



Plant Archives

Journal homepage: <http://www.plantarchives.org>

DOI Url : <https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-1.456>

TRAIT BASED BREEDING STRATEGIES FOR ENHANCING GRAIN YIELD AND NUTRITIONAL TRAITS IN FOXTAIL MILLET (*SETARIA ITALICA* L. P. BEAUV)

Bhavani Saiesha Chalapaathi*, N. Sabitha, R. Narasimhulu and K.V. N Madhuri

S.V. Agricultural College (Acharya N. G. Ranga Agricultural University) Tirupati-517502, A. P., India

*Corresponding author E-mail: bhavanisaiesha@gmail.com

(Date of Receiving : 13-10-2025; Date of Acceptance : 27-12-2025)

ABSTRACT

A study was conducted during *Rabi*, 2024- 2025 at S.V. Agricultural college, Wet land Farm, Tirupati, ANGRAU, Andhra Pradesh on Foxtail millet comprising of 40 genotypes along with two checks *viz.*, SiA 3156 and SiA 3159 in Alpha lattice design to study gene actions governing yield components and nutritional traits through the estimation of genetic parameters. The genotypes such as SiA 4244, SiA 4251 and IIMR F x M15 were found superior for most of the characters and had the high *per se* performance studied and may be utilized in hybridization programs. Genotypes SiA 4261, SiA 4312, and SiA 4346 for protein content; SiA 4256, SiA 4228, and GPUF 16 for iron content and IIMR F x M12, SiA 4330 and SiA 4346 for zinc content were found superior. Moderate to high PCV and GCV, heritability and genetic advance as percentage of mean recorded for number of productive tillers per plant, flag leaf length at flowering, flag leaf width at flowering, panicle length and plant height straw yield per plant, grain yield per plant, iron, zinc and protein content suggested that these traits are under the control of additive gene action and genetic improvement can be done by simple selection strategies for these traits. SPAD Chlorophyll Meter Readings (SCMR), relative water content (%), days to 50% flowering, 1000 grain weight and harvest index exhibited low to moderate variability coupled with high heritability and moderate genetic advance as a percentage of the mean indicated that both additive and non-additive gene actions were involved in the inheritance of the traits. Days to maturity had low variability and high heritability coupled with low genetic advance indicating the predominance of non-additive gene action in controlling the trait and simple selection may not be rewarding.

Keywords : Foxtail millet, Variability parameters, Nutritional traits, Yield components.

Introduction

Foxtail millet (*Setaria italica* (L.) P. Beauv.] is a self-pollinating, C4 monocot cereal crop. Foxtail millet (*Setaria italica* (L.) with a rich history of cultivation dating back to 5000-6000 BC along the Yellow River in China (Li and Wu, 1996). It is an important staple crop in some parts of China, India and Japan, and a potential bioenergy source. In India, foxtail millet is cultivated on about 0.8 lakh hectares area with 0.6 lakh tonnes production in Andhra Pradesh, Karnataka, Telangana, Rajasthan, Maharashtra, Tamil Nadu and north eastern states (Hariprasanna, 2023 and Pine, 2020). Foxtail millet is an important staple crop extensively cultivated for food grain, hay and pasture food and is referred as Italian millet. It is

tolerant to both biotic and abiotic stresses. Foxtail millet grains are rich source of nutrients such as protein, minerals (calcium, iron, zinc, potassium, magnesium) and vitamins in addition dietary fibre (Rai, 2002 and Srilatha *et al.*, 2020). It has a moderate glycemic index and is a good source of β -carotene (Murugan and Nirmalakumari, 2006 and Coulibaly and Chen, 2011). It is not only widely used as an energy source for pregnant and lactating women, but also for sick people and children, and especially for diabetics. It reduces blood sugar concentration in women diabetics (Sema and Sarita, 2002). The grains have long shelf-life, a preferable attribute (Ravi *et al.*, 2010). It has been suggested to use foxtail millet protein as a food component to fight type 2 diabetes and cardiovascular diseases (Choi *et al.*, 2005). The

phenolics in foxtail millet act as antioxidants by reducing the amount of free radical produced in the body. It is non-acidic and non-glutinous, making it easily digestible, also it facilitates the gradual release of sugars in the body without disrupting metabolic processes (Gupta *et al.*, 2013). Moreover, it exhibits antimicrobial properties, possesses anti-tumorigenic potential and aids in detoxifying the body (Thakur and Tiwari, 2009). Despite the foxtail millet being beneficial to health, it remained a neglected crop from the mainstream of crop improvement research compared to cereals such as maize, rice, wheat, sorghum and pearl millet. Improving millet grain yield is crucial for enhancing food security, nutrition and economic stability, especially in developing countries.

