Genetic Variability Studies for Morpho-Physiological and Yield Attributing Traits in Foxtail Millet (*Setaria italica* L. Beauv.)

Abstract - Foxtail millet is an underutilized crop which has high nutritional values and wide genetic resources, possessing the ability to tolerate several abiotic stresses efficiently. Those resources must be used in order to improve desired traits, primarily yield attributes. This investigation was carried out to assess the genetic parameters, such as variability, *per se* performance, heritability and genetic advance as percent over mean for sixteen morpho-physiological, yield attributing traits in fifty foxtail millet germplasm accessions at the Regional Agricultural Research Station, Nandyal during *Rabi*, 2023-2024. The study revealed the wide range of variation for all studied traits and that the accessions SiA 3290, SiA 4345, and SiA 4391 had potential for most traits and a high grain yield per plant. Thus, after multilocation testing, these accessions might be exploited for commercial cultivation. The assessment revealed that the phenotypic coefficient of variation (PCV) was slightly greater than the corresponding genotypic coefficient of variation (GCV), indicating the influence of the environment on the manifestation of these traits. It was also observed that the traits *viz..,* photosynthetic rate, transpiration rate, stomatal conductance, abortive grain rate, and grain yield per plant had high PCV and GCV and these traits significantly contributed to the overall variability and scope for selection. High heritability in combination with high genetic advance as percent of mean (GAM) was observed for photosynthetic rate, transpiration rate, stomatal conductance, 1000 grain weight, fodder yield per plant and grain yield per plant. This indicates that, these traits are mostly governed by additive genes and thus making them suitable for simple direct selection to improve these traits and further breeding efforts focused on increasing yields.

Keywords: Foxtail millet, PCV, GCV, heritability, morpho-physiological traits and grain yield.

INTRODUCTION

Foxtail millet (*Setaria italica* L. Beauv.) cultivate around the world and also referred as Chinese millet, German millet, Italian millet and Hay millet. It is a C_4 crop with short life cycle and a relatively small genome (~515 Mb), belongs to the family Poaceae. The crop is extremely autogamous, with a 4% cross-pollination rate, and has a diploid (2n = 2x = 18) chromosomal number (Lata *et al*. 2013). Foxtail millet continues to play a significant role in global agriculture, feeding millions of people who rely on marginal or poor soils of Europe and Asia. Apart from human use, the grain is also utilised as feed for cattle and poultry and its stover as fodder for animals. Foxtail millet is widely known for its exceptional drought tolerance and is naturally equipped with excellent water use efficiency and nitrogen use efficiency. Further, numerous morpho-physiological traits, such as dense and deep root systems, smaller leaf area and thicker cell walls were thought to contribute to durable tolerance to a range of abiotic stresses, majorly for drought, heat, and salinity (Lata *et al*. 2013; Diao *et al*. 2014). Recently, foxtail millet has gained recognition as an important food for diabetics. It has low levels of fat (4%) and a low glycaemic index (GI = 57). Its bran is rich in linoleic and oleic acids. It is rich in dietary fiber (6.7%), minerals (4%) and micronutrients (Fe, Ca, P) and protein (11–12%) (Liang *et al*. 2010).

In general, foxtail millet productivity is low, because of local cultivars, which yield poorly, are cultivated on marginal land of arid regions. Which, necessitates the development of more stable, highly productive and adaptable foxtail millet cultivars. Genetic variability is a key prerequisite for genetic improvement in plant breeding. Knowledge on the extent of variability existing in a crop species for different traits is crucial, because it serves as the basis for effective selection. To obtain a realistic indication of genetic variation in any trait, phenotypic variability must be partitioned into heritable and non-heritable components. The potential genetic gain from a selection process may be evaluated using estimations of heritability along with genetic advance. The aim of this research was to estimate the degree of variation among different morpho-physiological and grain yield related traits and identify the best suitable lines for increasing the grain yield of foxtail millet.

