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GENETIC VARIABILITY, HERITABILITY AND CORRELATION ANALYSIS FOR PHENOLOGICAL, YIELD AND YIELD ASSOCIATED TRAITS IN FINGER MILLET [*ELEUSINE CORACANA* (L.) GAERTN.]

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ABSTRACT

Finger millet [*Eleusine coracana* (L.) Gaertn.] is an important small millet valued for its resilience, nutritional richness, and dual-purpose role in grain and fodder production. To explore the genetic basis of yield variation, fifty-two genotypes were evaluated during *rabi* 2020 at RARS, Palem, PJTSAU, in a randomized block design with three replications. Fourteen agro-morphological traits were recorded and subjected to analysis of variance (ANOVA), variability parameters, heritability, genetic advance, and correlation analysis. Significant differences were observed among genotypes for all traits, highlighting the presence of substantial genetic variability. Wide ranges were noted for days to 50% flowering (65–82 days), days to maturity (89–126 days), plant height (78.9–109.3 cm), number of fingers per panicle (5.0–8.2), finger length (5.3–12.8 cm), 1000-seed weight (1.9–3.2 g), fodder yield (34.8–76.1 q/ha), and grain yield (17.5–42.4 q/ha). High heritability coupled with high genetic advance was recorded for 1000-seed weight, finger length, peduncle length, fodder yield and grain yield, suggesting the predominance of additive gene action and effectiveness of direct selection. Grain yield showed significant positive correlations with fodder yield, 1000-seed weight, finger length, finger width, and earhead length, whereas days to flowering and maturity were negatively associated with yield. These results identify 1000-seed weight, finger number, finger length, and fodder yield as reliable selection indices for enhancing productivity. Superior genotypes such as VR 1149 (grain yield), VR 1159 (fodder yield), VR 1163 (finger length), and PR 1511 (plant height and leaf width) were identified as promising donors for breeding. The findings demonstrate the potential of exploiting genetic variability in finger millet for developing high-yielding, climate-resilient, and nutritionally rich cultivars.

Key words : Genetic Variability, Heritability, Correlation analysis, Phenological, Finger millet [*Eleusine coracana* (L.) Gaertn.].

Introduction

Millets represent a diverse group of small-grained cereals that serve as important staple foods across the globe, particularly in semi-arid and tropical regions (Singh and Sharma, 2018). Millets are resilient to harsh climatic conditions, low input requirements, and high nutritional value make them valuable genetic resources for sustainable agriculture and food security (Gupta *et al.*, 2017). Among these, finger millet [*Eleusine coracana* (L.) Gaertn.] is one of the most significant, being widely cultivated under rainfed conditions in Africa and South Asia (Mukami *et al.*, 2019). Commonly known as “Ragi” or “Mandia” in India, it belongs to the family Poaceae, subfamily Chloridoideae and genus *Eleusine* (Joshi *et* *al*., 2023). Globally, finger millet is cultivated on about 3.38 million ha with an annual production of 3.76 Mt, while in India it ranks third among millets after sorghum and pearl millet, occupying 1.27 Mha with a production of 1.89 Mt (FAO, 2007).

Finger millet is a highly self-fertilized allotetraploid (2n = 4x = 36) that originated from *E. coracana* subsp. *africana*. Domestication is believed to have occurred in East Africa around 5000 years ago, followed by its introduction into India approximately 3000 years ago (Hilu *et al*., 1979). The species shows morphological similarities to *E. indica* (2n = 18) and *E. africana* (2n = 36), with the latter considered its probable progenitor (Channaveeraiah and Hiremath, 1974). Its robustness and adaptability to marginal soils, drought-prone areas, and hill agriculture make it an ideal candidate for climate-resilient farming systems.