Grain yield is a complex trait influenced by both genetic and environmental factors. Selection only for yield is ineffective as yield is complex trait (Madhavi Latha *et al.*, 2022 a& b). Phenotypic variance allows breeders to assess the overall variability in yield and yield related traits. On other hand, genotypic variance quantifies the genetic contribution to trait variability. Heritability indicates how much of a trait variation is due to genes (Schmidt *et al.*, 2019). Thus, genetic parameters assist the breeder in developing effective selection strategies in crop breeding. Heritability estimates along with genetic advances will be more reliable in formulating suitable and effective breeding methods and formulating suitable selection procedures (Johnson *et al.*, 1955) Therefore, more effective approach is to make for selection of traits that contribute to yield (Muniratnam *et al.*, 2006) Genetic variability studies for the identification of trait-specific genotypes for various agronomic and nutritional traits are lacking in foxtail millet and are hence seldom used in breeding. In the present study an attempt has been made to assess the amount of variability present among the genotypes for yield components and nutritional traits, study the nature of gene action associated with traits of economic importance, identify the traits which are amenable for selection and find out foxtail millet genotypes that produce high yield.

Materials and Methods

The experiment was carried out during *Rabi*, 2024-2025 at S.V. Agricultural college, Wet land Farm, Tirupati, ANGRAU, Andhra Pradesh, located at an altitude of 182.9 meters above the mean sea level, 13° N latitude and 79° N longitude. The experimental material comprised of 40 genotypes of foxtail millet including two checks *viz.*, SiA 3156 and SiA 3159

were laid out in Alpha lattice design with two replications. All the genotypes were raised in two rows of 3m length with a spacing of 22.5 cm between the rows and 10 cm between plants. All the recommended packages of practice were followed in raising a healthy crop.

Data were recorded from five randomly sampled competitive plants from each genotype and in each replication for yield component traits except for days to 50% flowering and days to maturity, for which data were recorded on per plot basis. Observations recorded on yield components include plant height (cm), number of productive tillers per plant, flag leaf length and width at flowering (cm), panicle length (cm), 1000 grain weight (g), straw yield per plant (g) and grain yield per plant (g).

SPAD Chlorophyll Meter Reading at 45 DAS was recorded using SCMR chlorophyll meter on the third leaf from top at three spots *viz.*, top, middle and lower portion of the leaf top of the plant and mean was considered as trait value. Relative Water Content (%) calculated using the formula given by Barr and Weatherley (1962). The harvest index was calculated for each genotype by applying the following formula (Donald, 1962). Iron Content and Zinc Content (mg/100g) in grains were estimated as per procedure given by Tandon (1999). The Nitrogen content (%) in the grounded flour sample was estimated by Micro Kjeldahl method and Protein content (%) was estimated as described by Sadasivam and Manickam (1996). The analysis of variance was conducted using the Panse and Sukhatme (1957) model. Burton (1952) and Sivasubramanian and Madhava Menon (1973) formulas were employed to calculate the phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV). Broad-sense heritability (h^2) was determined using the Lush (1940), Burton and De Vane (1953 and Singh and Chaudhary, 1977) formula. Genetic gain was assessed utilizing formulas proposed by Lush (1940 and Johnson *et al.*, 1955)

Results and Discussion

The analysis of variance revealed significant differences among 40 genotypes for all the yield components and nutritional traits under study, indicating the presence of substantial amount of genetic variability among the genotypes (Table 1). Comparable findings were also reported by Upadhyaya *et al.*, 2011 and Zhang *et al.*, 2023 in foxtail millet.

Table 1: ANOVA for grain yield, yield components and nutritional traits in Foxtail millet