MATERIAL AND METHODS

Fifty foxtail millet germplasm accessions including three checks *viz.,* SiA 3156, SiA 3223 and SiA 3159 were evaluated in two replications using a Randomised Complete Block Design (RCBD) at the Regional Agricultural Research Station, Nandyal, Andhra Pradesh, during *Rabi* season, 2023-2024. The location of the experimental site is 211.76 meters above mean sea level, in latitude 15°29' N and longitude 78°29' E. The accessions were sown at a spacing of 22.5 cm × 10 cm. Recommended agronomic practices were applied at the prime time. Five competitive plants per accession were selected randomly for recording observation on plant height (cm), number of productive tillers per plant, flag leaf length (cm), flag leaf width (cm), panicle length (cm), photosynthetic rate (µmol CO_2 $m^{-2}s^{-1}$), transpiration rate (mmol H_2O $m^{-2}s^{-1}$), stomatal conductance (mmol H_2O $m^{-2}s^{-1}$), relative water conductance (%), abortive grain rate, fodder yield per plant (g), harvest index (%) and grain yield per plant (g), while observations on days to 50% flowering and days to maturity were recorded on a plot basis. For 1000-grain weight, a random sample of 1000 grains were counted from the threshed seed and the weight was recorded in grams. The analysis of variance was estimated by Panse and Sukhatme (1967). Heritability in broad sense (h^2b) was calculated and classified into low (below 30%), medium (30- 60%) and high (above 60%) and genetic advance as percent over mean (at 5%) were computed and categorized into low (0-10%), moderate (10-20%) and high (≥ 20%) as given by Johnson *et al.* (1955). Estimates of PCV and GCV was calculated following Burton and De Vane (1953) and categorized into low (<10%), moderate (10-20%) and high (>20%) according to Sivasubramanian and Madhavamenon (1973).

RESULT and DISCUSSIONS

Analysis of variance for morpho-physiological and yield attributing traits in foxtail millet germplasm accessions are presented in Table 1. Results showed that, mean squares were significant for all studied traits, indicates presence of sufficient variability and scope for further selection and breeding superior and desirable genotypes. Average mean performance of the top ten high yielding accessions for a range of morpho-physiological attributes are presented in Table. 2. The germplasm accessions *viz..,* SiA 3290 (11.59 g/plant), SiA 4345 (11.35 g/plant) and SiA 4391 (11.32 g/plant) performed exceptionally well for the most of the yield attributes and had the best *per se* performance, when compared to that of best standard check SiA 3159 (11.04 g/plant). The SiA 3290 exceeded other accessions in terms of grain yield as well, including the harvest index, 1000-grain weight, and photosynthetic rate. SiA 4345 also performed better for most of the physiological traits *viz..,* transpiration rate, photosynthetic rate, stomatal conductance, and relative water content. In terms of the harvest index, abortive grain rate, transpiration rate, relative water content, and photosynthetic rate, SiA 4391 exhibited higher performance. Therefore, after multilocation testing, these accessions can thus be utilized for commercial exploitation. Estimates of range of variation and genetic variability parameters for the 16 traits in 50 foxtail millet accessions are illustrated in Table 3. In the current investigation, significant differences in mean values for all the traits were noticed. The traits grain yield per plant ranged from 4.44 to 11.59 (g); days to 50% flowering ranged from 48.00 to 60.50; days to maturity ranged from 77.00 to 94.00; plant height ranged from 109.50 to 155.70 (cm); number of productive tillers per plant ranged from 1.50 to 3.20; flag leaf length at flowering ranged from 23.10 to 39.70 (cm); flag leaf width at flowering ranged from 1.42 to 2.86 (cm); panicle length ranged from 12.90 to 21.90 (cm); 1000 grain weight ranged from 1.90 to 3.35 (g); fodder yield per plant ranged from 6.58 to 17.48 (g); harvest index ranged from 26.44 to 42.06 (%); photosynthetic rate ranged from 13.47 to 45.97 (μmol CO_2 m^{-2} s^{-1}); transpiration rate ranged from 2.98 to 6.88 (mmol H_2O $m^{-2}s^{-1}$); stomatal conductance ranged from 0.12 to 0.34 (mmol H_2O m^{-2} s^{-1}); relative water content ranged from 71.82 to 90.77 (%) and abortive grain rate ranged from 0.06 to 0.25. The experimental material had a favourable mean performance and wide range of variability for most of the traits studied and these prospective combinations might be used as potential lines aiming at simultaneous improvement for grain yield and other yield attributing traits.

