



## Inter-character association and path analysis in newly developed hybrids of pearl millet

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### Abstract

The current study looked at eight new pearl millet hybrids to assess both their quantity and quality characteristics, and to find out how different traits connected to yield are related. The experiment took place during the kharif season in 2025-2026 at the Field Experimentation Centre, which is part of the Department of Genetics and Plant Breeding at Naini Agricultural Institute in Prayagraj. It used a randomized block design with three replications. Researchers recorded data on several features including field germination, plant height, days until 50% tasseling, days until 50% silking, days to maturity, test weight, seed yield, grain color, stay-green trait, and levels of pests and diseases. The analysis of variance showed that there were big differences among the hybrids for all the quantitative traits, showing there was a lot of genetic variation. Seed yield varied from 6.54 to 22.21 grams per five plants, with PM-100 having the highest yield and PM-300 the lowest. The genetic correlations were usually higher than the phenotypic ones. Seed yield had a strong positive link with plant height ( $r = 0.902$ ;  $r^2 = 0.726$ ) and days to maturity ( $r = 0.870$ ;  $r^2 = 0.617$ ). Path analysis found that plant height had the biggest positive direct effect at the phenotypic level (0.569), while days to maturity had the greatest positive direct effect at the genotypic level (1.494). These traits, along with test weight, are helpful for selecting better pearl millet hybrids that can produce higher yields.

**Keywords:** Pearl millet, correlation coefficient, path analysis, seed yield, genetic variability, hybrid evaluation

### Introduction

Pearl millet [*Pennisetum glaucum* (L.) R.Br.] is an essential warm-season cereal from the grass family Poaceae. It is commonly grown in dry and semi-dry areas of Asia and Africa. This crop is very adaptable to high temperatures, low and unpredictable rainfall, and less fertile soils. Because of these traits, it is especially useful in places where other grains do not grow well. In addition to being a food crop, pearl millet is also valuable as animal feed and plays a big role in ensuring food, nutrition, and livelihood security. Its grains are rich in carbohydrates, protein, fiber, minerals, and other important nutrients, which makes it more important for food security and farming that can withstand climate changes (Saleh *et al.*, 2013). Pearl millet is also good for sustainable farming because it uses water efficiently and can handle harsh weather conditions.

Increasing the amount of grain produced is a main goal in pearl millet breeding. However, grain yield is a complex trait that depends on many factors and is affected by the environment. Traits like plant height, time to flowering, time to maturity, test weight, tillering ability, and other yield-related features can directly or indirectly influence how much grain is produced. Choosing only based on grain yield might not be the best strategy, especially when the environment changes a lot. Identifying other traits that are consistently linked to yield can help make the selection process more effective. For successful selection, there needs to be genetic diversity in the breeding materials. Understanding how traits are related to each other helps breeders see how the traits interact within the material.

Correlation analysis is a key method used to find how strongly and in what direction different traits are related to grain yield. Phenotypic correlation shows how traits are

connected as seen in the plants and is affected by both genes and environment. Genotypic correlation gives a clearer picture of the genetic connections between traits. In breeding, if a trait has a strong positive genotypic link to yield, improving that trait can also improve yield. Earlier studies have found that grain yield is connected to several traits like plant height, biological yield, harvest index, effective tillers, and test weight, but the strength and direction of these links can differ based on the plant material and environment (Bikash *et al.*, 2013; Kumar *et al.*, 2014; Kumar *et al.*, 2022; Jain *et al.*, 2023).

While correlation analysis helps understand the relationships between traits, it doesn't explain if the relationship with yield is direct or if it happens through another trait. Path coefficient analysis helps by breaking the correlation into direct and indirect effects, giving a clearer understanding of each trait's impact on yield. This has made path analysis an important tool in crop breeding to find the best traits for selection. In pearl millet, using correlation and path analysis has helped identify key yield traits and allowed for indirect selection to increase productivity (Diz *et al.*, 1994; Kumar *et al.*, 2022; Jain *et al.*, 2023).