S. No.	Trait(s)	Mean squares			
		Replications (df:1)	Genotypes (df:39)	Blocks (df:6)	Error (df:33)
1.	Days to 50% flowering	0.20	20.50*	0.63	0.58
2.	Days to maturity	6.05	13.98**	1.75	2.29
3.	Plant Height (cm)	23.28	223.11**	8.68	25.16
4.	Number of Productive Tillers per Plant	0.001	0.281**	0.011	0.026
5.	SCMR Reading	0.25	22.06**	1.45	0.81
6.	Relative Water Content (%)	19.68	70.62**	17.81	10.10
7.	Flag Leaf Length at Flowering (cm)	4.64	28.28**	10.61	4.50
8.	Flag Leaf Width at Flowering (cm)	0.005	0.11**	0.002	0.021
9.	Panicle Length (cm)	1.07	10.74**	0.28	0.60
10.	1000 grain weight (g)	0.0002	0.187**	0.06	0.03
11.	Straw Yield per Plant (g)	0.05	15.08**	0.25	1.00
12.	Harvest Index (%)	22.70	36.41**	3.24	6.07
13.	Iron Content (mg/100g)	0.01	5.71**	0.05	0.02
14.	Zinc Content (mg/100g)	0.01	1.70**	0.01	0.04
15.	Protein Content (%)	0.07	9.43**	0.05	0.15
16.	Grain Yield per Plant (g)	1.04	6.03**	0.33	0.34

** Significant at 1% Probability level

Mean performance

Mean is a simple statistic used in plant breeding to quantify phenotypic variability and eliminate undesirable genotypes. The general mean, maximum and minimum mean values and the top three genotypes that were significantly superior to the general mean of the traits studied were presented in Table 2. None of the genotypes had shown superior performance for all the traits. The genotypes *viz.*, SiA 4244, SiA 4251 and IIMR F x M15 performed exceptionally well for most of the yield-attributes and had the high *per se* performance, along with the two best standard checks SiA 3156 and SiA 3159. When compared to two standard checks, genotypes SiA 4261, SiA 4312, and SiA 4346 were found to have higher protein content. Similarly, SiA 4256, SiA 4228, and GPUF 16 were recognized as superior for iron content, while IIMR F x

M12, SiA 4330, and SiA 4346 had higher zinc content. In addition to grain yield, SiA 4244 demonstrated superior performance for the traits *viz.*, flag leaf width, panicle length, harvest index and 1000 grain weight. Similarly, SiA 4251 exhibited superior performance for grain yield per plant, relative water content, flag leaf length, flag leaf width and 1000 grain weight. While IIMR F x M15 recorded superior performance for plant height, number of productive tillers per plant, relative water content, flag leaf length, and straw yield per plant. Therefore, these genotypes can be employed for trait-specific breeding to produce transgressive segregants for commercial exploitation followed by multi location testing. Similar findings were reported by Madhavi Latha *et al.*, (2022a & b and Suthamathi *et al.*, 2025).

Table 2: Mean, range and superior genotypes identified for grain yield, yield components and nutritional traits in foxtail millet.

S. No	Trait(s)	Mean	Minimum	Maximum	Superior genotypes identified
1	Days to 50% Flowering	49.2	42.5	55.0	SiA 4243, SiA 3156, SiA 4363
2	Days to Maturity	87.9	83.5	91.5	SiA4305, SiA 4346, SiA3156
3	Plant Height (cm)	81.9	63.3	108.8	IIMR Fx M15, IIMR Fx M17, SiA 4251
4	Number of Productive Tillers per Plant	1.5	1.0	2.7	SiA 4316, IIMR FxM15, SiA 4361
5	SCMR Reading	40.4	33.8	49.1	SiA 4229, IIMR F x M17, TNsi 390
6	Relative Water Content (%)	84.2	73	96.1	IIMR Fx M15, SiA 4251, SiA 3159
7	Flag Leaf Length at Flowering (cm)	28.0	19.3	34.8	IIMR Fx M12, IIMR Fx M15, SiA 4251
8	Flag Leaf Width at Flowering (cm)	1.6	1.2	2.2	SiA 4244, SiA 4251, SiA 4232
9	Panicle Length (cm)	13.0	7.2	18.1	SiA 3159, SiA 4244, SiA 4316
10	Thousand Grain Weight (g)	2.8	2.2	3.2	SiA 4336, SiA 4251, SiA 4244
11	Straw Yield per Plant (g)	11.1	6.3	18.6	IIMR Fx M15, SiA 4316, SiA 4254

12	Harvest Index (%)	36.8	30.5	45.4	SiA 4244, SiA 3156, SiA 4336
13	Iron Content (mg/100g)	4.3	1.3	6.5	SiA 4256, SiA 4228, GPUF 16
14	Zinc Content (mg/100g)	4.1	1.7	6.1	IIMR Fx M12, SiA 4330, SiA 4346
15	Protein Content (%)	10.2	6.9	15.1	SiA 4261, SiA 4312, SiA 4346 and and and
16	Grain Yield per Plant (g)	6.4	3.6	11.5	SiA 4244, SiA 3159, SiA 4251