Results revealed that, the phenotypic coefficient of variation (PCV) was higher in magnitude than genotypic coefficient of variation (GCV) for all studied traits, suggesting that the environment has an impact on the expression of these traits. The higher estimate of PCV and GCV ($\geq$ 20%) were observed for the traits Photosynthetic rate (22.85% and 22.52%); Transpiration rate (22.64% and 19.77%); Stomatal conductance (29.71% and 25.73%) and Abortive grain rate (30.96% and 23.98%) with less difference between observed PCV and GCV estimates, indicating presence of exploitable genetic variance for these traits and scope for the possible improvement through selection (Figure. 1.). High PCV coupled with moderate GCV was reported for number of productive tillers per plant (21.02% and 14.14%) and grain yield per plant (22.55% and 19.46%). Similar results were reported by Yadav *et al.* (2024). Both PCV and GCV were found to be moderate for the traits flag leaf length (12.80% and 10.82%); flag leaf width (16.52% and 10.91%); panicle length (13.28% and 11.16%) as obtained by Amarnath *et al.* (2018), 1000 grain weight (12.40% and11.83%) similar to the results of Srilatha *et al.* (2020), harvest index (12.06 % and 10.70%); fodder yield per plant (16.50% and 12.99%) which were in line with the results of Yadav *et al.* (2024). Moderate PCV and GCV suggested that there is considerable scope of improvement in these traits in desired direction through a selection processes. The Low estimates of phenotypic and genotypic coefficient of variation were observed for the days to 50% flowering, day to maturity, plant height and relative water content, indicating the major role of genetic factors changing the expression of these traits with the environment.

Genotypic coefficient of variation cannot provide a clear estimate of the genetic gain of the trait, that can be anticipated from phenotypic-based selection, unless the heritability is known (Burton, 1952). Heritability and genetic advance as percentage of mean are the two primary selection criteria considered in the crop improvement. Heritability estimates for the different traits under investigation in this study varied from 43.60 to 97.20 percent, whereas the genetic advance as percentage of mean varied from 5.92 to 45.74 percent. The trends of heritability and genetic advance as percentage of mean are presented in Figure. 2. High heritability was noticed for the traits *viz.,* photosynthetic rate (97.20%), 1000-grain weight (91.00%), relative water content (90.50%), harvest index (78.60%), transpiration rate (76.30%), grain yield per plant (75.90%), stomatal conductance (75.00%), days to maturity

(73.90%), flag leaf length (71.50%), panicle length (70.60%), fodder yield per plant (61.90%) and abortive grain rate (60.00%). Whereas, high genetic advance as percent mean was also reported for stomatal conductance (45.90%), photosynthetic rate (45.74%), abortive grain rate (38.27%), transpiration rate (35.54%), grain yield per plant (35.24%), 1000 grain weight (23.25%), and fodder yield per plant (21.06%).

The estimates of heritability and genetic advance together are more accurate in assessing the potential genetic gain through selection (Johnson *et al*. 1955). Therefore, in the present study heritability and genetic advance both were estimated to access the possible extent of genetic improvement among the different accessions studied. High heritability in conjunction with high genetic advance as percent over mean (GAM) was observed for the traits photosynthetic rate (97.20% and 45.74%); transpiration rate (76.30% and 35.58%); stomatal conductance (75.00% and 45.90%); 1000 grain weight (91.00% and 23.52%) as obtained by Harish *et al.* (2022), fodder yield per plant (61.90% and 21.06%) similar to the report by Yadav *et al.* (2024) and grain yield per plant (75.90% and 35.24%) as published by Srilatha *et al.* (2020), Harish and Lavanya (2022). High heritability accompanied by moderate GAM was found for flag leaf length (71.50% and 18.84%) as reported by Pallavi *et al.* (2020), panicle length (70.60% and 19.30%) similar to the results shown by Johar (2015) and Shingane *et al.* (2016), relative water content (90.50% and 11.72%) as realised by Bheemesh *et al.* (2018) and harvest index (78.60% and 19.52%) which was alike the results of Yadav *et al.* (2024). High heritability coupled with high GAM indicates that the traits are governed majorly by additive genes and these traits *viz.,* photosynthetic rate, transpiration rate, stomatal conductance, 1000 grain weight, fodder yield per plant and grain yield per plant can be improved through simple selection. The traits with moderate to low heritability and GAM imply that the traits are influenced by both additive and non-additive genes and thus simple selection alone might not be rewarding for the improvement of these traits, hence, in this crop recurrent selection can be employed for improvement of these traits. The Low estimates of heritability and genetic advance over the percentage of mean that were observed for 1000 grain weight (g) indicates that Selection will be inefficient because of the substantial environmental influence on the trait.

