowest. At 75 DAS, Suryanandi (42.97 g) and Narashimaraya (42.37 g) were superior, followed by SiA 3156 (40.50 g). At harvest, Suryanandi maintained the highest dry matter accumulation (46.20 g), followed by Narashimaraya (45.14 g) and SiA 3156 (42.33 g), whereas SiA 3223 (27.83 g) recorded the lowest.

Water-use efficiency traits

Significant differences were noted among varieties for specific leaf area (SLA) at 45 DAS (CD = 36.79, P=0.05) and relative water content (RWC) at 30 DAS (CD = 10.35, P=0.05), while differences for SPAD chlorophyll meter readings (SCMR) were non-significant. The highest SCMR values were recorded in Krishnadevaraya (51.21 at 30 DAS) and Narashimaraya (47.59 at 45 DAS). SLA was highest in Narashimaraya (277.63 cm^2 at 30 DAS; 216.60 cm^2 at 45 DAS),

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whereas Suryanandi registered the lowest (178.76 cm² and 140.90 cm², respectively). RWC was maximum in Krishnadevaraya (69.45% at 30 DAS) and Narashimaraya (65.76% at 45 DAS), while Srilakshmi consistently recorded the lowest values (48.29% and 48.74%).

Yield and yield parameters:

Yield and yield parameters showed wide variability (Table 5). The number of tillers per plant ranged from 3.22 (Si A 3221) to 5.44 (Krishnadevaraya and Srilakshmi). Test weight was maximum in Si A 3085 (3.20 g) and lowest in Si A 3223 (1.65 g). Seed yield was significantly higher in Suryanandi (3210 kg/ha), followed by Krishnadevaraya (2948 kg/ha) and Si A 3156 (2946 kg/ha), whereas the lowest was obtained from Si A 3221 (353 kg/ha). Straw yield ranged from 4667 kg/ha (Si A 3156) to 6444 kg/ha (Si A 3223). Harvest index was maximum in Si A 3156 (64.92%) and Suryanandi (59.11%), while the lowest was in Si A 3221 (11.10%).

Soil moisture status

The soil moisture status declined progressively with crop growth (Table 6). During the vegetative stage (01.08.2015), mean soil moisture was 23.13%, which reduced to 18.53% at tillering (23.08.2015). By panicle emergence and flowering (08.09.2015), soil moisture further dropped to 15.13%, indicating that the crop experienced increasing soil moisture stress during later stages.

Discussion

This study revealed substantial genotypic variability in foxtail millet for growth, physiology, and yield under rainfed conditions, underscoring the crop's documented resilience yet sensitivity to seasonal moisture decline. Recent work likewise emphasizes foxtail millet's innate drought tolerance coupled with yield penalties when stress intensifies, reaffirming the need to pair adaptive traits with efficient sink development (Zhao *et al.,* 2023; Gao *et al.,* 2023; Zhang *et al.,* 2022).

Growth and canopy development

Greater plant height and larger canopy (e.g., Si A 3223, Si A 3221) did not translate into higher grain yield, indicating that luxuriant vegetative growth can be counterproductive under water limitation due to increased transpirational demand. Physiological studies in foxtail millet and related C4 cereals similarly caution that drought reduces photosynthetic capacity as canopies expand, unless supported by traits that stabilize water status (Zhao *et al.,* 2023; Gao et al., 2023).

Biomass accumulation and partitioning

Yield differences aligned with sustained dry-matter accumulation and superior harvest index (HI) in top performers (Suryanandi, Si A 3156, Krishnadevaraya). Comparative evidence across millets

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highlights the centrality of biomass partitioning—rather than pure vegetative growth—for maintaining yield under drought (Srivastava *et al.,* 2022; Grégoire *et al.,* 2024).