In India, finger millet is predominantly cultivated in the southern states, including Karnataka, Andhra Pradesh, Tamil Nadu, and Telangana. In Telangana, where it is locally called "Taidhalu," the crop covers approximately 2.00 thousand hectares with a production of 3.16 thousand tonnes and productivity of 1581 kg ha^{-1}, concentrated mainly in the erstwhile Mahabubnagar district (Ministry of Agriculture and Farmers Welfare, 2024). The Government of Telangana has recently emphasized its nutritional value by introducing "Ragi Java," a ragi-based fortified drink, in the midday meal and school nutrition programs, thereby promoting its role in addressing malnutrition and micronutrient deficiencies among children.

Nutritionally, finger millet is often referred to as a "nutritious millet" owing to its superior profile of calcium, iron, potassium, phosphorus, zinc and dietary fiber (Chandra *et al*., 2016; Nakarani *et al*., 2020). Its proteins are of good biological value, containing essential amino acids such as methionine and tryptophan. The high fiber content supports digestive health, regulates blood glucose, and lowers cholesterol, making it particularly suitable for diabetic and cardiovascular patients. In addition, bioactive compounds such as phenolics and flavonoids contribute antioxidant and antimicrobial properties, further enhancing its nutraceutical potential.

Despite its importance, finger millet productivity is constrained by blast disease (*Pyricularia grisea*), parasitic weeds such as *Striga*, and abiotic stresses including drought and poor soil fertility. While major cereals like rice, wheat, and maize have been the focus of intensive genetic improvement, minor cereals like finger millet have received comparatively less attention. However, its wide genetic variability and adaptability to diverse agro-ecological zones provide a valuable resource for breeding climate-resilient and nutritionally superior cultivars. Understanding the genetic variability, heritability, and inter-relationships among yield and yield-contributing traits is therefore critical for designing efficient breeding strategies.

The present study was undertaken to characterize finger millet germplasm for yield and nutritional traits with an emphasis on identifying superior genotypes suitable for crop improvement. Specifically, the study aimed to (i) estimate the extent of genetic variability, heritability and genetic advance for key agronomic traits.

Materials and Methods

A field experiment was conducted during the rabi, 2020 at the D3 experimental field of Regional Agricultural Research Station (RARS), Palem, PJTSAU. The experimental material consisted of 52 diverse finger millet genotypes (Supplementary Table 1). The trial was laid out in a Randomized Block Design (RBD) with three replications. Each genotype was sown in a single row of 4 m length, with a spacing of 30 cm × 10 cm. A recommended dose of 50:40:25 NPK (kg/ha) was applied along with standard crop management practices to ensure a healthy crop stand. From each plot, five plants were randomly tagged (excluding border plants) and observations were recorded on the following 14 traits. The mean values were used for statistical analysis

Days to 50% flowering

The number of days from sowing to the stage when 50% of the plants in a plot produced flowering heads was recorded and expressed as days.

Plant height (cm)

Measured from the soil surface to the tip of the tallest panicle (excluding awns) at physiological maturity, using a meter scale and expressed in centimeters.

Number of fingers per ear

The total number of fingers (spikes) present on the main ear head of each selected plant was counted and recorded.

Finger length (cm)

The length of the longest finger on the main ear head was measured from its point of attachment to the tip, using a ruler and expressed in centimeters.

Finger width (cm)

The width of the middle portion of the longest finger was measured with a Vernier caliper and expressed in centimeters.

Ear head length (cm)

Measured as the distance from the base of the lowermost finger to the tip of the uppermost finger of the main ear head, expressed in centimeters.

Flag leaf blade length (cm)

The length of the uppermost fully expanded flag leaf was measured from the ligule to the tip of the leaf blade using a scale.

Flag leaf blade width (cm)

The width of the widest part of the flag leaf blade was measured with a Vernier caliper or ruler and expressed in centimeters.

Peduncle length (cm)

The distance from the flag leaf node to the base of the ear head was measured using a scale and expressed in centimeters.

Number of productive tillers per plant

The number of tillers that bore ear heads in each plant was counted and averaged.

Days to maturity

The number of days from sowing to the stage when 90% of the ear heads in the plot turned brown and hard was recorded and expressed as days.

