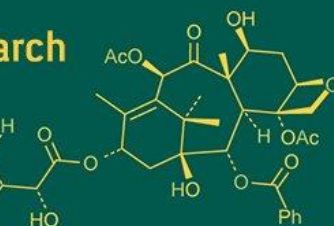
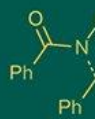


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**Shravan Kumar**  
M.Sc., Research Scholar,  
Department of Genetics and  
Plant Breeding, S. G. College of  
Agriculture and Research  
Station, Jagdalpur, Bastar,  
IGKV, Raipur, Chhattisgarh,  
India

**Bharat Kumar S**  
M.Sc., Research Scholar,  
Department of Genetics and  
Plant Breeding, S. G. College of  
Agriculture and Research  
Station, Jagdalpur, Bastar,  
IGKV, Raipur, Chhattisgarh,  
India

**Khoshboo Gupta**  
M.Sc., Research Scholar,  
Department of Genetics and  
Plant Breeding, S. G. College of  
Agriculture and Research  
Station, Jagdalpur, Bastar,  
IGKV, Raipur, Chhattisgarh,  
India

**RR Kanwar**  
Scientist, Department of  
Genetics and Plant Breeding,  
S. G. College of Agriculture and  
Research Station, Jagdalpur,  
Bastar, IGKV, Raipur,  
Chhattisgarh, India

**Prafull Kumar**  
Scientist, Department of  
Genetics and Plant Breeding,  
S. G. College of Agriculture and  
Research Station, Jagdalpur,  
Bastar, IGKV, Raipur,  
Chhattisgarh, India

**Corresponding Author:**  
**Prafull Kumar**  
Scientist, Department of  
Genetics and Plant Breeding,  
S. G. College of Agriculture and  
Research Station, Jagdalpur,  
Bastar, IGKV, Raipur,  
Chhattisgarh, India

## Phenotyping and crossability parameters studies in foxtail millet (*Setaria italica* L.) genotypes

**Shravan Kumar, Bharat Kumar S, Khoshboo Gupta, RR Kanwar and  
Prafull Kumar**

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### Abstract

A field experiment was conducted during *Kharif* 2024 at the Upland Research cum Instructional Farm, Lamker, Jagdalpur, Chhattisgarh, to evaluate 23 foxtail millet (*Setaria italica* L.) genotypes under the ICAR-AICRP on Foxtail Millet. The objective was to assess genetic variability, trait associations, genetic divergence, and crossability potential based on agro-morphological and yield-related traits. Seventeen traits (14 quantitative and 3 qualitative) were recorded following standard protocols. Qualitative analysis revealed notable variation in plant pigmentation, seed color and panicle color, indicating a broad genetic base. Quantitative analysis showed substantial variability, with grain yield exhibiting the highest genotypic and phenotypic coefficients of variation (28.98% and 29.19% respectively), while days to maturity recorded the lowest. High heritability was observed for fodder yield (98.57%), grain yield (89.21%) and plant height (85.64%), suggesting the effectiveness of selection for these traits. Grain yield was positively and significantly correlated with fodder yield, test weight, flag leaf dimensions, and plant height. Path analysis identified fodder yield as the major trait with the highest direct effect on grain yield. Principal Component Analysis (PCA) revealed that the first five components accounted for 85.1% of total variation, with PC1 alone contributing 46%. Genetic divergence based on Mahalanobis'  $D^2$  statistics grouped the genotypes into three distinct clusters, with the greatest genetic distance observed between Clusters I and III (5.86), indicating potential for heterotic hybrid combinations. Multiple linear regression further confirmed fodder yield as the only trait significantly influencing grain yield. Based on flowering and maturity duration, and pigmentation traits, genotypes such as SIA 4247, RPCAU-XM-2, and KOPFx2107 were identified as suitable parents for future hybridization programs. The study provides valuable insights for foxtail millet improvement through selection and breeding strategies.

**Keywords:** Genetic variability, Principal components, Cluster analysis, Regression analysis, Genetic divergence

### Introduction

Indian agriculture is well known for its various functions from providing environmental and food securities, employment and livelihood to nutritional (Sharma *et al.*, 2025) <sup>[20]</sup>. The global population is projected to reach nearly 10 billion by 2050, intensifying the demand for food (Kumari *et al.*, 2024) <sup>[12]</sup>. Employing high doses of fertilizers to achieve more yields is indispensable (Sharma *et al.*, 2020) <sup>[21]</sup> under intensive cropping, but blanket application of chemical fertilizers is considered as one of the major constraints to sustain crop production (Sharma *et al.*, 2021; Sharma *et al.*, 2025 and Kumari *et al.*, 2025) <sup>[22,20,11]</sup>. Recently next-generation precision farming technologies to enhance sustainable crop production and environmental sustainability (Yadav *et al.*, 2026b and Kumari *et al.*, 2026) <sup>[28,10]</sup>. With the global population steadily increasing, there is a growing need to boost agricultural productivity in order to ensure sufficient food supply for future generations (Gt *et al.*, 2025) <sup>[7]</sup>. Millets are traditional, small-grained, annual cereals cultivated in the Indian subcontinent for over 5000 years. These hardy, rainfed crops require less water and fertilizers than major cereals like rice and wheat, making them ideal for cultivation in arid and semi-arid regions. They have historically served as staple foods in Asia and Africa due to their adaptability, affordability and nutritional benefits. Among them, foxtail millet (*Setaria italica* L.), also known as Italian millet, holds significant importance. It is widely grown in Karnataka, India, and is native to Southern Asia. China's Yellow River basin accounts for 80% of global