Water-use physiology: SCMR, SLA, and RWC

Higher SPAD/SCMR and leaf water status (RWC) were associated with better yield potential in our dataset, while lower specific leaf area (SLA)—a proxy for thicker leaves—coincided with superior performance (e.g., Suryanandi, Krishnadevaraya). Multi-environment and omics studies in foxtail millet report similar patterns: drought commonly depresses chlorophyll and RWC, and genotypes maintaining higher levels sustain photosynthesis and grain filling (Gao *et al.,* 2023; Zhang *et al.,* 2022). Correlation between chlorophyll metrics and yield under both well-watered and stressed conditions has been shown in foxtail millet breeding contexts (Zhang *et al.,* 2022; Zhao *et al.,* 2023).

Stress timing and reproductive resilience

The progressive field moisture decline observed here mirrors projections that intensifying intra-seasonal drought will increasingly intersect with reproductive stages, a period of maximum yield sensitivity (Zhou *et al.,* 2024; Zhang *et al.,* 2022). Genotypes that preserved RWC and chlorophyll during this window retained gas-exchange and ultimately yield, a response consistent with recent foxtail millet stress-physiology reports (Chang *et al.,* 2024; Gao *et al.,* 2023).

Implications for selection

Collectively, our findings and current literature point to a pragmatic selection index for rainfed environments that prioritizes: (i) moderate plant stature with controlled canopy expansion, (ii) high SCMR/leaf chlorophyll, (iii) lower SLA, (iv) consistently higher RWC during critical stages, and (v) high HI. Such a trait bundle aligns with broader millet research targeting transpiration efficiency and drought-robust yield (Srivastava *et al.,* 2022; Grégoire *et al.,* 2024).

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Table 1: Plant height of different foxtail millet varieties under rainfed conditions.

Foxtail millet varieties	Plant Height (cm)				
	30 DAS	45 DAS	60 DAS	75 DAS	Harvest
Krishnadevaraya	72.87	105.22	119.78	120.00	124.93
Narashimaraya	72.87	111.11	121.00	127.33	128.17
Prasad	72.63	106.00	110.00	110.00	123.57
Srilakshmi	70.67	104.00	124.22	124.00	126.13
Si A 3085	71.17	102.44	112.78	115.64	117.07
Si A 3156	73.77	102.56	106.33	110.33	111.37
Suryanandi	67.10	100.67	104.78	109.53	110.83
Si A 3221	76.10	93.89	96.42	98.00	98.13
Si A 3223	74.53	108.00	127.78	132.54	133.17
S.E(m)±	***1.66***	***4.04***	***3.96***	***3.55***	***1.853***
C.D (P=0.05)	***NS***	***NS***	***11.98***	***10.76***	***5.602***
CV (%)	***3.99***	***6.71***	***5.96***	***5.2***	***2.691***

Table 2: Leaf area (cm^2 $plant^{-1}$) of different foxtail millet varieties under rainfed conditions

Foxtail millet varieties	Leaf area (cm^2 $plant^{-1)}$				
	30 DAS	45 DAS	60 DAS	75 DAS	Harvest
Krishnadevaraya	455.33	398.00	391.33	408.93	445.70
Narashimaraya	480.00	440.67	413.67	423.33	435.92
Prasad	389.00	472.00	468.67	474.60	487.65
Srilakshmi	396.33	435.33	334.67	376.37	395.47
Si A 3085	381.00	426.33	324.67	389.56	416.06
Si A 3156	402.00	384.67	348.33	377.33	419.25
Suryanandi	432.33	401.67	426.33	470.33	442.28
Si A 3221	487.00	570.67	433.00	456.00	486.62
Si A 3223	443.00	561.67	452.00	484.30	496.60
S.E(m)±	***29.42***	***35.16***	***30.99***	***30.5***	***21.568***
C.D (P=0.05)	***NS***	***106.33***	***93.73***	***92.24***	***65.216***
CV (%)	***11.86***	***1.9***	***13.75***	***13.43***	***8.352***

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Table 3: Dry matter production (g plant^{-1}) of different foxtail millet varieties under rainfed condition

