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GENETIC ANALYSIS OF GRAIN YIELD AND ITS COMPONENT IN PEARL MILLET (*PENNISETUM GLAUCUM* L. R. BR.) HYBRIDS

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ABSTRACT

The present study evaluated 28 pearl millet hybrids derived from a Line × Tester mating design to assess genetic variability, heritability, correlation and path coefficients for yield and its contributing traits. The significant variability was observed among hybrids for days to flowering, plant height, ear head length, ear head girth, number of productive tillers per plant, 1000 grain weight, days to maturity, iron content, zinc content and grain yield per plant. The phenotypic coefficient of variation (PCV) was slightly higher than the genotypic coefficient of variation (GCV) for all traits, indicating minor environmental influence. The high heritability coupled with high genetic advance as a percentage of mean was observed for grain yield per plant, ear head length, 1000 grain weight, iron content and zinc content suggesting the predominance of additive gene action and high potential for selection-based improvement. Correlation analysis showed that grain yield per plant had a significant positive association with plant height, ear head length, ear head girth, number of productive tillers per plant and 1000 grain weight. Path coefficient analysis further demonstrated that plant height, 1000 grain weight, days to maturity and number of tillers per plant had high positive direct effects on grain yield, identifying them as key yield determinants. The findings underscore the potential of exploiting genetic variability and inter-trait relationships to enhance grain yield and micronutrient content in pearl millet, supporting its role as a resilient crop for sustainable food and nutritional security.

Key words : Pearl millet, Correlation, Variability, Path-coefficient.

Introduction

Climate change threatens food security that sharply lower the yields (FAO, 2025). This creates the need for nutrient-rich, climate-resilient and widely accessible crops. Millets are uniquely suited to address these challenges due to their remarkable versatility. Pearl millet [*Pennisetum glaucum* (L.) Br.] ranks sixth among cereals and grown in Asia and Africa's arid regions (Satyavathi *et al.*, 2021). Pearl millet is a highly cross-pollinated diploid cereal (2n=2x=14) with a 1.79 Gb genome, noted for high photosynthetic efficiency and biomass yield (Varshney *et al.*, 2017).

In India, pearl millet is cultivated in approximately 7.21 million hectares, with an annual production of 10.86 million tonnes and an average yield of 1,507 kg/ha. Rajasthan is the top producer, followed by Uttar Pradesh, Gujarat, Haryana and Madhya Pradesh (Anonymous, 2025).

Pearl millet, mainly cultivated for grain purposes additionally, it is also a high-quality forage underpinning the livelihood and nutritional security of 90 million people worldwide (Yadav *et al.*, 2021).

Pearl millet germplasm displays considerable genotypic and phenotypic diversity, including resistance to both abiotic and biotic stresses offering a solid foundation for selecting desirable traits in breeding programs (Shrestha *et al.*, 2023). Correlation and path analysis are crucial biometrical tools for determining the contribution of different yield-contributing traits. It is useful for quantifying the degree and nature of association between these component traits (Anuradha *et al.,* 2018; Narasimhulu *et al.*, 2021). While correlations are valuable for quantifying the nature and degree of inter-trait association, they fail to elucidate the underlying causal mechanisms. An observed association or interrelationship between two traits may stem from a direct relationship or an indirect effect mediated through a third mutually associated character. To resolve these complex interrelationships, path coefficient analysis serves as a powerful statistical tool. This method effectively partitions the total correlation coefficient into its constituent direct and indirect effects, providing a clearer, more insightful picture of how each component trait influences the final expression of grain yield (Rakesh *et al.*, 2015). The primary objective of this research is to evaluate a set of pearl millet hybrids to examine variability in grain yield and its component traits. Additionally, this study aims to analyze the correlations and path coefficient analysis among these traits to determine how they interact with one another and how their relationships influence grain yield.