CONCLUSIONS

India has a wealth of foxtail millet genetic resources available; these resources must be utilized for harnessing the benefits. Evaluation and characterisation of the germplasm accessions can provide a substantial quantity of information about variability, which is essentially needed to improve the yield-related attributes and other desired traits. In the present study, efforts are made to unravel the variability in the germplasm lines and an analysis of variance revealed that germplasm accessions differed significantly for all the traits, providing sufficient diversity and range to select suitable genotypes. Among the tested accessions, SiA 3290, SiA 4345 and SiA 4391 were found to have potential for most of the traits and to be promising for high grain yield. All the traits showed higher PCV than corresponding GCV implying the existence of environmental influence. The traits photosynthetic rate, transpiration rate and stomatal conductance were known to possess high PCV and GCV, including the formerly mentioned traits, 1000 grain weight, fodder yield per plant and grain yield per plant has shown high heritability coupled with high GAM indicating the predominance of additive gene action on them and thus they can be improved through simple selection. Days to 50% flowering, days to maturity, plant height and relative water content possessed low to moderate variability, heritability and GAM which means that these traits are governed mostly by non-additive genes and impact of the environment is more in the expression of the traits, hence, simple selection may not be rewarding for the improvement of these traits.

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S. No	Traits	Mean sum of squares		
		Replications (df = 1)	**Treatments (df = 49)**	**Error (df = 49)**
1	Days to 50% flowering	6.250	11.597*	3.026
2	Days to maturity	0.040	22.936*	3.448
3	Plant height (cm)	189.888	202.206*	55.330
4	Number of productive tillers per plant	0.004	0.321*	0.121
5	Flag leaf length at flowering (cm)	0.774	27.795*	4.628
6	Flag leaf width at flowering (cm)	0.280	0.163*	0.064
7	Panicle length (cm)	6.452	9.921*	1.712
8	Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})	2.904	92.674*	1.332
9	Transpiration rate (mmol H_2O m^{-2} s^{-1})	0.271	1.949*	0.262

Table. 1. Analysis of variance (ANOVA) for morpho-physiological and yield attributing traits in foxtail millet germplasm accessions

10	Stomatal conductance (mmol H_2O m^{-2} s^{-1})	0.001	0.007*	0.001
11	Relative water content (%)	0.325	53.056*	2.635
12	Abortive grain rate	0.001	0.004*	0.001
13	1000 grain weight (g)	0.012	0.213*	0.010
14	Fodder yield per plant (g)	2.214	8.389*	1.971
15	Harvest index (%)	0.738	31.615*	0.790
16	Grain yield per plant (g)	1.201	6.155*	0.845

* Significant at 5% level of probability

Table. 2. Mean performance of the top ten accessions of foxtail millet including checks for morpho-physiological and yield attributing traits