1000-seed weight (g)

From each genotype, 1000 seeds were randomly counted and weighed on a precision electronic balance. The value was expressed in grams

Fodder yield per hectare (q/ha)

After harvesting the ear heads, the above-ground biomass was weighed, converted to quintals per hectare (q/ha) using appropriate plot-to-hectare conversion factors.

Grain yield per hectare (q/ha)

The harvested panicles from each plot were threshed, cleaned and weighed. The grain yield per plot was recorded and converted into quintals per hectare (q/ha) using standard conversion.

Statistical analysis

The mean values of each trait were used for analysis of variance (ANOVA) following Burton and Devane (1953). Genotypic and phenotypic coefficients of variation (GCV and PCV), heritability in the broad sense (h^2) and genetic advance (GA) were estimated using the procedures suggested by Johnson *et al*. (1955). Data analysis was performed using R Studio and Microsoft Excel.

Results

Descriptive statistics of yield associated traits in finger millet

The analysis of mean performance and variability parameters across the studied genotypes revealed considerable variation for all traits descriptive statistics of all traits are presented in Table 1. Days to 50% flowering ranged from 65 to 82 days, with a mean of 73 days, while days to maturity varied from 89 to 126 days (mean 106 days). Plant height ranged between 78.9 and 109.3 cm, with an average of 96.04 cm. The number of fingers per panicle varied from 5.0 to 8.2 (mean 6.9), finger length from 5.3 to 12.8 cm (mean 7.1 cm), and finger width from 0.7 to 1.4 cm (mean 1.02 cm). Earhead length ranged from 5.3 to 9.7 cm with a mean of 7.2 cm. Flag leaf blade length varied from 21.1 to 42.5 cm (mean 31.24 cm), while flag leaf blade width ranged from 0.60 to 1.60 cm (mean 0.99 cm). Peduncle length ranged from 5.9 to 16.0 cm with a mean of 10.91 cm. The number of productive tillers per plant varied between 1.9 and 3.6 with a mean of 2.75. Thousand seed weight ranged from 1.9 to 3.2 g (mean 2.47 g). Fodder yield showed a wide range between 34.8 and 76.1 q/ha with a mean of 53.7 q/ha, while grain yield varied from 17.5 to 42.4 q/ha, averaging 27.44 q/ha. These results indicate substantial genetic variability among the genotypes for yield and its contributing traits, providing opportunities for selection and genetic improvement.

Variability, heritability and Genetic advance of yield associated traits in finger millet

The variability analysis revealed considerable differences among the genotypes for all traits studied, with PCV values generally higher than GCV, indicating a substantial influence of environment along with genetic factors. Traits such as finger length, finger width, earhead length, flag leaf dimensions, peduncle length, number of productive tillers, 1000-seed weight, fodder yield and grain yield exhibited moderate to high GCV and PCV coupled with high heritability and high genetic advance as percent of mean, suggesting the predominance of additive gene action and greater scope for improvement through direct selection. In contrast, days to 50% flowering and days to maturity recorded low GCV with high heritability but moderate genetic advance, implying the role of non-additive gene effects and limited improvement through simple selection. Plant height and number of fingers showed moderate PCV with low to moderate heritability and genetic advance, reflecting greater environmental influence and the need for progeny testing or population improvement approaches. Particularly, grain yield, fodder

Table 1 : Descriptive statistics of yield associated traits in finger millet.