production, with India ranking second at around 10%. Globally, millets rank sixth among cereal crops, with 2020 production at 89.17 million metric tons over 74 million hectares. Sorghum and pearl millet dominate production, followed by foxtail, finger, proso, barnyard, little, and kodo millets. In India, during 2021-22, millets were cultivated on 13.83 lakh hectares, producing 15.53 million tons at a productivity of 1248 kg/ha. Foxtail millet had the highest productivity at 2166 kg/ha. Despite having 5.88 million hectares of cultivable land, Chhattisgarh recorded low millet productivity in 2006 at just 210 kg/ha. Nutritionally, millets are rich in vitamins, minerals, fiber, sulphur-containing amino acids (Yadav *et al.*, 2026a) <sup>[27]</sup> and phytochemicals, earning them the term “Nutri-cereals.” Foxtail millet supports a steady glucose release, making it suitable for diabetic and heart-healthy diets. It also finds use in cosmetics and poultry feed. Crop improvement programs for foxtail millet rely on genetic variability, morphological characterization, and understanding of genotype-environment interactions. Heritability and genetic advance estimates guide effective selection, while genetic divergence helps identify diverse parent lines for hybridization (Kumari *et al.*, 2026) <sup>[10]</sup>. Thus, genetic evaluation and trait-based clustering are essential for developing improved foxtail millet cultivars.

Methods and materials

The present study was conducted during *Kharif* 2024 at the Upland Research cum Instructional Farm, Lamker, under Shaheed Gundadhoor College of Agriculture and Research Station, Jagdalpur, Chhattisgarh (19°4'0" N, 82°2'0" E; 552 m AMSL). The region experienced temperatures between 19.4°C and 32.9°C, with total rainfall of 1080 mm, highest in July (432 mm). The experiment involved 23 foxtail millet

(*Setaria italica* L.) germplasm lines under the ICAR-AICRP on Small Millets to evaluate crossability, performance, and phenotypic traits. The trial followed a randomized block design with three replications. Each plot (7.5 m<sup>2</sup>) had 10 rows (3 m length), with 2.5 m inter-row and 10 cm intra-row spacing. Sowing was done on July 5, 2024 and standard agronomic practices were followed. Observations were recorded from five randomly selected plants per plot for all traits except days to 50% flowering and days to maturity, which were recorded on a plot basis, following ICAR-IIMR guidelines. A total of 17 traits were studied, including 14 quantitative (e.g., days to panicle initiation, anthesis, maturity, plant height, flag leaf dimensions, panicle length, test weight, fodder and grain yield, and productive tillers) and 3 qualitative traits (plant pigmentation, panicle color and seed color). The collected data were used for statistical analysis to study genetic variability and adaptability of the genotypes under local agro-climatic conditions.

Result and Discussion  
Qualitative traits description

In genetics, qualitative characters are typically controlled by either a single gene (monogenic) or multiple genes (polygenic), with their expression remaining unaffected by environmental conditions. These traits were traditionally treated as separate variables, using counts and ratios to determine their frequencies. Qualitative traits generally do not exhibit transgressive segregation, tend to have high heritability, and show significant variation across different family lines. Three qualitative traits were specifically selected for analysis: plant pigmentation at the junction of the leaves, panicle color and seed color presented in figure 1.

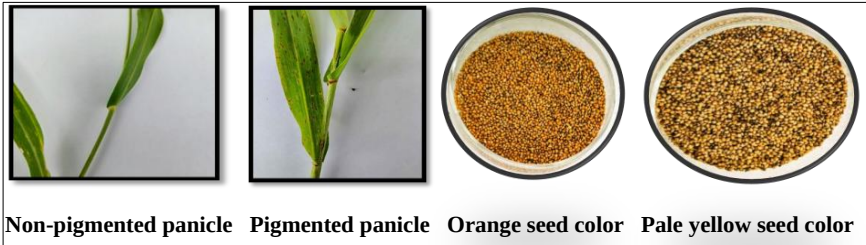


Fig 1: Qualitative traits of Foxtail millet (*Setaria italica* L.) genotypes



There were total of 23 genotypes assessed. Among these, 8 genotypes (35%) showed purple pigmentation at the leaf juncture and remaining 8 genotypes (65%) showed green

pigmentation at the leaf juncture, which was regarded as the absence of pigmentation shown in table 1.

Table 1: Characterization of foxtail millet genotypes on the basis of nodal and panicle pigmentation

| Pigmented genotypes                                                                     | Non-pigmented genotypes                                                                                                                                                      |
|-----------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| SIA 4247, SIA 4253, TNPsi396, IIMR FXM-18, CRS FXM-22, SIA 3156, DHFT-109-3,Local Check | KOPFx2107, IIMR FXM 14, IIMR FXM 17, RPCAU-FXM-2, CRS-FXM-11, SIA 4261, KIFXG-22-09, kifxg-22-02, IIMR FXM-19, IIMR FXM-20, IIMR FXM-21, PKS-22, F 62-20-1, PKS-22, SIA 3222 |

Similar result was also found by Tiwari (2024) [25]. Out of 23 genotypes there were 20 genotypes (87%) with brown seeds, 2 genotypes (9%) with pale yellow color seeds, 1 genotype (4%) with pale orange seeds shown in table 2.