Variability analysis

Estimates of genetic parameters for yield, yield components and nutritional traits were presented in Table 3. Genetic and environmental factors contribute to variation within populations. While genetic variability is heritable across generations, distinguishing between heritable and non-heritable traits poses challenges for breeders during the selection process. Therefore, before initiating a thoughtful breeding effort, breeders need to differentiate between traits that are heritable and those that are not. In the present study traits such as number of productive tillers per plant (25.60 and 23.30), straw yield per plant (25.40 and 23.90), iron content (38.70 and 38.50), zinc content (22.70 and 22.10), protein content (21.43 and 21.10) and grain yield per plant (27.50 and 25.90) recorded higher PCV and GCV estimates while Plant height (13.50 and 12.10), flag leaf length at flowering (14.50 and 12.10), flag leaf width at flowering (15.60 and 13.00), panicle length (18.20 and 17.20), 1000 grain weight (11.80 and 9.60) and harvest index (12.40 and 10.60) registered moderate estimates of PCV and GCV values, respectively. The traits, days to 50% flowering (6.60 and 6.40), days to maturity (3.20 and 2.70), SPAD meter reading (8.30 and 8.00) and relative water content (7.50 and 6.40) showed lower estimates of PCV and GCV values. Similar studies reported by Smita *et al.*, 2016; Singh *et al.*, 2016; Jyothsna *et al.*, 2016; Sachan, 2017; Kavya *et al.*, 2017; Ayesha *et al.* 2019; Pawan Kumar, 2019; Anuradha *et al.*, 2017, 2019 and 2020; Jhansi Rani *et al.*, 2020; Kamal *et al.*, 2021; Bhakuni *et al.*, 2021; Harish and Lavanya, 2022; Karvar *et al.*, 2023; Dhanish Kumar *et al.*, 2023; Zhang *et al.*, 2023; and Purusothama Rao and Chaturvedi, 2025).

Heritability and Genetic advance are crucial in crop improvement. In the present study, higher estimates of broad sense heritability were recorded for all the 16 traits studied making them ideal for selection in breeding programs. These results agree with the findings of Tyagi *et al.*, 2011; Jyoshna *et al.*, 2016; Amarnath *et al.*, 2018; Kumar *et al.*, 2019; Anand *et al.*, 2020; Venkatesh *et al.*, 2020; Pallavi *et al.*, 2020 and Yadav *et al.*, 2024) Moderate to high genetic advance over mean were observed for SPAD meter reading (15.93), relative water content (11.49), days to 50% flowering (12.80), 1000 grain weight (15.93),

harvest index (18.56), flag leaf length at flowering (21.01), flag leaf width at flowering (22.40), plant height (22.53), panicle length (33.70), protein content (42.84), number of productive tillers per plant (43.90), straw yield per plant (46.30), grain yield per plant (42.84), iron (79.01) and zinc (74.40) while low genetic advance over mean was noted for days to maturity (4.82). Similar findings were reported in foxtail millet by several researchers (Johar *et al.*, 2015; Smita *et al.*, 2016; Kumar *et al.*, 2019; Pavani, 2019; Pawan Kumar, 2019; Anuradha *et al.*, 2017, 2019 and 2020; Venkatesh *et al.*, 2020; Srilatha *et al.* 2020; Karvar *et al.*, 2021 and Ayesha *et al.*, 2024).

Genetic advance measures the potential extent a population can progress through selection. While heritability alone may not consistently indicate substantial genetic gains, it becomes significant when coupled with a high genetic advance. Higher PCV, GCV, heritability and genetic advance as percentage of mean recorded for number of productive tillers per plant, straw yield per plant, grain yield per plant, iron, zinc and protein content suggests that these traits are under the control of additive gene action and genetic improvement can be done by simple selection for these traits. The other traits such as flag leaf length at flowering, flag leaf width at flowering, panicle length and plant height with moderate PCV, GCV coupled with high heritability and genetic advance as percentage of mean indicated that these traits are strongly influenced by genetic factors and can be improved through traditional breeding methods. These traits predominantly under the control of additive gene action and genetic improvement can be done by simple selection for these traits. Plant height with moderate PCV and GCV, high heritability coupled with genetic advance as percent of mean suggested that the trait is under the control of additive gene action. Emphasis should be given for these traits while making selection SPAD Chlorophyll Meter Readings (SCMR), relative water content (%), days to 50% flowering showed low PCV and GCV, high heritability coupled with moderate genetic advance as percentage of mean reveals the operation of both additive and non-additive gene action. Similarly for 1000 grain weight low to moderate variability, high heritability coupled with moderate genetic advance as percentage of mean; harvest index with moderate PCV, GCV and high heritability coupled with moderate genetic advance as