Entry	DFF	DM	PH	NPT	FLL	FLW	PL	TGW	FYPP	HI	PR	TR	SC	RWC	AGR	GYPP
SiA 3290	56.50	88.00	138.00	2.40	33.30	2.34	17.90	2.90	15.31	39.87	36.56	5.63	0.27	83.92	0.16	11.59
SiA 4345	53.50	85.50	146.80	2.55	30.40	2.30	18.10	2.75	16.24	37.91	40.43	6.49	0.29	90.77	0.17	11.35
SiA 4391	56.50	84.50	141.50	2.25	34.20	1.98	19.00	2.55	15.39	41.33	37.57	6.35	0.24	88.8	0.06	11.32
SiA 3359	56.00	89.50	129.90	1.90	31.40	1.95	19.90	2.45	14.82	38.99	36.94	4.49	0.24	87.99	0.18	10.79
SiA 4435	56.50	91.50	141.70	2.30	35.80	2.10	18.30	2.50	13.66	40.13	34.59	3.98	0.15	90.00	0.13	10.16
SiA 4436	57.00	92.00	153.00	2.30	32.30	1.88	19.20	3.10	15.93	36.53	39.27	6.88	0.33	88.10	0.14	10.14
SiA 4468	54.50	88.00	142.00	2.70	32.00	2.00	19.70	2.85	11.94	41.70	34.43	4.71	0.19	85.79	0.15	9.80
SiA 3156 (C)	54.00	89.00	143.50	1.90	33.50	2.41	19.75	3.05	12.68	40.29	33.01	5.98	0.26	86.79	0.15	9.77
SiA 3223 (C)	53.50	91.00	152.50	1.90	34.60	2.52	19.40	3.05	14.39	38.74	41.51	6.21	0.34	88.38	0.13	10.09
SiA 3159 (#C)	50.00	84.00	143.20	2.10	32.50	2.29	21.05	2.95	13.82	42.06	45.97	6.24	0.29	90.55	0.11	11.04
C.V%	**3.15**	**2.10**	**5.29**	**15.55**	**6.84**	**12.40**	**7.20**	**3.71**	**10.17**	**5.58**	**3.85**	**11.02**	**14.85**	**1.93**	**19.58**	**11.08**
S. E+_(m)	**1.23**	**1.31**	**5.26**	**0.18**	**1.52**	**0.24**	**0.92**	**0.07**	**0.99**	**1.38**	**0.82**	**0.36**	**0.021**	**1.15**	**0.017**	**0.65**
C.D at 5%	**3.49**	**3.73**	**14.95**	**0.51**	**4.32**	**0.70**	**2.63**	**0.20**	**2.82**	**3.91**	**2.32**	**1.03**	**0.059**	**3.26**	**0.049**	**1.85**

C - Checks and #C - Best performing check

DFF: Days to 50% flowering; **DM:** Days to maturity; **PH:** Plant height (cm); **NPT:** No. of productive tillers per plant; **FLL:** Flag leaf length at flowering (cm); **FLW:** Flag leaf width at flowering (cm)**; PL:** Panicle length (cm); **TGW:** Thousand grain weight (g); **FYPP:** Fodder yield per plant (g); **HI:** Harvest index (%); **PR:** Photosynthetic rate (µmol CO_2 m^{-2} s^{-1}); **TR:** Transpiration rate (mmol H_2O m^{-2} s^{-1}); **SC:** Stomatal conductance (mmol H_2O m^{-2} s^{-1}); **RWC:** Relative water content (%); **AGR:** Abortive grain rate; **GYPP:** Grain yield per plant (g).

Table. 3. Estimates of range of variation and genetic variability parameters for the 16 traits in 50 foxtail millet accessions