Table 2: Categorization of foxtail millet genotypes on the basis of seed color

| Pigmentation | Genotypes                                                                                                                                                                                                                              |
|--------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Brown color  | KOPFx2107, SIA 4247, IIMR FXM 14, IMR FXM 17, PCAU-XM-2, CRS-FXM-11, SIA 4261, KIFXG-22-09, kifxg-22-02, TNPsi396, IIMR FXM-18, IMR FXM- 19, IIMR FXM-20, IIMR FXM-21, F 62-20-1, PKS-22, CRS FxM-22, SIA 3156, DHT-109-3, Local Check |
| Pale yellow  | SIA 4253, PKS-22                                                                                                                                                                                                                       |
| Pale orange  | SIA 3222                                                                                                                                                                                                                               |

Similarly, Charitha (2023) [3] studied 64 genotypes and showed similar result. Among 23 genotypes, 8 genotypes (35%) showed pigmented panicle (purple color) and remaining 15 genotypes (65%) showed non- pigmented panicle or green color shown in table 3. Similar result also found by Nanda and Agrawal (2008) [15].

Table 3: Cluster classification of foxtail millet genotype

| Source of variation | D F | Days to panicle initiation n | Days to spikelet initiation n | days to 50% flowerin g | Days to anthesis completio n | Days to maturit y | Plant height (cm) | Panicl e length (cm) | No. of tiller | No. of leaves | Flag leaf length (cm) | Flag leaf width (cm) | Test weight (g) | Fodder yield (kg/plot ) | Grain yield (kg/plot ) |
|---------------------|-----|------------------------------|-------------------------------|------------------------|------------------------------|-------------------|-------------------|----------------------|---------------|---------------|-----------------------|----------------------|-----------------|-------------------------|------------------------|
| Rep.                | 2   | 2.84                         | 3.58                          | 1.45                   | 2.80                         | 5.28              | 0.14              | 0.27                 | 0.001         | 0.178         | 12.54                 | 0.002                | 0.004           | 0.002                   | 0.002                  |
| Treat               | 22  | 19.14**                      | 18.01**                       | 26.73**                | 29.72**                      | 23.97**           | 172.96* *         | 5.91**               | 0.015* *      | 1.665* *      | 21.70* *              | 0.042* *             | 0.022* *        | 1.465**                 | 0.089**                |
| Error               | 44  | 3.75                         | 4.26                          | 1.90                   | 2.57                         | 3.17              | 9.15              | 0.60                 | 0.005         | 0.185         | 2.78                  | 0.005                | 0.008           | 0.007                   | 0.003                  |
| Total               | 68  | 8.70                         | 8.69                          | 9.92                   | 11.36                        | 9.96              | 61.89             | 2.31                 | 0.008         | 0.664         | 9.19                  | 0.017                | 0.012           | 0.479                   | 0.031                  |
| Mean                |     | 49                           | 52                            | 57                     | 61                           | 89                | 111               | 16.01                | 1.12          | 6             | 31.34                 | 1.70                 | 2.64            | 2.41                    | 0.87                   |
| Min                 |     | 42                           | 46                            | 47                     | 52                           | 81                | 83                | 13.23                | 1.00          | 4             | 24.83                 | 1.49                 | 2.45            | 1.20                    | 0.63                   |
| Max                 |     | 52                           | 55                            | 61                     | 65                           | 94                | 118               | 18.57                | 1.27          | 8             | 36.20                 | 1.93                 | 2.79            | 3.60                    | 1.12                   |
| SE(d) ±             |     | 1.58                         | 1.69                          | 1.13                   | 1.31                         | 1.45              | 2.47              | 0.63                 | 0.06          | 0.35          | 1.36                  | 0.06                 | 0.07            | 0.07                    | 0.05                   |
| C.V. (%)            |     | 3.93                         | 3.97                          | 2.44                   | 2.63                         | 2.01              | 5.48              | 8.97                 | 6.40          | 6.64          | 12.58                 | 11.49                | 3.36            | 14.70                   | 15.35                  |

Quantitative traits description

Quantitative characters are traits in plants that show continuous variation and are usually controlled by multiple genes (polygenes), often influenced by environmental factors. The traits recorded included days to panicle initiation, days to spikelet initiation, days to anthesis completion, days to 50% flowering, days to maturity (flowering stage), panicle length and plant height (maturity stage), and test weight fodder yield and grain yield per plot (post-harvest). Days to panicle initiation ranged from 42 days (SIA 3222) to 52 days (Local check) after sowing. Out

of 23 genotypes assessed 2 genotypes (9%) were classified as medium and 21 genotypes (91%) as late panicle initiation. Maximum days to panicle initiation recorded in Local Check and PKS-22 (52 DAS) with mean value of 49 and a coefficient of variation of 3.93 was recorded for this character. Days to spikelet initiation ranged from 46 (IIMR FXM 14) days to 55 (IIMR FXM-18) days after sowing. Out of 23 genotypes assessed 3 genotypes (13%) were classified as medium and 20 genotypes (87%) as late spikelet initiation with mean value of 52 and a coefficient of variation of 3.97 were recorded for this character (Table 4).