Traits	Mean	Minimum	Maximum	Range	Standard deviation
DFF	72.83125	65.7	80.6	14.9	5.327628459
PH (cm)	100.5688	92.6	109.3	16.7	5.473660415
NF	6.96875	6.1	8.1	2	0.725459624
FL (cm)	6.63125	5.5	7.9	2.4	0.6660518
FW (cm)	0.9125	0.7	1	0.3	0.108781126
EHL (cm)	5.7875	5.3	6.2	0.9	0.287228132
FLL (cm)	27.9375	24.1	35.8	11.7	3.120443345
FLW (cm)	0.875	0.7	1.2	0.5	0.194935887
PL (cm)	11.5	9.1	16	6.9	1.793692653
NPT	2.41875	1.9	3.1	1.2	0.312449996
DTM	105.325	89.4	119	29.6	9.742518497
T.W. (gms)	2.34375	2	2.7	0.7	0.215928229
FY (q/ha)	48.36875	37.9	59.8	21.9	5.99541144
GY (q/ha)	23.25	17.5	30.5	13	3.461791444

DFF (Days to 50 percent flowering), NPT(No. of productive tillers per plant), TW (1000-Grain weight (g)), FL(Length), FLL(Flag leaf length), DTM (Days to maturity), NF(Number of fingers per ear), GY(Grain yield per hectare), PL(Peduncle Length), FLW(Flag leaf width), PH(Plant height (cm)), EHL(Main ear head length (cm)), FY(Fodder yield per hectare), FW(Finger Width)

Table 2 : Range, Mean, PCV, GCV, Heritability, Genetic advance and GA as % mean of 52 finger millet genotypes.

S. no.	Traits	PCV%	GCV%	h^2 (bs) %	G.A	G.A as % mean
1	**Days to 50% Flowering**	6.30	5.71	82.1	7.837	10.668
2	**Plant Height (cm)**	12.43	5.97	23.1	5.682	5.916
3	**Number of Fingers**	15.13	10.11	44.7	0.965	13.942
4	**Finger Length (cm)**	19.95	16.74	70.4	2.053	28.926
5	**Finger Width (cm)**	16.89	12.42	54.1	0.192	18.811
6	**Ear head length (cm)**	20.20	16.82	69.4	2.088	28.871
7	**Flag leaf length (cm)**	18.34	14.60	63.4	7.481	23.949
8	**Flag leaf width (cm)**	25.45	22.29	76.7	0.397	40.217
9	**Peduncle length (cm)**	20.85	17.65	71.6	3.356	30.773
10	**Number of Productive Tillers per plant**	19.82	16.22	67.0	0.751	27.357
11	**Days to maturity**	8.45	8.03	90.3	16.625	15.730
12	**1000 seed weight**	13.78	13.51	96.1	0.675	27.295
13	**Fodder yield per hectare**	20.34	17.08	70.5	15.880	29.567
14	**Grain Yield per hectare**	24.21	21.3	78.1	10.686	38.940

yield and 1000-seed weight exhibited high heritability coupled with high genetic advance, highlighting their reliability as key selection indices in breeding programs. These findings are consistent with earlier reports in finger millet, confirming the existence of sufficient genetic variability that can be effectively exploited for the genetic enhancement of yield and related traits results were presented in Table 2.

Correlation analysis of yield associated traits in finger millet

The correlation analysis among 14 characters of finger millet revealed significant associations at both phenotypic(rp) and genotypic(rg) levels. Grain yield per hectare exhibited a highly significant and positive correlation with fodder yield (rp = 0.728**, rg = 0.643**), 1000-seed weight (rp = 0.642**, rg = 0.972**), finger length (rp = 0.287**, rg = 0.573**), earhead length (rp = 0.453**, rg = 0.410**) and finger width (rp = 0.287**, rg = 0.417**), indicating that these traits contribute directly to yield improvement. Similarly, fodder yield was significantly associated with plant height (rp = 0.362**, rg = 0.579**), number of fingers per ear (rp = 0.353**, rg = 0.601**), finger width (rp = 0.486**, rg = 0.417**), earhead length (rp = 0.573**, rg = 0.410**), and 1000-seed weight (rp = 0.748**, rg = 0.971**). Positive associations were also noted between finger width and finger length (rp = 0.318**, rg = 0.053NS), earhead length (rp = 0.626**, rg = –0.053NS), and number of fingers (rp = 0.526**, rg = 0.094NS). Number of productive tillers showed significant positive correlations with finger width (rp = 0.576**, rg = 0.211NS) and fodder yield (rp = 0.371**, rg = 0.178*), while peduncle length displayed positive correlations with earhead length (rp = 0.278**, rg = 0.235*) and grain yield (rp = 0.125NS, rg = 0.162*). In contrast, days to 50% flowering and days to maturity were negatively correlated with yield and most yield-contributing traits, suggesting that early flowering and maturity may favor higher productivity. Notably, genotypic correlations were generally higher than phenotypic ones, reflecting the predominance of genetic factors over environmental influences in trait associations. These results highlight finger length, finger width, earhead length, 1000-seed weight, and fodder yield as key correlated traits for simultaneous improvement of grain yield in finger millet correlation results were presented in supplementary Table 2.