### Materials and Methods

#### Experimental site and material

The experiment was conducted during kharif 2025-2026 at the Field Experimentation Centre of the Department of Genetics and Plant Breeding, Naini Agricultural Institute, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, Uttar Pradesh. Eight entries, including a check, were evaluated: PM-100, PM-200, PM-300, PM-400, PM-500, PM-600, PM-700, and C-800.

## Experimental design and layout

The trial was laid out in a randomized block design with three replications, giving 24 plots. Each plot measured 5 m × 5 m (25 m<sup>2</sup>). The field included 0.5-m irrigation channels and 0.30-m bunds; the reported gross dimensions were 42.1 m × 17.8 m, with a gross area of 760.06 m<sup>2</sup>. Entries were independently randomized within each replication.

**Table 1:** Randomization of pearl millet entries across three replications.

| Plot position | Replication I | Replication II | Replication III |
|---------------|---------------|----------------|-----------------|
| 1             | PM-100        | C-800          | PM-300          |
| 2             | PM-200        | PM-700         | PM-400          |
| 3             | PM-300        | PM-600         | PM-500          |
| 4             | PM-400        | PM-100         | PM-600          |
| 5             | PM-500        | PM-200         | PM-700          |
| 6             | PM-600        | PM-300         | C-800           |
| 7             | PM-700        | PM-400         | PM-200          |
| 8             | C-800         | PM-500         | PM-100          |

## Observations recorded

The recorded characters were field germination (%), days to 50% tasseling, days to 50% silking, plant height (cm), days to maturity, grain colour, 1000-seed weight (test weight, g), seed yield (g per five plants per plot), stay-green habit at maturity, disease severity, and pest severity.

## Statistical analysis

Data were analyzed by analysis of variance appropriate for a randomized block design using the model  $Y_{ij} = \mu + G_i + R_j + e_{ij}$ , where  $Y_{ij}$  is the observation of the  $i$ th genotype in the  $j$ th replication,  $\mu$  is the overall mean,  $G_i$  is the genotype effect,  $R_j$  is the replication effect, and  $e_{ij}$  is experimental error. Standard error of the mean, critical difference at the 5% probability level, and coefficient of variation were estimated. Phenotypic and genotypic correlation coefficients were computed among quantitative traits. Path coefficient analysis was used to partition correlations with seed yield into direct and indirect effects.

## Results and Discussion

### Analysis of variance and genetic variability

The analysis of variance showed very significant differences between treatments for all the measured traits. The average

values for each treatment were: 337.95 for field germination, 1362.02 for plant height, 189.98 for days to 50% tasseling, 232.90 for days to 50% silking, 380.10 for days to maturity, 11.23 for test weight, and 59.31 for seed yield. This suggests there is enough genetic variation among the tested hybrids to make selection decisions.

For each characteristic, the phenotypic coefficient of variation was higher than the genotypic coefficient of variation, indicating that environmental factors played a major role in how the traits were expressed. Seed yield had the highest genotypic coefficient of variation (24.66%) and phenotypic coefficient of variation (33.03%), followed by test weight (GCV 20.78%; PCV 23.67%). Test weight had a heritability of 77.08%, while seed yield had the highest genetic gain as a percentage of the mean (37.94%). The presence of considerable variation, heritability, and genetic gain supports the idea of selecting for these traits. However, the difference between phenotypic and genotypic coefficients for seed yield suggests that testing in multiple environments would be useful.

### Mean performance of hybrids

Significant differences were seen between the tested hybrid varieties. When it came to germination in the field, the lowest rate was 41.67% for PM-300, while the highest was 73.33% for PM-500. In terms of plant height, PM-300 was the shortest at 111.68 cm, and C-800 was the tallest at 175.97 cm. PM-300 also reached key growth stages earlier than the other hybrids—reaching 50% tasseling in 25 days, 50% silking in 27.33 days, and full maturity in 59 days. The other hybrids, on the other hand, took about 90 to 91 days to mature.