Materials and Methods

Genetic material and field experiment

The experimental set comprised 28 pearl millet hybrids developed by a Line × Tester mating scheme involving seven female (7042S, J-2372, J-2517, J-2467, ICMB94555, ICMB95222 and ICMB96222) and four male testers (JMSB20172, JMSB20175, J-2532 and J-2539). Hybridization was carried out at Centre for Millets Research (CMR), Sardarkrushinagar Dantiwada Agricultural University, Deesa, during the summer of 2023. The research site is situated in North Gujarat Zone IV at 24°15' N latitude, 72°12' E longitude and at an elevation of 146 meters above mean sea level. The soil at this location is loamy, with a pH ranging from 7.5 to 9.3. All entries were evaluated using a Randomized block design (RBD) with three replications during the *kharif* 2023 at CMR, Deesa. Each entry was sown in a 4.0 m row, with an inter-row spacing of 45 cm and an intra-row spacing of 15 cm with standard agronomic practice. The grain micronutrient iron (Fe) and zinc (Zn) were estimated from the acid extract prepared by wet digestion procedure of Singh *et al.* (2005) using di-acid mixture at Department of Soil Science and Agricultural Chemistry, C.P. College of Agriculture, S. D. Agricultural University, Sardarkrushinagar, Gujarat.

Observation recorded

Hybrid performance evaluated for days to flowering, days to maturity, plant height (cm), ear head length (cm), ear head girth (mm), number of productive tiller per plant, 1000 grain weight (g), iron content (ppm), zinc content (ppm) and grain yield per plant (g). Five plants were randomly selected and tagged for taking observations.

Data analysis

The genetic parameters of the study were calculated using established statistical methods. The phenotypic and genotypic coefficients of variation (PCV and GCV) were determined following the procedure outlined by Burton and Devane (1953). Broad-sense heritability was calculated according to Allard (1960) and the resulting heritability and genetic advance values were classified as low, medium and high based on the categories proposed by Johnson *et al*. (1955). Genotypic and phenotypic correlations between the traits were computed using the methodology described by Falconer (1981). Path coefficient analysis was estimated as suggested by Wright (1921, 1935) and elaborated by Dewey and Lu (1959). The analysis was carried out using INDOSTAT software version 8.1 and RStudio 2025.09.0+387.

Results and Discussion

Mean performance of hybrids

The mean performance of hybrids for grain yield per plant and its attributing traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.] is represented by violin graphs (Fig 1). These plots displayed the distribution and variability of grain yield per plant and related traits among the evaluated hybrids. The overall shape and width of each violin reflect the extent of variation in trait expression. A wider section of the plot reflects a higher density of data points pointing a more uniform performance across hybrids for that trait. In contrast, narrower section denotes greater variation or fewer hybrids sharing similar trait values. These variations in violin shape demonstrate differences in the spread and central tendency of traits, enabling clearer visual comparison of trait distribution in hybrids. The wider or more spread-out violin indicates a broader range of performance within the population, whereas a more compact shape suggests more consistent trait expression across the hybrids. This graphical approach provides effective visualization of genetic diversity and performance within the hybrids, highlighting both the mean value and the degree of variability for a particular trait studied.

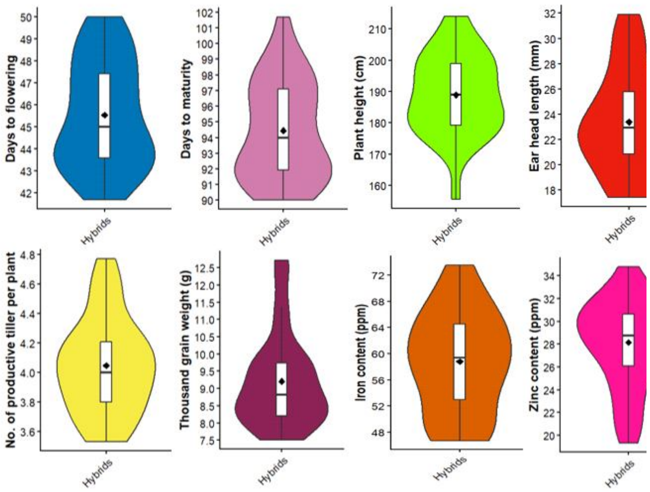

Fig. 1 : Violin graph representing the mean performance of hybrids for grain yield and its attributing characters in pearl millet [*Pennisetum glaucum* (L.) R. Br.].