S. no	Traits	Range		Mean	Coefficients of variation (%)		Heritability in broad sense (h^2b) (%)	Genetic advance as percent of mean (%)
		Min.	Max.		Phenotypic	Genotypic		
1	Days to 50% flowering	48.00	60.50	55.15	4.90	3.75	58.60	5.92
2	Days to maturity	77.00	94.00	88.46	4.11	3.53	73.90	6.25
3	Plant height (cm)	109.50	155.70	140.50	8.08	6.10	57.00	9.49
4	Number of productive tillers per plant	1.50	3.20	2.04	21.02	14.14	45.20	19.60
5	Flag leaf length at flowering (cm)	23.10	39.70	31.44	12.80	10.82	71.50	18.84
6	Flag leaf width at flowering (cm)	1.42	2.86	2.24	16.52	10.91	43.60	14.84
7	Panicle length (cm)	12.90	21.90	18.61	13.28	11.16	70.60	19.30
8	Photosynthetic rate (µmol CO_2 m^{-2} s^{-1})	13.47	45.97	29.99	22.85	22.52	97.20	45.74
9	Transpiration rate (mmol H_2O m^{-2} s^{-1})	2.98	6.88	4.64	22.64	19.77	76.30	35.58
10	Stomatal conductance (mmol H_2O m^{-2} s^{-1})	0.12	0.34	0.212	29.71	25.73	75.00	45.90
11	Relative water content (%)	71.82	90.77	83.96	6.28	5.98	90.50	11.72
12	Abortive grain rate	0.06	0.25	0.16	30.96	23.98	60.00	38.27
13	1000 grain weight (g)	1.90	3.35	2.69	12.40	11.83	91.00	23.25
14	Fodder yield per plant (g)	6.58	17.48	13.79	16.50	12.99	61.90	21.06
15	Harvest index (%)	26.44	42.06	34.88	12.06	10.69	78.60	19.52
16	Grain yield per plant (g)	4.44	11.59	8.29	22.55	19.64	75.90	35.24

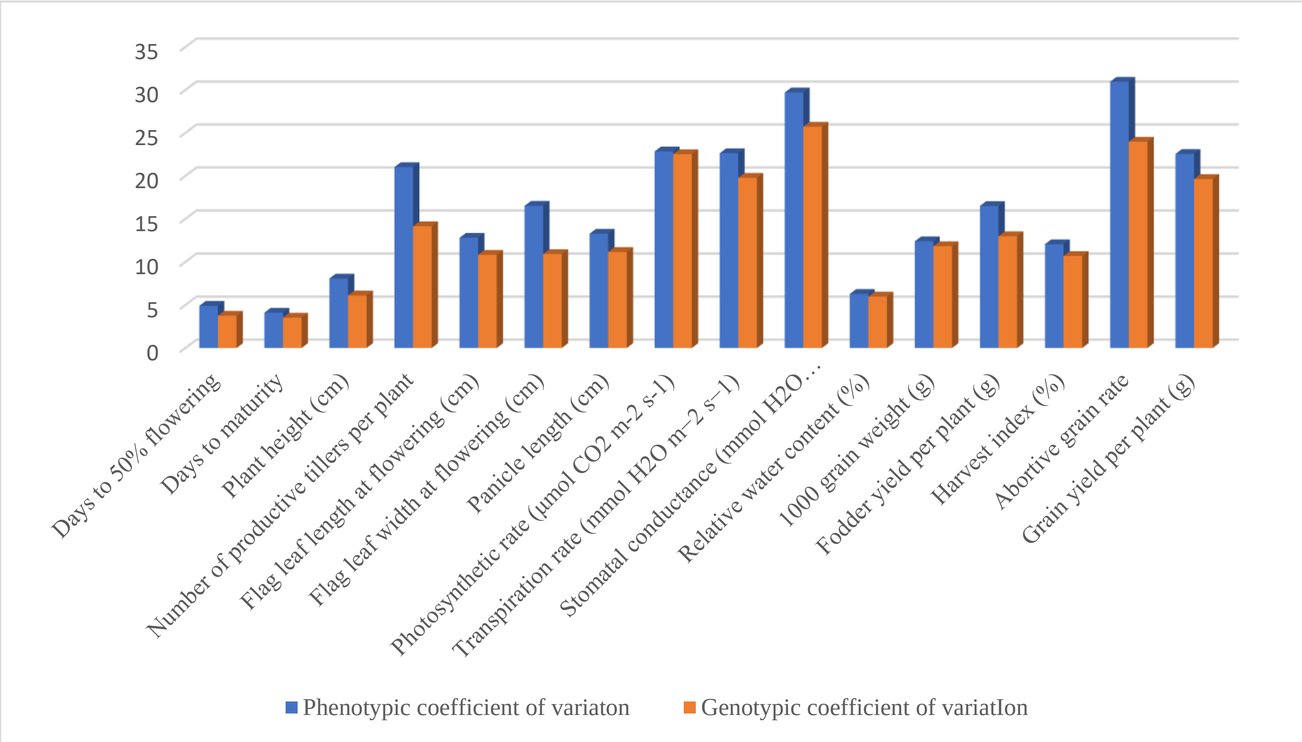

Fig.1. Histogram depicting estimates of phenotypic and genotypic coefficient of variation for 16 morpho-physiological and yield attributing traits in 50 foxtail millet germplasm accessions