percentage of mean suggests the involvement of both additive and non-additive gene action in the inheritance of the traits. This also suggests that genetic improvement can be achieved through traditional breeding methods, as well as by harnessing non-additive gene interactions. Days to maturity showed low variability and high heritability coupled with low genetic advance indicating the predominance of non-additive gene action and simple selection may not be rewarding for the trait. This indicates that improvement through selection and breeding might be limited. This

could be due to the involvement of non-additive gene actions, where gene interactions play a larger role than individual genes. The high heritability and low genetic advance observed in traits days to maturity indicate that their expression is strongly influenced by environmental factors and involves non-additive gene action. These traits require specialized breeding strategies and alternative approaches to achieve significant improvement. Similar study was also reported by Patel *et al.* (2018).

Table 3 : Estimates of genetic parameters for yield, yield components and nutritional traits in foxtail millet.

S. No.	Trait(s)	Coefficient of Variation (%)		Heritability (bs) (%)	Genetic Advance	Genetic Advance as per cent of mean (%)
		Genotypic	Phenotypic			
1	Days to 50% Flowering	6.40	6.60	94.46	6.31	12.80
2	Days to Maturity	2.70	3.20	72.23	4.24	4.82
3	Plant Height (cm)	12.10	13.50	80.65	18.46	22.53
4	Number of Productive Tillers per Plant	23.30	25.60	83.41	0.67	43.90
5	SCMR Reading	8.00	8.30	92.48	6.45	15.93
6	Relative Water Content (%)	6.40	7.50	73.68	9.67	11.49
7	Flag Leaf Length at Flowering (cm)	12.10	14.50	70.09	5.88	21.01
8	Flag Leaf Width at Flowering (cm)	13.00	15.60	69.37	0.36	22.40
9	Panicle Length (cm)	17.20	18.2	89.74	4.40	33.70
10	1000 grain Weight (g)	9.60	11.80	66.67	0.46	16.22
11	Straw Yield per Plant (g)	23.90	25.40	88.21	5.14	46.30
12	Harvest Index (%)	10.60	12.40	72.30	6.84	18.56
13	Iron Content (mg/100g)	38.50	38.70	98.89	3.45	79.01
14	Zinc Content (mg/100g)	22.10	22.70	94.87	1.82	44.40
15	Protein Content (%)	21.10	21.43	97.01	4.37	42.84
16	Grain Yield per Plant (g)	25.90	27.50	89.23	3.28	50.55

Conclusions

Based on mean performance of genotypes for yield components, grain yield and nutritional traits, the genotypes SiA 4244, SiA 4251 and IIMR F x M15 were found superior for most of the characters studied and may be utilized in hybridization programs to bring genetic improvement in foxtail millet. The genotypes SiA 4261, SiA 4312, and SiA 4346 for protein content; SiA 4256, SiA 4228, and GPUF 16 for iron content and IIMR F x M12, SiA 4330 and SiA 4346 for zinc content were found superior. Additive gene action for number of productive tillers per plant, flag leaf length at flowering, flag leaf width at flowering, panicle length and plant height straw yield per plant, grain yield per plant, iron, zinc and protein content while both additive and non-additive gene actions were found to govern the traits such as SPAD Chlorophyll Meter Readings (SCMR), relative water content (%), days to 50% flowering, 1000 grain weight and harvest index. Non additive gene actions were found predominant for days to maturity. Simple selection may be exercised for

the traits governed by additive gene action while for the traits governed by either non additive or both additive and non-additive gene action, population improvement and recurrent selection may be followed for the improvement of the traits.

Conflict of Interest

All authors declare that they have no conflict of interest.

References

- Amarnath, K., Prasad, A. V. S. D., Reddy, C. V. C. M., & Sreenivasulu, K. N. (2018). Genetic variability in Indian foxtail millet genetic resources [*Setaria italica* (L.) Beauv.]. *Green Farming*, *9*(4), 612–614.
- Anand, G., Thamizhmani, S., & Vanniarajan, C. (2020). Genetic diversity study in germplasm lines of foxtail millet (*Setaria italica* (L.) P. Beauv.). *Electronic Journal of Plant Breeding*, *11*(3), 976–980.
- Anuradha, N., & Patro, T. S. S. K. (2019). Genetic variability, heritability and genetic advance in foxtail millet breeding lines. *International Journal of Chemical Studies*, *7*(3), 2967–2969.