PM-100 had the highest seed yield, producing 22.21 grams per five plants, which was 23.46% more than the next highest, PM-200, which gave 17.99 grams. PM-300 had the lowest yield at just 6.54 grams. The difference in seed yield between PM-100 and PM-300 was much larger than what could be explained by experimental error. Also, the high variability in seed yield—measured by a coefficient of variation of 21.97%—suggests that environmental factors may have played a big role. Studies by Bikash *et al.* (2013)<sup>[1]</sup> and Jain *et al.* (2023)<sup>[3]</sup> have also highlighted the importance of using this kind of variability among pearl millet types.

**Table 2:** Mean performance of pearl millet hybrids. \*Seed yield expressed as g per five plants per plot.

| Genotype | Field germ. (%) | Plant height (cm) | 50% tasseling(d) | 50% silking (d) | Maturity (d) | Test weight (g) | Seed yield* |
|----------|-----------------|-------------------|------------------|-----------------|--------------|-----------------|-------------|
| PM-100   | 45.00           | 174.77            | 42.67            | 45.00           | 91.33        | 8.03            | 22.21       |
| PM-200   | 43.33           | 169.07            | 41.33            | 44.00           | 91.00        | 11.00           | 17.99       |
| PM-300   | 41.67           | 111.68            | 25.00            | 27.33           | 59.00        | 5.57            | 6.54        |
| PM-400   | 50.00           | 153.18            | 48.67            | 47.33           | 91.00        | 9.47            | 16.75       |
| PM-500   | 73.33           | 147.93            | 47.00            | 50.33           | 90.67        | 7.63            | 14.25       |
| PM-600   | 48.33           | 160.93            | 34.00            | 29.00           | 90.00        | 9.57            | 17.47       |
| PM-700   | 60.00           | 171.15            | 40.00            | 44.00           | 90.33        | 8.23            | 16.62       |
| C-800    | 46.67           | 175.97            | 47.33            | 48.67           | 91.33        | 11.57           | 16.43       |
| Mean     | 51.04           | 158.09            | 40.75            | 41.96           | 86.83        | 8.88            | 16.03       |
| SE(m)    | 5.64            | 14.13             | 5.58             | 4.50            | 8.90         | 0.82            | 2.88        |
| CD (5%)  | 12.10           | 30.31             | 11.96            | 9.66            | 19.10        | 1.76            | 6.17        |
| CV (%)   | 13.54           | 10.95             | 16.76            | 13.14           | 12.56        | 11.33           | 21.97       |
| Maximum  | 73.33           | 175.97            | 48.67            | 50.33           | 91.33        | 11.57           | 22.21       |
| Minimum  | 41.67           | 111.68            | 25.00            | 27.33           | 59.00        | 5.57            | 6.54        |

### Qualitative characters

Laboratory germination was uniformly high (98.00-99.00%), confirming good seed viability. Grain colour varied among grey, greyish-brown, and brown classes, providing a visible basis for varietal identification. All entries were recorded as poor for stay-green habit at

maturity, while disease and pest severity were described as minimum resistant under the observed field conditions. The uniformity of the latter ratings suggests that more discriminating disease and pest screening, possibly across environments or under artificial epiphytotic conditions, may be required.

**Table 3:** Qualitative characters of pearl millet hybrids. \*The presentation labels the eighth entry as PM-800 in this table but as C-800 in the experimental layout.