Variability

The variability parameters estimated across the 28 pearl millet hybrids showed substantial variability for all the studied traits (Table 1). Estimates of genotypic coefficients of variation (GCV) and phenotypic coefficients of variation (PCV) are impactful for assessing the extent of environmental influence on trait expression (Bisoriya *et al.*, 2025 and Angel *et al.*, 2024). The magnitude of the difference between GCV and PCV reflects the degree to which environmental factors contributed to variation in a given character. In most cases, the phenotypic coefficient of variation (PCV) exceeded the corresponding genotypic coefficient of variation (GCV), indicating that environmental effects played a significant role in the expression of these traits (Kumari *et al.*, 2013 and Pallavi *et al.*, 2020).

The phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) for all the studied traits, indicating the influence of the environment on the expression of all the traits. However, the small difference between PCV and GCV for several traits, such as days to flowering, ear head length etc., indicated that the genotypic variance was the primary contributor to the total variance, making selection for these traits effective. The highest estimates of genotypic and phenotypic coefficients of variation (GCV and PCV) were recorded for grain yield per plant (29.44 and 31.18%, respectively). These findings are in agreement with the reports of Kumari *et al.* (2013), Saikumar *et al.* (2020), Kumar *et al.* (2019), Jaiswal *et al.* (2025) and Rajpoot *et al.* (2023). Moderate estimates of GCV and PCV were observed for ear head length (16.57 and 17.41%) followed by 1000grain weight (13.76 and 15.78%), zinc content (13.67 and 14.20%) and iron content (12.92 and 13.56%). The results represented enough genetic variability among the studied hybrids to make selection an effective strategy for improvement of these traits. These results were in consonance with Kumari *et al*. (2013), Angel *et al*. (2024), Jaiswal *et al*. (2025) and Narasimhulu *et al*. (2021) for both ear head length and 1000grain weight; Pallavi *et al*. (2020), Bisoriya *et al*. (2025) and Rajpoot *et al*. (2023) for ear head length; Kumar *et al.* (2019) and Barathi and Reddy (2023) for iron and zinc content. In contrast, low GCV and PCV were recorded for days to maturity (3.09 and 3.89%) followed by days to flowering (5.19 and 5.60%), plant height (6.25 and 8.17%), number of productive tiller per plant (6.05 and 10.91%) and ear head girth (8.81 and 10.39%) (Table 1). similar variation for these traits were also reported in pearl millet by Narasimhulu *et al*. (2021) and Rajpoot *et al*. (2023) for days to flowering, days to maturity and plant height; Kumar *et al*. (2019) and Athoni *et al.* (2022) for number of productive tiller per plant; Jaiswal *et al*. (2025) for ear head girth.

Heritability represents the proportion of the total phenotypic variance that is attributable to genetic factors, reflecting the degree to which a trait is transmitted from parents to offspring. Genetic advance provides an estimate of the expected improvement in a trait under effective selection pressure. The combination of high heritability with high genetic advance as a percentage of the mean (GAM) offers a more reliable indication of the effectiveness of selection than heritability alone, as it reveals the extent of additive gene action governing the trait (Johnson *et al*., 1955). Hence, simultaneous consideration of heritability and genetic advance is essential for predicting the genetic gain and formulating an efficient selection strategy (Burton and DeVane, 1953; Falconer and Mackay, 1996). High heritability coupled with high genetic advance as per cent of mean was recorded for ear head length (h^2_{bs} = 90.52%; GAM = 32.47%), 1000 grain weight (h^2_{bs} = 76.11%; GAM = 24.74%), iron content (h^2_{bs} = 90.74%; GAM = 25.35%), zinc content (h^2_{bs} = 92.51%; GAM = 27.06%) and grain yield per plant (h^2_{bs} = 89.18%; GAM = 57.27%) indicating the predominance of additive gene effects in controlling these characters (Table 1). The breeder can employ early and straightforward selection methods to effectively capture and fix additive gene effects responsible for trait expression. The results are in line with the findings of Jaiswal *et al*. (2025) for ear head length, 1000grain weight, iron content, zinc content and grain yield per plant; Saikumar *et al*. (2020) and Rajpoot *et al*. (2023) for ear head length, 1000grain weight and grain yield per plant;

Table 1 : Estimation of genotypic (r) and phenotypic (r_p) correlation coefficients for 10 characters in pearl millet hybrids.