Table 4: Analysis of variance

| Clusters | No of genotypes | Genotypes                                                                                                          |
|----------|-----------------|--------------------------------------------------------------------------------------------------------------------|
| I        | 4               | IIMR FXM 14, RPCAU-XM-2, F 62-20-1, SIA 3222                                                                       |
| II       | 12              | KOPFx 2107, SIA 4247, IIMR FXM 17, SIA 4253, SIA4261, KIFXG-22-09, kifxg-22-02, IIMR FXM-20, IIMR FXM-21, SIA 3156 |
| III      | 7               | CRS-FXM-11, TNPsi 396, IIMR FXM-18, IIMR FXM-19, PKS-2, PKS-22, CRS FxM-22, Local Check                            |

Days to anthesis completion ranged from 52 (IIMR FXM 14) days to 65 (IIMR FXM-18) days after sowing. Out of 23 genotypes assessed 9 genotypes (41%) were classified as medium and 13 genotypes (59%) as late anthesis completion with mean value of 61 and a coefficient of variation of 2.63 were recorded for this character. Similarly, Sapkota *et al.* (2016) [18] performed an experiment and found similar result. Among 23 genotypes under investigation, 8 genotypes (35%) showed medium duration flowering (45-55 DAS) and 15 genotypes (65%) displayed late duration flowering (>55 DAS) with mean value of 57 and a coefficient of variation of 2.44 were recorded for this character. Similar result was found by Elangovan *et al.* (2022) [5] who performed an

experiment on finger millet. Days to maturity ranged from 81 (SIA 3322) days to 94 (Local check) days after sowing. Out of 23 genotypes assessed 7 genotypes (30%) were classified as medium, 16 genotypes (70%) as late maturity with mean value of 89 and a coefficient of variation of 2.01 were recorded for this character. Previously Sapkota *et al.* (2016) [18] performed an experiment and found similar result. Among the 23 accessions analyzed all the 23 genotypes (100%) were of medium height and varied from 81 cm (SIA 3222) to 118 cm (TNPsi396) with mean value of 111 cm and a coefficient of variation of 5.48 were recorded for this character. All the 23 out of 23 genotypes medium flag leaf length and varied from 24.83 cm (IIMR FXM 14) to 36.20

cm (IIMR FXM 17) with an overall mean of 31.34 cm and a coefficient of variation of 8.97 were recorded for this character. Similarly, Makwana *et al.* (2023) [14] studied 93 foxtail genotypes originated similar result. All the 23 out of 23 genotypes shown medium flag width at dough stage and ranged varied from 1.49 cm (IIMR FXM 17) to 1.93 cm (IIMR FXM-18) with mean value of 1.70 cm and a coefficient of variation of 11.49 were recorded for this character. Among the 23, 10 genotypes consisted of medium panicle (43.47%), 13 genotypes comprised of long panicle (56.53%) and none of the genotypes showed short panicle length and ranged varied from 13.23 cm (SIA 3222) to 18.57 cm (CRS-FXM-11) with an average mean of 16.01 cm and coefficient of variation of 5.49 were recorded for this character. In similar way Sapkota *et al.* (2016) [18] also performed an experiment and found that the mean panicle length was 8.85 cm. Test weight ranged from 2.45 g (F 62-20-1) to 2.79 g (KIFXG-22-09) with general mean of 2.64 g and 23 out of 23 (100%) genotypes shown medium test weight with mean value of 2.64 g

and coefficient of variation of 3.36 was recorded for this character. Previously, Ramesh *et al.* (2023) [16] also found significant variation was found for this trait. Number of leaves ranged from 4 (RPCAU-XM-2) to 8 (IIMR FXM-18). Among 23 out of 23 genotypes consisted of minimum number of leave with mean value of 7 and a coefficient of variation of 6.64 were recorded for this character.

Similar result was also showed by Upadhyaya *et al.* (2016) [26]. Fodder yield ranged from 1.2 kg/plot (SIA 3222) to 3.36 kg/plot (IIMR FXM-18) in which 19 genotypes (83%) out of 23 genotypes shown low and 4 genotypes (17%) shown medium fodder yield. Similarly, Makwana *et al.* (2023) [14] studied 93 foxtail and showed similar result. Grain yield ranged from 0.63 kg/plot (PKS-22) to 1.12 kg/plot (SIA 4247) in which 7 genotypes (35%) out of 23 genotypes shown low and 16 genotypes (65%) shown medium grain yield with mean value of 2.41 kg/plot and a coefficient of variation of 15.35 were recorded for this character which is depicted in table 5. Sapkota *et al.* (2016) [18] who also performed an experiment and found similar result.