- Anuradha, N., & Patro, T. S. S. K. (2020). Estimates of variability, heritability and genetic advance in foxtail millet. *Journal of Pharmacognosy and Phytochemistry*, **9**(1), 1614–1616.
- Anuradha, N., Patro, T. S. S. K., Divya, M., Rani, S. Y., & Triveni, U. (2017). Genetic variability, heritability and correlation of quantitative traits in little millet genotypes. *Journal of Pharmacognosy and Phytochemistry*, **6**(6), 489–492.
- Ayesha, M., Babu, D. R., Babu, J. D. P., & Rao, V. S. (2019). Genetic parameters for grain yield and nutritional quality traits in foxtail millet [*Setaria italica* (L.) Beauv.]. *International Journal of Current Microbiology and Applied Sciences*, **8**(2), 4–9.
- Barr, H. D., & Weatherley, P. E. (1962). A re-examination of the relative turgidity technique for estimating water deficit in leaves. *Australian Journal of Biological Sciences*, **15**(3), 413–428.
- Bhakuni, V., Prasad, R., & Shukla, P. S. (2021). Genetic variability and correlation studies for morphology and seed quality parameters in foxtail millet (*Setaria italica* (L.) Beauv.). *The Pharma Innovation Journal*, **10**(4), 160–165.
- Burton, G. W. (1952). Quantitative inheritance in grasses. In *Proceedings of the VI International Grassland Congress* (pp. 277–283).
- Burton, G. W., & Devane, E. H. (1953). Estimating heritability in tall fescue (*Festuca arundinaceae*) from replicated clonal material. *Agronomy Journal*, **45**, 478–481.
- Choi, Y. Y., Osada, K., Ito, Y., Nagasawa, N., Choi, M., & Nishizawa, N. (2005). Effects of dietary protein of Korean foxtail millet on plasma adiponectin, HDL-cholesterol and insulin levels in genetically type 2 diabetic mice. *Bioscience, Biotechnology, and Biochemistry*, **69**(1), 31–37. <https://doi.org/10.1271/bbb.69.31>
- Coulibaly, A., & Chen, J. (2011). Evaluation of energetic compounds, antioxidant capacity, some vitamins and minerals, phytase and amylase activity during germination of foxtail millet. *American Journal of Food Technology*, **6**(1), 40–51.
- Dharmishkumar, M., Suthamathi, P., Gnanamalar, R. P., Renuka, R., Sathiyaa, K., Vaithiyalingan, M., & Hemalatha, G. (2023). Genetic variability studies in foxtail millet (*Setaria italica* L.). *Biological Forum – An International Journal*, **15**(9), 212–216.
- Donald, C. M. (1962). In search of yield. *Journal of the Australian Institute of Agricultural Sciences*, **28**, 171–178.
- Hariprasanna, K. (2023). Foxtail millet: Nutritional importance and cultivation aspects. *Indian Farming*, **73**(1), 47–49.
- Harish, & Lavanya, G. R. (2022). Genetic variability and trait association studies in foxtail millet (*Setaria italica* L.) for grain yield traits. *International Journal of Environment and Climate Change*, **12**(11), 2929–2938.
- Jhansi Rani, P., Sameer Kumar, C. V., & Sooganna. (2020). Estimates of variability, trait association and path analysis among components of yield in foxtail millet (*Setaria italica* L.). *Biological Forum – An International Journal*, **13**(4), 1323–1328.
- Johar, J. S. (2015). A study on the nature of gene action for yield and yield components in exotic genotypes of Italian millet (*Setaria italica* (L.) Beauv.). *International Journal of Agricultural Sciences*, **5**(4), 667–670.