Character	DF	DM	PH	EL	EG	NPTPP	TGW	Fe	Zn	GYPP	
DF	r_g	1 **	0.8634 **	-0.3913 *	-0.5198 **	-0.4426 *	-0.543 **	-0.0717	0.1923	0.1009	-0.4903 **
	r_p	1 **	0.6306 **	-0.3261 **	-0.4475 **	-0.3735 **	-0.3259 **	-0.0515	0.1464	0.082	-0.4133 **
DM	r_g		1 **	-0.4082 *	-0.3783 *	-0.4551 *	-0.4945 **	-0.1779	0.2736	0.1793	-0.3579
	r_p		1 **	-0.2855 **	-0.2925 **	-0.3831 **	-0.2868 **	-0.1592	0.2464 *	0.1165	-0.2459 *
PH	r_g			1 **	0.6544 **	0.6953 **	0.5368 **	0.0344	-0.5249 **	-0.3735	0.5944 **
	r_p			1 **	0.4978 **	0.4519 **	0.2013	0.0399	-0.3818 **	-0.2786 *	0.4241 **
EL	r_g				1 **	0.659 **	0.8028 **	0.2569	-0.4239 *	-0.1856	0.6945 **
	r_p				1 **	0.5371 **	0.4135 **	0.2141	-0.3761 **	-0.1753	0.6023 **
EG	r_g					1 **	0.8736 **	0.5637 **	-0.2741	-0.5474 **	0.6135 **
	r_p					1 **	0.4497 **	0.379 **	-0.2726 *	-0.4415 **	0.4616 **
NPTPP	r_g						1 **	0.8024 **	-0.2338	-0.7662 **	0.867 **
	r_p						1 **	0.4088 **	-0.1317	-0.3872 **	0.4213 **
TGW	r_g							1 **	0.0227	-0.2662	0.5588 **
	r_p							1 **	0.002	-0.2195 *	0.4816 **
Fe	r_g								1 **	0.3183	-0.2097
	r_p								1 **	0.2932 **	-0.1899
Zn	r_g									1 **	-0.3532
	r_p									1 **	-0.3207 **
GYPP	r_g										1 **
	r_p										1 **

Where, DF: days to flowering, DM: days to maturity, PH: plant height in cm, EL: ear head length in cm, NPTPP: number of productive tiller per plant, TGW: 1000grain weight, Fe: iron content in ppm, Zn: zinc content in ppm, GYPP: grain yield per plant.