**Table 5:** Genetic variability parameters

| Characters                  | Mean   | Min   | Max    | Var (g) | Var (p) | GA    | Heritability (%) | GA% mean | GCV (%) | PCV (%) |
|-----------------------------|--------|-------|--------|---------|---------|-------|------------------|----------|---------|---------|
| Days to panicle initiation  | 49.28  | 42.00 | 51.67  | 5.130   | 8.88    | 57.77 | 3.55             | 7.20     | 4.60    | 6.05    |
| Days to spikelet initiation | 51.99  | 46.00 | 55.00  | 4.584   | 8.85    | 51.82 | 3.18             | 6.11     | 4.12    | 5.72    |
| days to 50% flowering       | 56.58  | 46.67 | 61.33  | 8.277   | 10.18   | 81.30 | 5.34             | 9.44     | 5.08    | 5.64    |
| Days to anthesis completion | 60.86  | 52.00 | 65.00  | 9.051   | 11.62   | 77.89 | 5.47             | 8.99     | 4.94    | 5.60    |
| Days to maturity            | 88.51  | 81.00 | 94.00  | 6.932   | 10.10   | 68.63 | 4.49             | 5.08     | 2.97    | 3.59    |
| Plant height (cm)           | 110.60 | 83.13 | 117.93 | 54.60   | 63.75   | 85.64 | 14.09            | 12.74    | 6.68    | 7.22    |
| Panicle length (cm)         | 16.01  | 13.23 | 18.57  | 1.768   | 2.37    | 74.59 | 2.37             | 14.77    | 8.30    | 9.61    |
| No. of tiller               | 1.12   | 1.00  | 1.27   | 0.003   | 0.01    | 40.16 | 0.08             | 6.84     | 5.24    | 8.26    |
| No. of leaves               | 6.48   | 4.33  | 7.73   | 0.493   | 0.68    | 72.67 | 1.23             | 19.02    | 10.83   | 12.71   |
| Flag leaf length (cm)       | 31.34  | 24.83 | 36.20  | 6.305   | 9.09    | 69.36 | 4.31             | 13.75    | 8.01    | 9.62    |
| Flag leaf width (cm)        | 1.70   | 1.49  | 1.93   | 0.012   | 0.02    | 70.13 | 0.19             | 11.17    | 6.48    | 7.73    |
| Test weight (g)             | 2.64   | 2.45  | 2.79   | 0.005   | 0.01    | 37.14 | 0.09             | 3.24     | 2.58    | 4.24    |
| Fodder yield (kg/plot)      | 2.41   | 1.20  | 3.60   | 0.486   | 0.49    | 98.57 | 1.43             | 59.28    | 28.98   | 29.19   |
| Grain yield (kg/plot)       | 0.87   | 0.63  | 1.12   | 0.029   | 0.03    | 89.21 | 0.33             | 37.80    | 19.43   | 20.57   |

### Genetic variability, heritability and genetic advance

The study showed considerable genetic variability across traits using GCV and PCV. Grain yield recorded the highest GCV (28.98%) and PCV (29.19%), while days to maturity had the lowest (GCV: 2.97%, PCV: 3.59%). Number of productive tillers also showed high variability (GCV: 25.94%, PCV: 28.32%). High heritability was observed in fodder yield (98.57%), grain yield (89.21%), and plant height (85.64%). Genetic advance was highest in plant height (14.09) and lowest in productive tillers (0.08). As a percentage of mean, fodder yield (59.28%) and grain yield (37.80%) had the highest values, while test weight (3.24%) and days to maturity (5.08%) were lowest consistent with Anuradha *et al.* (2020) [11], Jyothsna *et al.* (2016) [9] and Tiwari (2024) [18].

### Character association studies

Character association studies refer to the statistical analysis of relationships between different plant traits (characters) to understand how they co-vary. These studies commonly use correlation coefficients and path coefficient analysis.

### Correlation analysis

Grain yield exhibited positive and significant correlation with number of leaves (0.281\*), flag leaf length (0.356\*\*), plant height (0.358\*\*), flag leaf width (0.262\*), test weight (0.477\*\*), fodder yield (0.766\*\*) and shown positive non-significant correlation with days to panicle initiation (0.210), days to spikelet initiation (0.203), days to 50% flowering (0.088), days to anthesis completion (0.045), days to maturity (0.060), panicle length (0.102). grain yield shows negative correlation with number of productive tillers (-0.207) which is depicted in table 6.

**Table 6:** Phenotypic correlations

| Characters                  | Days to panicle initiation | Days to spikelet initiation | days to 50% flowering | Days to anthesis completion | Days to maturity | Plant height (cm) | Panicle length (cm) | No. of productive tillers | No. of leaves | Flag leaf length (cm) | Flag leaf width (cm) | Test weight (g) | Fodder yield (kg/plot) | Grain yield (kg/plot) |
|-----------------------------|----------------------------|-----------------------------|-----------------------|-----------------------------|------------------|-------------------|---------------------|---------------------------|---------------|-----------------------|----------------------|-----------------|------------------------|-----------------------|
| Days to panicle initiation  | 1.000                      | 0.955**                     | 0.677**               | 0.631**                     | 0.656**          | 0.571**           | 0.436**             | 0.169                     | 0.281*        | 0.464**               | 0.185                | 0.201           | 0.324**                | 0.210                 |
| Days to spikelet initiation |                            |                             | 0.701**               | 0.643**                     | 0.630**          | 0.486**           | 0.404**             | 0.137                     | 0.336**       | 0.485**               | 0.125                | 0.187           | 0.322**                | 0.203                 |
| days to 50% flowering       |                            |                             |                       | 0.929**                     | 0.711**          | 0.356**           | 0.427**             | 0.201                     | 0.243*        | 0.489**               | 0.100                | 0.156           | 0.257*                 | 0.088                 |
| Days to anthesis completion |                            |                             |                       |                             | 0.709**          | 0.353**           | 0.421**             | 0.246*                    | 0.211         | 0.453**               | 0.135                | 0.095           | 0.287*                 | 0.045                 |
| Days to maturity            |                            |                             |                       |                             |                  | 0.517**           | 0.459**             | 0.167                     | 0.369**       | 0.405**               | 0.050                | 0.198           | 0.272*                 | 0.060                 |
| Plant height (cm)           |                            |                             |                       |                             |                  |                   | 0.567**             | -0.064                    | 0.065         | 0.327**               | 0.184                | 0.274*          | 0.489**                | 0.358**               |
| Panicle length (cm)         |                            |                             |                       |                             |                  |                   |                     | 0.368**                   | -0.030        | 0.267*                | 0.160                | 0.216           | 0.376**                | 0.102                 |
| No. of productive tillers   |                            |                             |                       |                             |                  |                   |                     |                           | -0.146        | 0.013                 | -0.014               | 0.158           | -0.067                 | -0.207                |
| No. of leaves               |                            |                             |                       |                             |                  |                   |                     |                           |               | 0.424**               | 0.137                | 0.251*          | 0.276*                 | 0.281*                |
| Flag leaf length (cm)       |                            |                             |                       |                             |                  |                   |                     |                           |               |                       | 0.094                | 0.174           | 0.355**                | 0.356**               |
| Flag leaf width (cm)        |                            |                             |                       |                             |                  |                   |                     |                           |               |                       |                      | 0.225           | 0.317**                | 0.262*                |
| Test weight (g)             |                            |                             |                       |                             |                  |                   |                     |                           |               |                       |                      |                 | 0.464**                | 0.477**               |
| Fodder yield (kg/plot)      |                            |                             |                       |                             |                  |                   |                     |                           |               |                       |                      |                 |                        | 0.766**               |
| Grain yield (kg/plot)       |                            |                             |                       |                             |                  |                   |                     |                           |               |                       |                      |                 |                        | 1.000                 |