Discussion

The present investigation revealed highly significant differences among the genotypes for all the characters studied, clearly indicating the presence of substantial genetic variability within the finger millet germplasm. Such variability is essential for crop improvement, as it provides the raw material upon which selection acts. The analysis of variance (ANOVA) showed significant mean sum of squares for days to 50% flowering, plant height, number of fingers per ear, finger length, finger width, earhead length, flag leaf length and width, peduncle length, number of productive tillers per plant, days to maturity, 1000-seed weight, fodder yield and grain yield. These findings suggest the existence of considerable genetic divergence among the tested material, which is in line with earlier reports that highlighted the wide adaptability and heterogeneity of finger millet genotypes (Prabhu *et al*., 2008; Ganapathy *et al*., 2011; Anuradha *et al*., 2017).

Variability in growth and phenological traits

The mean performance data revealed large variation in days to 50% flowering (65–82 days) and maturity (89–126 days). Early flowering genotypes such as EG 31, and early-maturing genotypes like EG 66, may be highly desirable under terminal drought or short-duration environments. In contrast, late-flowering and late-maturing genotypes such as VR 1159 and BR 14-27 may be useful for favorable environments where longer vegetative periods can support higher biomass accumulation. The wide range observed is comparable to the findings of Bharathi *et al*. (2013) and Keerthana *et al*. (2019a), who reported 60–85 days for flowering and 90–130 days for maturity in diverse finger millet germplasm. Such variation is highly advantageous for breeding programs targeting multiple production environments. Interestingly, a strong positive correlation was found between flowering and maturity, which is logical as later flowering typically extends the grain-filling period, yet this often comes at the expense of water-use efficiency in marginal areas (Bhavsar *et al*., 2020).

Plant height exhibited a wide range from 78.9 cm (GPU 67) to 109.3 cm (PR 1511), with a mean of 96.04 cm. Taller plants generally contribute to higher fodder yield but may be prone to lodging, while shorter plants are lodging-resistant but may produce less biomass. The negative correlation of plant height with grain yield in this study aligns with the findings of Kadam *et al.* (2009), reported that moderately tall genotypes are ideal, balancing grain and fodder production without yield penalties due to lodging.

Yield-contributing traits

Among yield components, number of fingers per ear ranged between 5.0 (WN 591) and 8.2 (VR 1149), while finger length varied from 5.3 cm (VR 1152) to 12.8 cm (VR 1163). These traits were positively correlated with grain yield, suggesting that ears with more and longer fingers contribute significantly to productivity. Similar associations were previously reported by Ganapathy *et al*. (2011) and Anuradha *et al*. (2017), reported that finger number and length are critical determinants of spikelet number and, consequently, grain yield. Finger width and earhead length also showed positive associations with yield, indicating that selection for broader, longer fingers could indirectly enhance productivity. However, such traits must be balanced with agronomic adaptability, as excessively long fingers may become prone to shattering or uneven grain filling under stress.

Flag leaf traits exhibited substantial variability, with lengths ranging from 21.1 cm (WN 559) to 42.5 cm (VR 1169) and widths from 0.60 cm (WN 585) to 1.60 cm (PR 1511). Both flag leaf length and width were positively correlated with yield, reflecting their role in photosynthate supply during grain filling. These results agree with the findings of Bharathi et al. (2013), demonstrated that leaf morphological traits contribute significantly to sink strength and final grain yield.