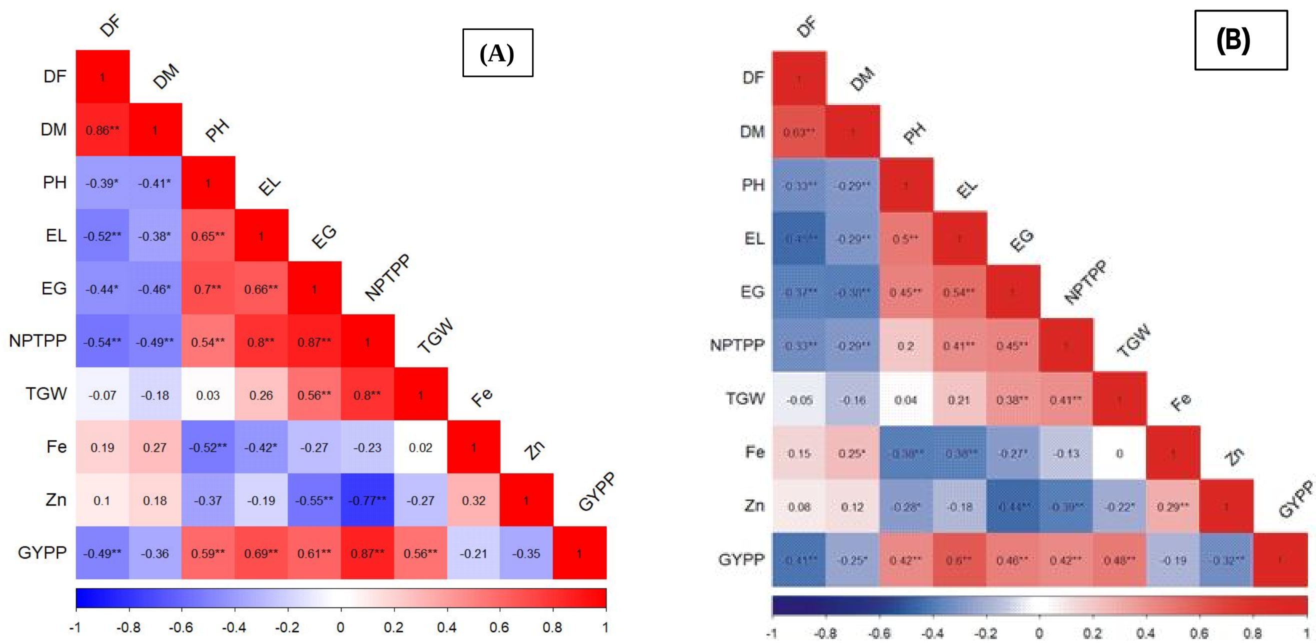

Fig. 2 : Genotypic (A) and phenotypic (B) correlation among grain yield and related traits. Where, DF: days to flowering, DM: days to maturity, PH: plant height in cm, EL: ear head length in cm, NPTPP: number of productive tiller per plant, TGW:1000grain weight, Fe: iron content in ppm, Zn: zinc content in ppm, GYPP: grain yield per plant.

Kumar *et al*. (2019) and Barathi and Reddy (2023) for iron content and zinc content.

High heritability along with moderate genetic advance as per cent of mean recorded for ear head girth (h^2_{bs} = 72.02%; GAM = 15.41%) suggest that the trait is controlled by non-additive gene action. The observed high heritability is likely deceptive, caused more by a favorable environment than by superior genes. Consequently, trying to improve this trait through selection would probably be ineffective. Earlier Athoni *et al.* (2023) and Jaiswal *et al*. (2025) also reported similar results for ear head girth in pearl millet. Whereas, high heritability in conjunction with low genetic advance as per cent of mean was observed for days to flowering (h^2_{bs} = 85.81%; GAM = 9.90%) and days to maturity (h^2_{bs} = 63.11%; GAM = 5.06%). This indicates that trait is inherited in a complex way, involving dominant and epistatic genes. Therefore, recurrent selection would be the most effective method for its improvement. Such confirmatory findings are also mentioned by Saikumar *et al*. (2020) and Bisoriya *et al.* (2025). Moderate heritability accompanied by low genetic advance as a percentage of mean was recorded for plant height (h^2_{bs} = 58.53%; GAM = 9.85%) and number of productive tiller per plant (h^2_{bs} = 30.77%; GAM = 6.91%). This combination suggests the predominance of non-additive gene action, indicating that improvement of these traits through simple selection would be less effective. Similar findings were earlier reported by Kalagare *et al*. (2021) and Kumar *et al.* (2024).