Foxtail millet varieties	Dry matter production (g)				
	30 DAS	45DAS	60 DAS	75 DAS	Harvest
Krishnadevaraya	17.50	25.33	35.00	35.43	37.52
Narashimaraya	23.00	30.17	39.00	42.37	45.14
Prasad	19.50	28.50	40.17	33.33	36.31
Srilakshmi	25.33	33.33	23.67	25.37	27.80
Si A 3085	14.63	24.00	24.83	28.13	29.33
Si A 3156	17.17	30.33	27.33	40.50	42.33
Suryanandi	20.83	34.83	40.50	42.97	46.20
Si A 3221	20.33	34.00	30.17	31.20	32.23
Si A 3223	20.00	27.00	22.67	26.03	27.83
S.E(m)±	***2.37***	***4.64***	***5.73***	***4.1***	***1.63***
C.D (P=0.05)	***NS***	***NS***	***NS***	***12.4***	***4.95***
CV (%)	***20.74***	***27.06***	***35.97***	***22.21***	***7.86***

Table 4: Water use efficiency traits of foxtail millet varieties under rainfed conditions

Foxtail millet Varieties	SCMR		Specific leaf area		Relative water content	
	30	45	30	45	30	45
Krishnadevaraya	51.21	43.39	205.03	193.47	69.45	68.03
Narashimaraya	48.94	47.59	277.63	216.60	65.83	65.76
Prasad	45.20	40.26	183.46	190.77	58.77	57.01
Srilakshmi	51.00	46.83	206.22	201.48	48.29	48.74
SiA 3085	48.27	45.61	195.68	152.88	63.99	63.45
SiA 3156	49.25	40.12	183.68	162.13	65.88	58.37
Suryanandi	48.14	38.39	178.76	140.90	60.97	60.85
SiA3221	48.47	47.82	166.85	156.05	63.92	56.74
SiA3223	49.73	41.39	206.54	192.55	66.83	62.78
S.E(m)±	***1.74***	***2.37***	***23.11***	***12.16***	***3.42***	***4.12***
C.D (P=0.05)	***NS***	***NS***	***NS***	***36.79***	***10.35***	***NS***
CV (%)	***6.16***	***9.44***	***19.97***	***11.8***	***9.4***	***11.87***

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Table 5: Yield and yield parameters of different foxtail millet varieties under rainfed conditions.

Foxtail millet varieties	No. of tillers per plant	Test weight(g)	Seed yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)
Krishnadevaraya	5.44	2.64	2948	6395	46.67
Narashimaraya	5.22	2.45	2346	6148	38.28
Prasad	3.78	1.96	2516	5136	49.84
Srilakshmi	5.44	2.32	2610	6198	41.92
Si A 3085	5.00	3.20	2874	5506	52.38
Si A 3156	4.11	2.95	2946	4667	64.92
Suryanandi	4.33	2.32	3210	5432	59.11
Si A 3221	3.22	1.94	353	3185	11.10
Si A 3223	3.67	1.65	1694	6444	26.15
S.E(m)±	***0.47***	***0.08***	***173.73***	***280.80***	***4.312***
C.D (P=0.05)	***1.44***	***0.24***	***525.31***	***849.09***	***13.04***
CV (%)	***18.5***	***5.81***	***12.60***	***8.913***	***17.221***

Table 6: Soil Moisture percent at different growth stages of foxtail millet crop during kharif 2015

Date	Growth stage	Moisture percent			Mean
		RI	RII	RIII	
01.08.2015	Vegetative stage	24.2	18.4	26.8	23.13
23.08.2015	Tillering stage	18.6	17.5	19.5	18.53
08.09.2015	Panicle emergence and flowing stage	13.9	14.7	16.8	15.13

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Krishnadevaraya	Srilakshmi
	
SiA 3221	**Suryanandi**
	

Complete rolling of leaves (needle leaves) is seen in the Krishanadevaraya and Srilakshmi due to moisture stress conditions

SiA 3221 and Suryanandi varieties has performed well without showing any symptoms of leaf rolling