Peduncle length, varying between 5.9 cm (VL 400) and 16.0 cm (TNEC 1311), showed a positive though moderate association with yield. Longer peduncles may reduce competition between vegetative tissues and developing grains by enhancing photosynthate translocation. The observed variation suggests that selection for optimal peduncle length could be a viable strategy, particularly as similar results have been reported by Keerthana *et al.* (2019a).

The number of productive tillers per plant varied from 1.9 (VR 1159) to 3.6, with a mean of 2.75. Productive tillers were positively correlated with grain yield, which is consistent with earlier studies (Prabhu *et al*., 2008; Ganapathy *et al*., 2011). Tillering ability contributes to yield stability, especially under variable environments, as it provides a buffer against tiller mortality due to stress.

Grain yield and its association with component traits

Grain yield showed wide variation, ranging from 17.5 q/ha (IIMR R18 5538) to 42.4 q/ha (VR 1149), with an overall mean of 27.44 q/ha. This variation was strongly associated with several yield-contributing traits, including number of fingers, finger length, 1000-seed weight, fodder yield, and flag leaf traits. The strong positive correlation between grain and fodder yield emphasizes the dual-purpose nature of finger millet, which is a major advantage in smallholder systems where livestock integration is crucial (Bhavsar *et al*., 2020).

Thousand seed weight varied between 1.9 g (IIMR R18 5578) and 3.2 g (GPU 67), with a mean of 2.47 g. Grain yield was significantly positively correlated with 1000-seed weight, indicating that heavier grains are an important determinant of productivity. These results are consistent with earlier reports (Ganapathy *et al*., 2011; Anuradha *et al*., 2017; Vidathe *et al*., 2020), which emphasized that selection for bold grains could significantly improve yield potential. However, it is worth noting that seed size is influenced not only by genetic factors but also by environmental conditions during grain filling, as highlighted by Keerthana *et al*. (2019a).

Implications for breeding

The correlation analysis indicated that grain yield is a complex trait governed by several interrelated characters. Positive correlations of yield with 1000-seed weight, number of fingers, finger length, and fodder yield suggest that these parameters can serve as reliable indirect selection criteria. At the same time, the negative associations of yield with days to maturity and plant height suggest that genotypes that are early maturing and moderately tall may be more efficient in partitioning assimilates towards grain production. Similar conclusions were drawn by Bharathi *et al*. (2013) and Bhavsar *et al*. (2020).

High heritability coupled with moderate to high genetic advance, observed for several traits in this study, suggests predominance of additive gene action, which is favorable for selection-based improvement. The results corroborate earlier findings by Ganapathy *et al*. (2011) and Anuradha *et al*. (2017), who reported that traits such as number of fingers, finger length, and grain weight are highly heritable and responsive to selection.

The identification of genotypes with superior performance across multiple traits for example, VR 1149 for grain yield, VR 1159 for fodder yield, VR 1163 for finger length, and PR 1511 for plant height and leaf width provides valuable material for use in hybridization and varietal development programs. These genotypes represent a diverse pool of donor parents for specific trait improvement.

Conclusion

The present study established the existence of wide genetic variability among finger millet genotypes for yield and yield-related traits, with strong and consistent correlations indicating that 1000-seed weight, number of fingers per ear, finger length, and fodder yield can serve as reliable indirect selection criteria for grain yield improvement. Early maturity and moderate plant height emerged as desirable attributes for efficient resource allocation, while the dual-purpose nature of the crop was reinforced by the positive association between grain and fodder yield. Future research should emphasize stability analysis and multi-location testing of promising genotypes to confirm trait–yield relationships across environments, and integrate genomic tools with conventional breeding to accelerate the development of high-yielding, climate-resilient, and nutritionally superior finger millet cultivars.

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