- Gupta, A., Sood, S., Agrawal, P. K., & Bhatt, J. C. (2013). Under-utilized food crops of Himalayan region: Utilization and prospective. In *Newer Approaches to Biotechnology* (pp. 101–120).
- Johnson, H. W., Robinson, H. F., & Comstock, R. E. (1955). Genotypic and phenotypic correlations in soybeans and their implications in selection. *Agronomy Journal*, **47**, 477–483.
- Jyothsna, S., Patro, T. S. S. K., Rani, S. Y., Ashok, S., Neeraja, B., & Triveni, U. (2016). Studies on genetic variability and inter-relationship between grain yield and its components in foxtail millet (*Setaria italica*). *International Journal of Agriculture Science*, **8**(5), 1015–1017.
- Kamal, K., Sharma, & Dangi, V. (2021). Studies on genetic parameters, correlation and path analysis for grain yield and its components in foxtail millet (*Setaria italica*). *International Journal of Current Microbiology and Applied Sciences*, **10**(3), 1741–1747.
- Karvar, S. H., Vaidya, E. R., Kohakade, S. N., Mohurle, N. A., & Sasane. (2021). Evaluation of genetic variability for quality traits in foxtail millet (*Setaria italica* (L.) P. Beauv.). *Journal of Pharmacognosy and Phytochemistry*, **10**(1), 1035–1038.
- Kavya, P., Sujatha, M., Pandravada, S. R., & Hymavathi, T. V. (2017). Variability studies in foxtail millet (*Setaria italica* (L.) P. Beauv.). *International Journal of Current Microbiology and Applied Science*, **6**(9), 955–960.
- Kumar, G. P., Prasad, A. D., Reddy, C. V. C. M., & Sreenivasulu, K. N. (2019). Genetic variability analysis for yield and nutritional traits in foxtail millet (*Setaria italica* (L.) Beauv.). *International Journal of Current Microbiology and Applied Sciences*, **8**(6), 2273–2279.
- Li, Y., & Wu, S. (1996). Traditional maintenance and multiplication of foxtail millet [*Setaria italica* (L.) P. Beauv.] landraces in China. *Euphytica*, **87**, 33–38.
- Lush, J. L. (1940). Intra-sire correlation and regression of offspring in dam as a method of estimating heritability of characters. *Proceedings of the American Society of Animal Production*, **33**, 292–301.
- Madhavilatha, L., Reddy, C. V., Priya, M. S., Anuradha, N., Narasimhulu, R., Reni, Y. P., & Kumar, M. H. (2022a). AMMI analysis of yield performance in foxtail millet [*Setaria italica* (L.) P. Beauv.] genotypes for adaptation to rainfed conditions in Andhra Pradesh. *Indian Journal of Agricultural Research*, **56**(4), 422–428. <https://doi.org/10.18805/IJAR.A-5950>
- Madhavilatha, L., Rao, M. S., Priya, M. S., & Kumar, M. H. (2022b). Studies on variability, correlation and path analysis in foxtail millet (*Setaria italica* (L.) Beauv.). *Agricultural Research Journal*, **59**(2), 348–351.
- Munirathnam, P., Reddy, A. S., & Sawadhkar, S. M. (2006). Evaluation of foxtail millet varieties under low fertility conditions. *Agricultural Science Digest*, **26**(3), 197–199.
- Murugan, R., & Nirmala Kumari, A. (2006). Genetic divergence in foxtail millet (*Setaria italica* (L.) Beauv.). *Indian Journal of Genetics*, **66**(4), 339–340.
- Panase, V. G., & Sukhatme, P. V. (1957). *Statistical methods for agricultural workers*. ICAR, New Delhi.
- Pavani, A. (2019). *Character association and selection indices in foxtail millet (Setaria italica L.)* (M.Sc. (Ag.) thesis). Acharya N.G. Ranga Agricultural University, Guntur.