| Hybrid | Laboratory germ. (%) | Grain colour  | Stay-green habit | Disease severity | Pest severity |
|--------|----------------------|---------------|------------------|------------------|---------------|
| PM-100 | 98.33                | Grey          | Poor             | Moderate         | Moderate      |
| PM-200 | 99.0                 | Greyish brown | Poor             | Moderate         | Moderate      |
| PM-300 | 98.0                 | Brown         | Poor             | Moderate         | Moderate      |
| PM-400 | 98.0                 | Grey          | Poor             | Moderate         | Moderate      |
| PM-500 | 98.67                | Brown         | Poor             | Moderate         | Moderate      |
| PM-600 | 98.67                | Greyish brown | Poor             | Moderate         | Moderate      |
| PM-700 | 98.0                 | Grey          | Poor             | Moderate         | Moderate      |
| C-800* | 98.0                 | Brown         | Poor             | Moderate         | Moderate      |

### Genotypic and phenotypic correlations

Genotypic correlations were usually higher than phenotypic ones, which suggests that environmental differences made some natural connections less obvious. Seed yield had a strong positive link with plant height ( $r = 0.902$ ;  $r^2 = 0.726$ ) and days to maturity ( $r = 0.870$ ;  $r^2 = 0.617$ ). It also had positive relationships with days to 50% tasseling, days to 50% silking, and test weight. Field germination wasn't connected much to seed yield, and there was a slight negative genotypic coefficient ( $r = -0.013$ ).

The strong connection between yield and plant height and maturity shows that biomass growth and how long the crop takes to mature were important in this group. These results match previous studies that say yield-related traits in pearl millet are genetically linked and that genotypic correlations often are higher than phenotypic ones (Kumar *et al.*, 2022; Jain *et al.*, 2023) [3, 5]. However, choosing for later maturity needs to be carefully balanced with the need for plants to adapt to drought at the end of the growing season and the specific conditions where they will be grown.

**Table 4:** Phenotypic ( $r$ ) and genotypic ( $r^g$ ) correlation coefficients among quantitative characters.

| Character         | Level | Germ.  | Plant ht. | Tassel | Silk  | Maturity | Test wt. | Yield  |
|-------------------|-------|--------|-----------|--------|-------|----------|----------|--------|
| Field germination | $r$   | 1.000  | 0.255     | 0.287  | 0.283 | 0.247    | -0.118   | 0.204  |
|                   | $r^g$ | 1.000  | 0.038     | 0.415  | 0.471 | 0.342    | -0.195   | -0.013 |
| Plant height      | $r$   | 0.255  | 1.000     | 0.350  | 0.294 | 0.574    | 0.487    | 0.726  |
|                   | $r^g$ | 0.038  | 1.000     | 0.637  | 0.571 | 0.887    | 0.743    | 0.902  |
| 50% tasseling     | $r$   | 0.287  | 0.350     | 1.000  | 0.841 | 0.612    | 0.538    | 0.398  |
|                   | $r^g$ | 0.415  | 0.637     | 1.000  | 0.942 | 0.817    | 0.577    | 0.604  |
| 50% silking       | $r$   | 0.283  | 0.294     | 0.841  | 1.000 | 0.627    | 0.423    | 0.265  |
|                   | $r^g$ | 0.471  | 0.571     | 0.942  | 1.000 | 0.691    | 0.425    | 0.495  |
| Days to maturity  | $r$   | 0.247  | 0.574     | 0.612  | 0.627 | 1.000    | 0.550    | 0.617  |
|                   | $r^g$ | 0.342  | 0.887     | 0.817  | 0.691 | 1.000    | 0.701    | 0.870  |
| Test weight       | $r$   | -0.118 | 0.487     | 0.538  | 0.423 | 0.550    | 1.000    | 0.384  |
|                   | $r^g$ | -0.195 | 0.743     | 0.577  | 0.425 | 0.701    | 1.000    | 0.576  |
| Seed yield        | $r$   | 0.204  | 0.726     | 0.398  | 0.265 | 0.617    | 0.384    | 1.000  |
|                   | $r^g$ | -0.013 | 0.902     | 0.604  | 0.495 | 0.870    | 0.576    | 1.000  |

### Path coefficient analysis

At the phenotypic level, plant height had the biggest positive direct effect on seed yield (0.569), followed by days to maturity (0.407), 50% silking (0.401), days to 50% tasseling (0.394), and test weight (0.167). Field germination had a small negative direct effect (-0.061). Plant height also had an indirect effect through maturity (0.233), which explains part of its strong positive link with yield.