Significant correlations demonstrate that larger, more vigorous plants with broader and longer flag leaves are better able to support grain development. In contrast negative correlation indicating that higher tillering may not always translate to better grain output. These findings are in accordance with the results of Ganapathy *et al.* (2011) <sup>[6]</sup> and Shinde *et al.* (2014) <sup>[23]</sup>.

#### Phenotypic Path Coefficient analysis

At phenotypic path among all the component, fodder yield

kg/plot exhibited the highest direct effect (0.7167) on the grain yield followed by days to 50% flowering (0.2882), days to panicle initiation (0.1823), flag leaf length (0.1632), test weight (0.1453), plant height (0.0902), number of leaves (0.0198), flag leaf width (0.0093) and days to anthesis completion (-0.3707), panicle length (-0.1645), days to maturity (-0.01645) and number of productive tillers (-0.0575) recorded negative direct effect on grain yield at phenotypic level which is depicted in table 7.

**Table 7:** Phenotypic path with Grain yield

| Characters                  | Days to panicle initiation | Days to spikelet initiation | days to 50% flowering | Days to anthesis completion | Days to maturity | Plant height (cm) | Panicle length (cm) | No. of tiller | No. of leaves | Flag leaf length | Flag leaf width | Test weight (g) | Fodder yield (kg/plot) | Grain yield (kg/plot) |
|-----------------------------|----------------------------|-----------------------------|-----------------------|-----------------------------|------------------|-------------------|---------------------|---------------|---------------|------------------|-----------------|-----------------|------------------------|-----------------------|
| Days to panicle initiation  | 0.1823                     | -0.1294                     | 0.1952                | -0.2338                     | -0.1079          | 0.0515            | -0.0825             | -0.0098       | 0.0056        | 0.0758           | 0.0017          | 0.0292          | 0.2319                 | 0.210                 |
| Days to spikelet initiation | 0.1741                     | -0.1356                     | 0.2019                | -0.2383                     | -0.1035          | 0.0438            | -0.0764             | -0.0079       | 0.0067        | 0.0791           | 0.0012          | 0.0271          | 0.2307                 | 0.203                 |
| days to 50% flowering       | 0.1235                     | -0.0950                     | 0.2882                | -0.3445                     | -0.1170          | 0.0322            | -0.0809             | -0.0116       | 0.0048        | 0.0798           | 0.0009          | 0.0227          | 0.1844                 | 0.088                 |
| Days to anthesis completion | 0.1150                     | -0.0872                     | 0.2678                | -0.3707                     | -0.1166          | 0.0318            | -0.0798             | -0.0142       | 0.0042        | 0.0740           | 0.0013          | 0.0138          | 0.2055                 | 0.045                 |
| Days to maturity            | 0.1196                     | -0.0854                     | 0.2049                | -0.2627                     | -0.1645          | 0.0466            | -0.0868             | -0.0096       | 0.0073        | 0.0661           | 0.0005          | 0.0287          | 0.1950                 | 0.060                 |
| Plant height (cm)           | 0.1041                     | -0.0658                     | 0.1027                | -0.1309                     | -0.0850          | 0.0902            | -0.1073             | 0.0037        | 0.0013        | 0.0534           | 0.0017          | 0.0398          | 0.3502                 | 0.358**               |
| Panicle length (cm)         | 0.0795                     | -0.0547                     | 0.1232                | -0.1562                     | -0.0755          | 0.0512            | -0.1893             | -0.0212       | -0.0006       | 0.0436           | 0.0015          | 0.0314          | 0.2697                 | 0.102                 |