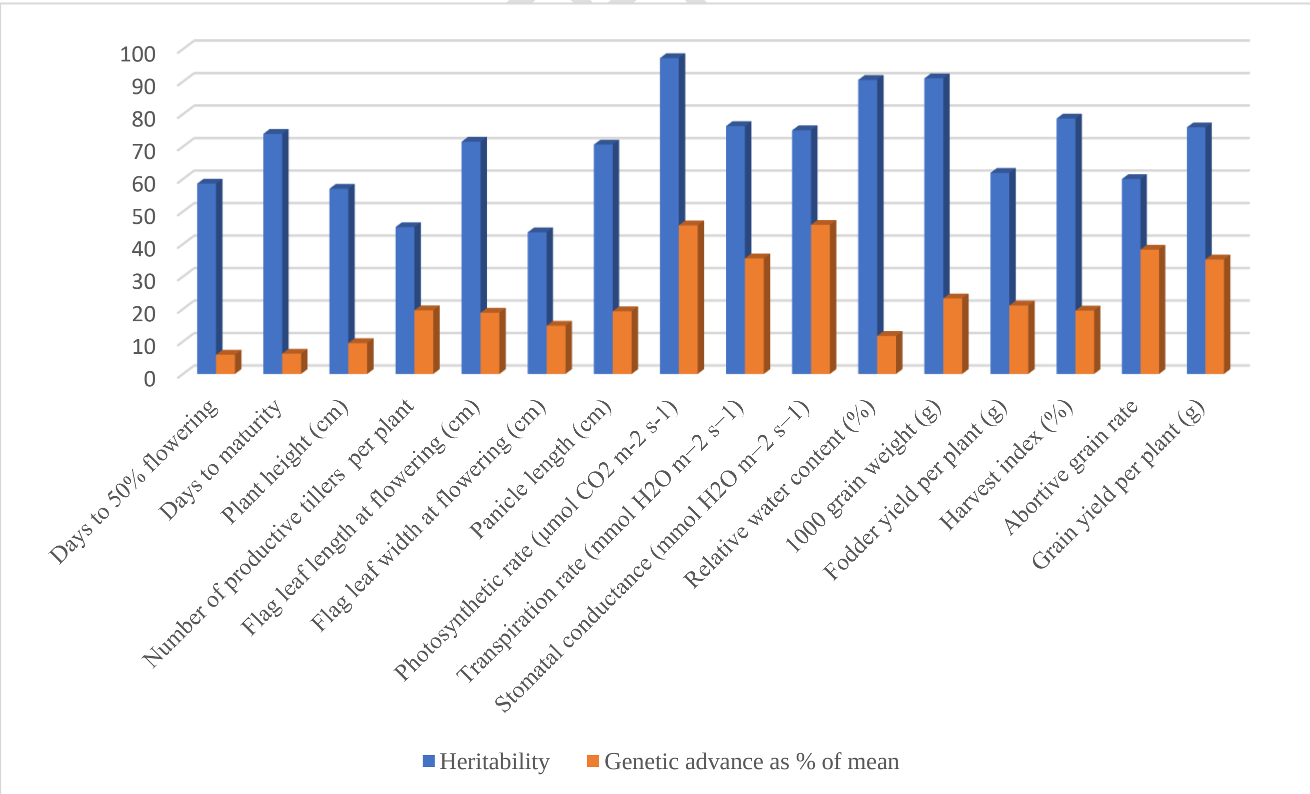

Fig.2. Histogram depicting estimates of heritability and genetic advance as percent of mean for 16 morpho-physiological and yield attributing traits in 50 foxtail millet germplasm accessions