At the genotypic level, days to maturity had the largest positive direct effect (1.494), along with germination

(0.635) and test weight (0.606). Plant height had only a small direct effect (0.101) at the genotypic level, but a large indirect effect through maturity (1.324). This difference shows why relying only on correlation can be misleading: the strong link between plant height and yield is mostly because of their connection with maturity. The usefulness of path analysis in distinguishing direct and indirect effects matches what Diz *et al.* (1994) [2] found, as well as more recent studies on pearl millet (Kumar *et al.*, 2022; Jain *et al.*, 2023) [3, 5].

**Table 5:** Direct (diagonal) and indirect effects of quantitative characters on seed yield.

| Character    | Level | Germ.  | Plant ht. | Tassel | Silk   | Maturity | Test wt. | Yield  |
|--------------|-------|--------|-----------|--------|--------|----------|----------|--------|
| Germination  | $r$   | -0.061 | 0.145     | 0.113  | -0.114 | 0.100    | 0.020    | 0.204  |
|              | $r^g$ | 0.635  | 0.004     | -0.113 | 0.102  | 0.511    | 0.118    | -0.013 |
| Plant height | $r$   | -0.016 | 0.569     | 0.138  | -0.118 | 0.233    | -0.081   | 0.726  |
|              | $r^g$ | -0.024 | 0.101     | -0.173 | 0.124  | 1.324    | -0.450   | 0.902  |

|                 |                |        |       |        |        |       |        |       |
|-----------------|----------------|--------|-------|--------|--------|-------|--------|-------|
| 50% tasseling   | r <sup>□</sup> | -0.018 | 0.199 | 0.394  | -0.337 | 0.249 | -0.090 | 0.398 |
|                 | r <sup>g</sup> | -0.263 | 0.064 | 0.271  | 0.204  | 1.220 | -0.350 | 0.604 |
| 50% silking     | r <sup>□</sup> | -0.017 | 0.167 | 0.331  | 0.401  | 0.255 | -0.071 | 0.265 |
|                 | r <sup>g</sup> | -0.299 | 0.058 | -0.256 | 0.217  | 1.033 | -0.258 | 0.495 |
| Daysto maturity | r <sup>□</sup> | -0.015 | 0.327 | 0.241  | -0.251 | 0.407 | -0.092 | 0.617 |
|                 | r <sup>g</sup> | -0.217 | 0.090 | -0.222 | 0.150  | 1.494 | -0.425 | 0.870 |
| Test weight     | r <sup>□</sup> | 0.007  | 0.277 | 0.212  | -0.170 | 0.224 | 0.167  | 0.384 |
|                 | r <sup>g</sup> | 0.124  | 0.075 | -0.157 | 0.092  | 1.047 | 0.606  | 0.576 |

## Conclusion

The eight pearl millet hybrids showed a lot of differences in all the measured traits. PM-100 gave the highest yield, with 22.21 grams from five plants. PM-500 had the best germination rate in the field, at 73.33%. C-800 was the tallest, reaching 175.97 cm in height, and also had the highest test weight of 11.57 grams. PM-300 was the first to mature but had the lowest yield, showing that there is a trade-off between early maturity and yield in these hybrids. Plant height and the time it takes for the plants to mature were strongly linked to seed yield, both in terms of the plants' genetic makeup and their actual physical traits. Path analysis showed that plant height was the biggest factor affecting yield at the physical level, while the time to maturity was the main factor at the genetic level. Because of this, when selecting the best hybrids, attention should focus first on plant height, days to maturity, test weight, and seed yield. However, the speed of maturing and how well the plants adapt to the environment should be considered depending on where they are grown. PM-100 is a good candidate for further testing in different locations because it has the potential to be a high-yielding variety.

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