Correlation coefficient

Correlation analysis revealed the interrelationships among various plant traits and their influence on yield and its components, thereby assisting breeders in identifying superior genotypes for genetic improvement. The genotypic and phenotypic correlation coefficients estimated among 28 hybrids exhibited several significant associations, highlighting the interconnected nature of traits and their collective contribution to yield performance. Moreover, the genotypic correlation coefficients were higher than their corresponding phenotypic correlation coefficients for all the traits studied (Table 1). Grain yield per plant had a positive and highly significant correlation at both genotypic and phenotypic levels with plant height (r_g = 0.5944; r_p = 0.4242), ear head length (r_g = 0.6945; r_p = 0.6023), ear head girth (r_g = 0.6135; r_p =0.4616), number of productive tiller per plant (r_g = 0.867; r_p =0.4213) and 1000grain weight (r_g = 0.5588; r_p =0.4816) indicating that these traits play a crucial role in yield improvement and should be given priority in selection programs. Similar findings were also reported earlier by Rakesh *et al*. (2015) for plant height; Dadarwal *et al.* (2020) and Patil *et al*. (2021) for ear head length, ear head girth, 1000grain weight and number of productive tiller per plant. At both levels (genotypic and phenotypic), grain yield per plant showed negative and highly significant correlation with days to flowering (r_g = -0.4903; r_p =-0.4133) which suggests that early flowering could be beneficial for short duration season

Table 2 : Direct (diagonal) and indirect (non-diagonal) effects of various traits on grain yield in Hybrids of Pearl millet at genotypic (G) levels.

Character	DF	DM	PH	EL	EG	NPTPP	TGW	Fe	Zn	GYPP
DF	**-0.76262**	0.5158	-0.36875	-0.00793	0.38289	-0.21806	-0.05202	0.02466	-0.00425	-0.4903**
DM	-0.65847	**0.59738**	-0.38464	-0.00577	0.39368	-0.19857	-0.12901	0.03509	-0.00756	-0.3579
PH	0.2984	-0.24382	**0.94241**	0.00998	-0.6015	0.21559	0.02496	-0.06731	0.01574	0.5944**
EL	0.3964	-0.22601	0.61672	**0.01525**	-0.5701	0.3224	0.18638	-0.05437	0.00782	0.6945**
EG	0.33751	-0.27184	0.65522	0.01005	**-0.86514**	0.35085	0.40889	-0.03516	0.02307	0.6135**
NPTPP	0.41408	-0.29537	0.50589	0.01224	-0.7558	**0.4016**	0.58202	-0.02998	0.03229	0.867**
TGW	0.05469	-0.10625	0.03243	0.00392	-0.4877	0.32225	**0.72534**	0.00292	0.01122	0.5588**
Fe	-0.14664	0.16347	-0.49465	-0.00646	0.23716	-0.09389	0.01649	**0.12824**	-0.01342	-0.2097
Zn	-0.07695	0.10711	-0.35202	-0.00283	0.47355	-0.3077	-0.19308	0.04082	**-0.04215**	-0.3532

Where, DF: days to flowering, DM: days to maturity, PH: plant height in cm, EL: ear head length in cm, NPTPP: number of productive tiller per plant, TGW: 1000grain weight, Fe: iron content in ppm, Zn: zinc content in ppm, GYPP: grain yield per plant.

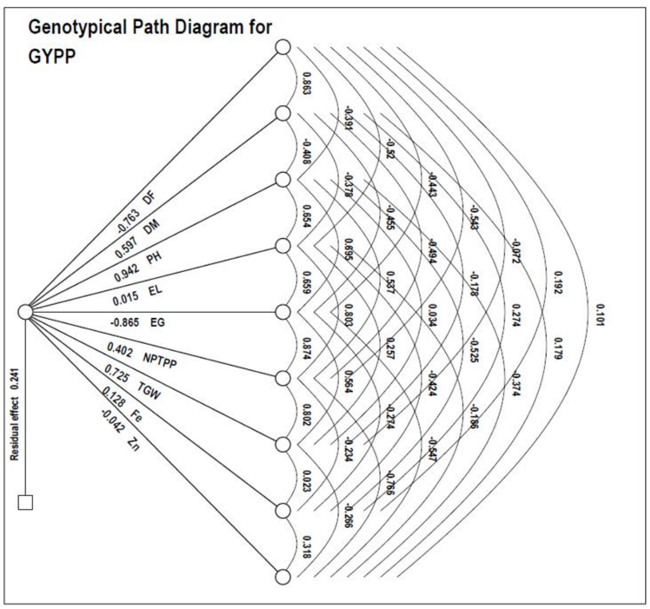

Fig. 3 : Path diagram at genotypic level for grain yield per plant in pearl millet. Where, DF: days to flowering, DM: days to maturity, PH: plant height in cm, EL: ear head length in cm, NPTPP: number of productive tiller per plant, TGW:1000grain weight, Fe: iron content in ppm, Zn: zinc content in ppm, GYPP: grain yield per plant.