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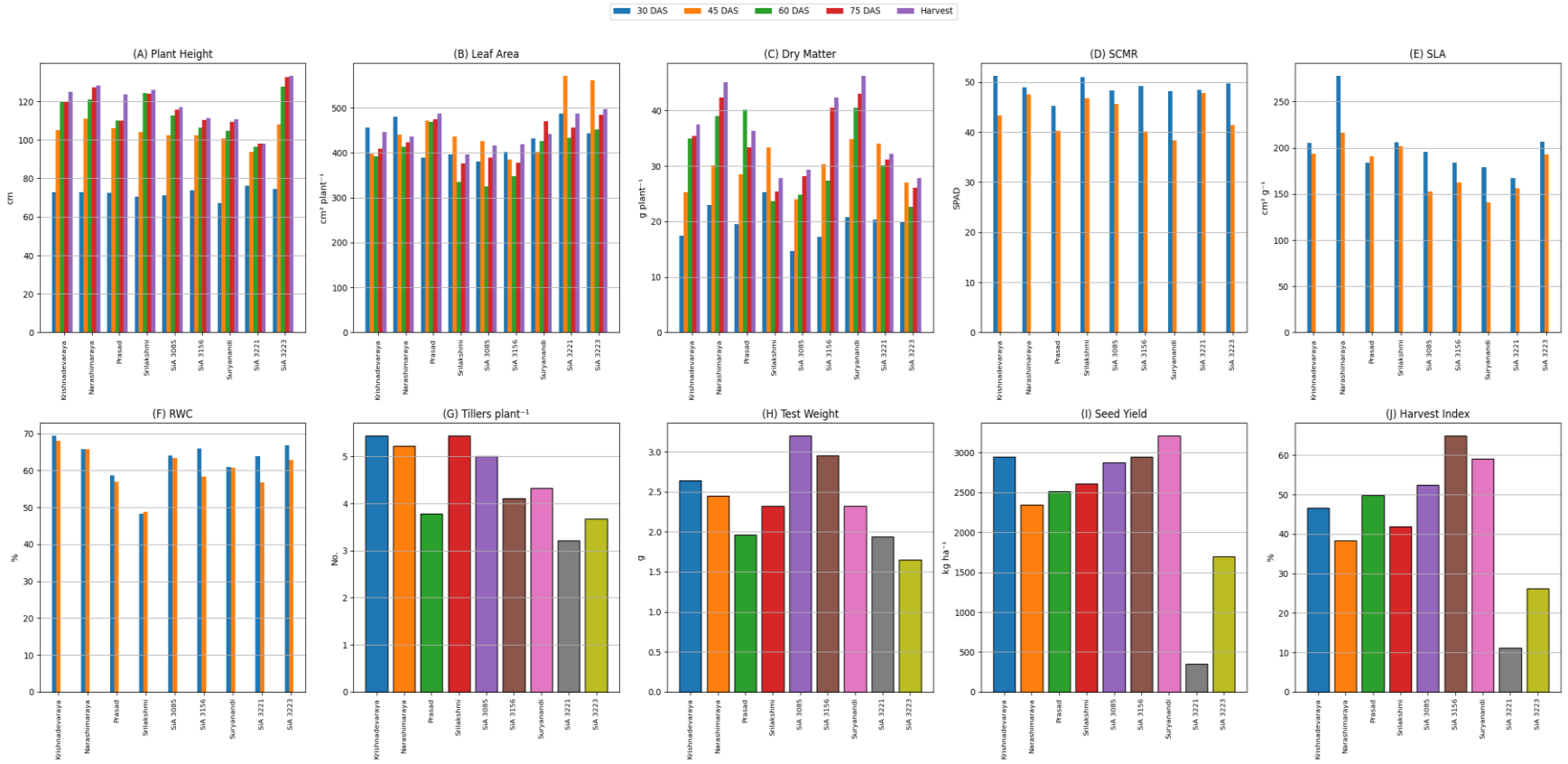

Figure 1: Growth, physiological, water-use efficiency and yield traits of foxtail millet varieties under rainfed conditions. (A) Plant height, (B) Leaf area, (C) Dry matter production, (D) SPAD chlorophyll meter reading (SCMR), (E) Specific leaf area (SLA), (F) Relative water content (RWC), (G) Number of tillers plant^{-1}, (H) Test weight, (I) Seed yield, and (J) Harvest index. Values represent means of three replications; error bars indicate SEM. Differences among varieties were significant at $P = 0.05$.