- Patel, S. N., Patil, H. E., Modi, H. M., & Singh, T. J. (2018). Genetic variability study in little millet (*Panicum miliare* L.) genotypes in relation to yield and quality traits. *International Journal of Current Microbiology and Applied Sciences*, **7**(6), 2712–2725.
- Pawan Kumar, G. K. (2019). *Diversity in morpho-physiological and biochemical components in genetic resources of foxtail millet (Setaria italica (L.) Beauv.)* (M.Sc. (Ag.) thesis). Acharya N.G. Ranga Agricultural University, Guntur.
- Pine, S. (2020). Nutrient management in foxtail millet: A review. *Indian Journal of Natural Sciences*, **10**(60), 23156–23160.
- Purusotama Rao, D., & Chaturvedi, H. P. (2025). Genetic variability, character association and path analysis for yield and yield components in foxtail millet [*Setaria italica* (L.) P. Beauv.] accessions under multi environments in foothills of Nagaland. *Environment and Ecology*, **43**(1), 161–168. <https://doi.org/10.60151/envec/QNDD8134>
- Rai, M. (2002). Nutritive cereals. In *Survey of Indian Agriculture* (pp. 59–62). The Hindu, Chennai, Tamil Nadu, India.
- Ravi, S. B., Hrideek, T. K., Kumar, A. T. K., Prabhakaran, T. R., Mal, B., & Padulosi, S. (2010). Mobilizing neglected and underutilized crops to strengthen food security and alleviate poverty in India. *Indian Journal of Plant Genetic Resources*, **23**, 117–121.
- Sachan, M. S. (2017). Genetic variability, correlation and path analysis of foxtail millet in Mon district of Nagaland. *Journal of Hill Agriculture*, **8**(3), 270–273.
- Sadasivam, S., & Manickam, A. (1996). *Biochemical methods*. New Age International Publishers, New Delhi.
- Schmidt, P., Hartung, J., Bennewitz, J., & Piepho, H. P. (2019). Heritability in plant breeding on a genotype-difference basis. *Genetics*, **212**(4), 991–1008.
- Singh, D., Lawrence, K., Marker, S., Bhattacharjee, I., Lawrence, R., Choudhary, R., Ercisli, S., & Karunakaran, R. (2023). Rainfed assessment of foxtail millet (*Setaria italica* L. Beauv.) germplasms through genotyping and principal component analysis. *Frontiers in Plant Sciences*, **14**, 101–118.
- Singh, R. K., & Chaudhary, B. D. (1977). *Biometrical methods in quantitative genetic analysis*.
- Sivasubramanian, S., & Madhavamenon, P. (1973). Combining ability in rice. *Madras Agricultural Journal*, **60**, 419–421.
- Smita, S., Patil, J. V., Sunil, G., & Ganapathy, K. N. (2016). Genetic variability and association analysis for grain yield and nutritional quality in foxtail millet. *International Journal of Bio-Resource and Stress Management*, **7**(6), 1239–1243.
- Srilatha, J., Haritha, T., Reddy, C. V. C. M., & Ramesh, D. (2020). Genetic variability studies for yield and nutritional traits in foxtail millet (*Setaria italica* (L.) Beauv.). *Journal of Pharmacognosy and Phytochemistry*, **9**(6), 931–936.
- Suthamathi, P., Dharnishkumar, M., & Manimozhi Selvi, V. (2025). Genetic divergence in foxtail millet (*Setaria italica* L.) germplasm accessions for quality and yield contributing traits. *Indian Journal of Agricultural Research*, Advance online publication, 1–6. <https://doi.org/10.18805/IJARE.A-63>
- Tandon, H. L. S. (1999). *Methods of analysis of soils, plants, waters and fertilizers*. Fertilizer Development and Consultation Organisation, New Delhi, India.
- Thakur, M., & Tiwari, P. (2019). Millets: The untapped and under-utilized nutritious functional foods. *Plant Archives*, **19**(1), 875–883.
- Tyagi, V., Ramesh, B., Kumar, D., & Pal, S. (2011). Genetic architecture of yield contributing traits in foxtail millet (*Setaria italica*). *Current Advances in Agricultural Sciences*, **3**(1), 29–32.
- Venkatesh, R., Lakshmi Pallavi, N., Jalandar Ram, B., & Suresh, B. G. (2020). Genetic divergence analysis in the foxtail millet (*Setaria italica*) germplasm as determined by phenotypical traits. *International Journal of Current Microbiology and Applied Sciences*, **9**(12), 1119–1127.
- Upadhyaya, H. D., Ravishankar, C. R., Narasimhudu, Y., Sarma, N. D. R. K., Singh, S. K., Varshney, S. K., Reddy, V. G., Singh, S., Parzies, H. K., Dwivedi, S. L., Nadaf, H. L., Sahrawat, K. L., & Gowda, C. L. L. (2011). Identification of trait-specific germplasm and developing a mini core collection for efficient use of foxtail millet genetic resources in crop improvement. *Field Crops Research*, **123**, 459–467. <https://doi.org/10.1016/j.fcr.2011.08.004>
- Yadav, Y., Dhoot, R., Kumhar, S. R., & Roy, C. (2024). Estimates of variability, heritability and genetic advance in foxtail millets. *Annals of Arid Zone*, **63**(1), 121–123.
- Zhang, H., Feng, Z., Wang, J., Yun, X., Qu, F., Sun, C., & Wang, Q. (2023). Genotype by environment interaction for grain yield in foxtail millet (*Setaria italica*) using AMMI model and GGE biplot. *Plant Growth Regulation*, **99**(1), 101–112.