or under terminal stress environment. Similar results were also reported by Govindraj *et al.* (2010). Grain yield per plant and iron content were non-significantly and negatively correlated at both the genotypic and phenotypic levels (r_g = -0.2097; r_p = -0.1899). Zinc content, however showed non-significant and negatively correlation at genotypic level (r_g = -0.3532) and negative and highly significant correlation at phenotypic level (r_p = -0.3207). The present findings agree with the previous results of Yadav *et al.* (2012) for iron content and Govindraj *et al.* (2013) for zinc content.

Genotypic Path Coefficient analysis

Path analysis shows direct and indirect effects on grain yield per plant. According to path analysis plant height had highest direct effect (0.94241) on grain yield per plant followed by 1000grain weight (0.72534), days to maturity (0.59738), number of tillers per plant (0.4016), iron content (0.12824) and ear head length (0.01525) indicating that selecting these traits will improve the grain yield directly. The remaining traits *viz*., days to flowering (-0.76262), ear head grith (-0.86514) and zinc content (-0.0421) showed negative direct effect on grain yield per plant. The residual effect of path analysis was 0.241 which was low. Low residual value indicates that character that are included in the present investigation shows greater variation on the grain yield. Plant height shows high positive direct effect which indicates highly correlated (r_g = 0.5944) with grain yield. Ear head girth shows positive correlation with negative direct effect on grain yield. Thus, its positive correlation is due to the indirect effects *via* plant height. Path analysis states that plant height, 1000 grain weight should be considered as major grain yield contributing traits, selection of these characters for the improvement of yield as they show high positive direct effect along with significantly positive correlated with grain yield per plant. Therefore, selection of these characters should be considered in the crop improvement programme.

Path studies shows that plant height had positive direct effect towards grain yield per plant followed by 1000 grain weight and ear head length. Similar results were reported by Kumar *et al*. (2014), Nehra *et al*. (2017), Talwar *et al* . (2017), Bhasker *et al*. (2017) for number of tillers plant. Jain *et al*. (2023) and Kumar *et al*. (2020) also reported negative direct effects of zinc content and days to 50% flowering towards grain yield per plant.

Sumati *et al*. (2016) reported positive direct effect of 1000 grain weight towards grain yield.

Conclusion

The present study demonstrated considerable variation among the pearl millet hybrids for most traits, indicating significant potential for genetic improvement through selection and hybridization. Violin plots illustrating the mean performance of hybrids for grain yield per plant and its associated traits in pearl millet [*Pennisetum glaucum* (L.) R. Br.] effectively depicted the distribution, variability and genetic diversity among the evaluated hybrids. The phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation (GCV) for all the studied traits indicating the influence of the environment on expression of all the traits. However, the small difference between PCV and GCV indicated that the genotypic variance was the primary contributor to the total variance, making selection for these traits effective. Out of ten characters studied, ear head length, 1000 grain weight, iron content, zinc content and grain yield per plant showed maximum heritability coupled with high genetic advance as per cent of mean. This suggests these traits might be under the control of additive gene effects. Present study revealed that yield component attributes like., plant height, ear head length, ear head girth, number of productive tiller per plant and 1000 grain weight were positively correlated with grain yield per plant and simultaneously all the yield component traits were mutually interrelated and influenced grain yield either directly or indirectly through their association with other traits. The studies on path analysis revealed that plant height, 1000 grain weight, days to maturity, number of productive tillers per plant, iron content and ear head length exerted the strongest direct effect on grain yield per plant, indicating that direct selection for these key traits could effectively enhance grain yield.

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