|                        |        |         |        |         |         |        |         |         |        |        |        |        |         |         |
|------------------------|--------|---------|--------|---------|---------|--------|---------|---------|--------|--------|--------|--------|---------|---------|
| No. of tiller          | 0.0309 | -0.0186 | 0.0580 | -0.0913 | -0.0275 | -      | -0.0696 | -       | -      | 0.0022 | -      | 0.0230 | -0.0483 | -0.207  |
| No. of leaves          | 0.0512 | -0.0456 | 0.0700 | -0.0784 | -0.0608 | 0.0058 | 0.0057  | 0.00575 | 0.0029 | 0.0001 | 0.0230 | 0.0365 | 0.1981  | 0.281*  |
| Flag leaf length (cm)  | 0.0847 | -0.0657 | 0.1409 | -0.1681 | -0.0666 | 0.0295 | -0.0505 | -       | 0.0008 | 0.0084 | 0.1632 | 0.0009 | 0.0253  | 0.2546  |
| Flag leaf width (cm)   | 0.0338 | -0.0170 | 0.0287 | -0.0502 | -0.0083 | 0.0166 | -0.0303 | 0.0008  | 0.0027 | 0.0153 | 0.0093 | 0.0327 | 0.2275  | 0.262*  |
| Test weight (g)        | 0.0366 | -0.0253 | 0.0451 | -0.0351 | -0.0325 | 0.0247 | -0.0408 | -       | 0.0091 | 0.0050 | 0.0284 | 0.0021 | 0.1453  | 0.3324  |
| Fodder yield (kg/plot) | 0.0590 | -0.0436 | 0.0741 | -0.1063 | -0.0448 | 0.0441 | -0.0712 | 0.0039  | 0.0055 | 0.0580 | 0.0030 | 0.0674 | 0.7167  | 0.766** |

Above findings revealed that among all traits evaluated, fodder yield exhibited the highest positive direct effect on grain yield, indicating that biomass accumulation plays a major and direct role in enhancing grain production. These findings are in agreement with earlier results of Kumari and Nagarajan (2008) <sup>[13]</sup>, Sirisha *et al.* (2009) <sup>[24]</sup>, Sathya *et al.* (2014) <sup>[19]</sup>.

### Genetic Divergence

Genetic diversity analysis using Mahalanobis' D<sup>2</sup> statistics grouped 23 genotypes into three clusters: Cluster II (12

genotypes), Cluster III (7), and Cluster I (4), indicating substantial genetic divergence. The highest intra-cluster distance was in Cluster I (3.46), followed by Cluster II (2.68), and the lowest in Cluster III (2.26). Maximum inter-cluster distance was between Cluster I and III (5.86), while the lowest was between Cluster II and III (2.77). Key traits contributing to divergence included days to spikelet initiation (11.04%), days to maturity (9.08%), anthesis completion (8.95%) and panicle initiation (8.81%) (Table 8) supporting earlier findings by Ayesha *et al.* (2019) <sup>[2]</sup>.

**Table 8:** Cluster mean mahabalanis D<sup>2</sup> statistics

| Clusters |      | Days to panicle initiation | Days to spikelet initiation | days to 50% flowering | Days to anthesis completion | Days to maturity | Plant height (cm) | Panicle length (cm) | No. of tiller | No. of leaves | Flag leaf length (cm) | Flag leaf width (cm) | Test weight (g) | Fodder yield (kg/plot) | Grain yield (kg/plot) |
|----------|------|----------------------------|-----------------------------|-----------------------|-----------------------------|------------------|-------------------|---------------------|---------------|---------------|-----------------------|----------------------|-----------------|------------------------|-----------------------|
| I        | Mean | 45.08                      | 48.08                       | 52.25                 | 56.33                       | 84.58            | 101.77            | 14.49               | 1.08          | 5.97          | 27.18                 | 1.64                 | 2.52            | 1.65                   | 0.69                  |
|          | SE±  | 2.90                       | 2.38                        | 3.82                  | 3.14                        | 2.47             | 12.97             | 1.49                | 0.10          | 1.09          | 1.80                  | 0.08                 | 0.07            | 0.52                   | 0.06                  |
| II       | Mean | 49.94                      | 52.64                       | 57.03                 | 61.14                       | 88.61            | 112.22            | 15.98               | 1.10          | 6.69          | 32.36                 | 1.73                 | 2.69            | 2.88                   | 1.01                  |
|          | SE±  | 1.35                       | 1.70                        | 1.93                  | 2.22                        | 2.01             | 5.20              | 1.04                | 0.06          | 0.67          | 1.99                  | 0.14                 | 0.05            | 0.54                   | 0.09                  |
| III      | Mean | 50.52                      | 53.10                       | 58.29                 | 62.95                       | 90.57            | 112.86            | 16.95               | 1.17          | 6.43          | 31.96                 | 1.68                 | 2.63            | 2.03                   | 0.72                  |
|          | SE±  | 1.18                       | 1.21                        | 1.51                  | 1.85                        | 1.89             | 3.81              | 1.25                | 0.05          | 0.60          | 1.89                  | 0.09                 | 0.07            | 0.36                   | 0.07                  |

### Principal Component Analysis (PCA)

Principal Component Analysis (PCA) was used to reduce dimensionality and explore the underlying structure of agronomic and physiological traits. These included phenological traits (e.g., days to flowering, maturity), morphological traits (e.g., plant height, panicle length, leaf dimensions) and yield components such as fodder yield, test weight, and grain yield. By analyzing eigenvectors, the contribution of each trait to principal components was assessed, aiding in understanding trait relationships and their impact on grain yield. A total of 14 principal components

(PCs) were extracted. The first five principal components had eigenvalues greater than or close to 1 and together accounted for approximately 85.1% of the total variation in the dataset. The principal component analysis revealed that the first component (PC1) contributed the most to genotype divergence, accounting for 46% of total variation with an eigenvalue of 6.43. The second, third, and fourth canonical vectors added 17.0%, 9.8%, and 6.9% respectively, while the fifth and sixth components contributed 5.4% which is depicted in table 9.

**Table 9:** Eigenvalues, Proportion, Cumulative Proportion characters

| Principal Component | Eigenvalues | Proportion | Cumulative Proportion |
|---------------------|-------------|------------|-----------------------|
| PC1                 | 6.434       | 46%        | 46%                   |
| PC2                 | 2.378       | 17%        | 62%                   |
| PC3                 | 1.375       | 9.8%       | 72.8%                 |
| PC4                 | 0.968       | 6.9%       | 79.7%                 |
| PC5                 | 0.753       | 5.4%       | 85.1%                 |

Altogether, these five principal components explained a cumulative variability of 85.1% among genotypes assessed for various agro-morphological traits. The first principal component (PC1) had an eigenvalue of 6.434, explaining 46.0% of the total variance, second principal component (PC2), with an eigenvalue of 2.378, accounted for 17.0% of the total variance, third principal component (PC3) had an

eigenvalue of 1.375, contributing 9.8% to the total variation, fourth principal component (PC4) accounted for 6.9% of the variance and fifth principal component (PC5) had an eigenvalue of 0.753, contributing 5.4% to the total variation which is depicted in table 10. Similarly, Reddy *et al.* (2020) <sup>[17]</sup> also studied and showed similar result.

**Table 10:** Principal component of yield and yield attributing characters

| Characters                  | PC1   | PC2    | PC3    | PC4    | PC5    |
|-----------------------------|-------|--------|--------|--------|--------|
| Days to panicle initiation  | 0.365 | -0.066 | -0.101 | 0.063  | -0.076 |
| Days to spikelet initiation | 0.366 | -0.072 | -0.191 | -0.016 | -0.055 |
| Days to 50% flowering       | 0.329 | -0.228 | -0.085 | -0.112 | -0.075 |
| Days to anthesis completion | 0.333 | -0.243 | -0.007 | -0.140 | -0.130 |
| Days to maturity            | 0.333 | -0.184 | -0.099 | 0.137  | 0.036  |
| Plant height (cm)           | 0.274 | 0.105  | 0.178  | 0.586  | -0.226 |
| Panicle length (cm)         | 0.273 | -0.138 | 0.402  | 0.179  | 0.095  |
| No. of productive tillers   | 0.114 | -0.397 | 0.414  | -0.380 | 0.349  |
| No. of leaves               | 0.172 | 0.193  | -0.536 | -0.334 | 0.155  |
| Flag leaf length (cm)       | 0.281 | 0.061  | -0.293 | -0.022 | 0.047  |
| Flag leaf width (cm)        | 0.110 | 0.237  | 0.303  | -0.515 | -0.711 |
| Test weight (g)             | 0.199 | 0.322  | 0.253  | -0.212 | 0.478  |
| Fodder yield (kg/plot)      | 0.236 | 0.409  | 0.199  | 0.051  | 0.103  |
| Grain yield (kg/plot)       | 0.158 | 0.538  | 0.053  | 0.030  | 0.119  |

### Crossability parameters study

Under current experiment criteria followed to draw the inference about making possible crosses among foxtail millet genotypes on the basis of flowering synchronization days to 50% flowering medium flowering genotypes (55-70 DAS) might be better as compared to medium (45-55) and late (>55 DAS) such as IIMR FXM 14, SIA 3222, RPCAU-XM-2, kifxg-22-02, KOPFx2107, SIA 4261, PKS-22 showed medium duration flowering and for days to maturity medium maturing genotypes (RPCAU-XM-2, kifxg-22-02, SIA 4261, F 62-20-1, KOPFx2107, KIFXG-22-09, SIA 3156, IIMR FXM-20, IIMR FXM-21) can be preferred over early and late maturing variety. On the basis of dominant morphological marker (node and panicle color) purple (pigmented) such as SIA 4247, SIA 4253, TNPsi 396 and green color (non-pigmented) such as KOPFx2107, IIMR FXM 14, IIMR FXM 17 can be preferred for making cross. Medium-duration flowering and maturing genotypes along with pigmented and non-pigmented types identified based on key morphological markers such as panicle and node colour were found suitable for potential hybridization programs. Highest inter cluster distance was found between cluster I and cluster III (5.86) followed by cluster I and cluster II (5.73), cluster II and cluster III (2.77). So, the cross between the genotypes of Cluster III and cluster I followed by cluster I and cluster Iet I will generate heterotic individual. These findings are in accordance with the results of Dodake *et al.* (1998) <sup>[4]</sup> and Gupta *et al.* (2012) <sup>[8]</sup> in finger millet.

### Conclusion

The study revealed significant genetic variability among foxtail millet genotypes across both qualitative and quantitative traits, with grain yield showing the highest variation and strong positive associations with fodder yield, plant height, test weight, and flag leaf dimensions. High heritability estimates for key traits like fodder yield, grain yield, and plant height indicate the potential effectiveness of selection in breeding programs. Path and regression analyses consistently identified fodder yield as the most influential trait on grain yield, while PCA and genetic divergence analyses highlighted substantial genetic diversity and grouped genotypes into distinct clusters, offering opportunities for heterotic hybrid combinations. Genotypes such as SIA 4247, RPCAU-FXM-2 and KOPFx2107 emerged as promising parents for future hybridization efforts, emphasizing the study's utility in guiding targeted

selection and breeding strategies for foxtail millet improvement.

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