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GENETIC VARIATION AND INTER TRAIT RELATIONSHIPS FOR YIELD AND GRAIN MICRONUTRIENTS IN PEARL MILLET [*PENNISETUM GLAUCUM* (L.) R. BR.]

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SUMMARY

The present study was conducted during *Kharif* 2024 at Rajasthan Agricultural Research Institute (RARI), Durgapura, to assess genetic variability, heritability, inter-trait correlations, and the contribution of various traits toward grain yield in pearl millet. A total of 158 diverse genotypes were evaluated under rainfed conditions in a Randomized Block Design (RBD) with three replications. Observations were recorded on ten agronomic and nutritional traits, and data were analysed using standard statistical procedures. Significant variation was observed among genotypes for all traits, indicating ample genetic diversity. High heritability coupled with high genetic advance was recorded for grain yield, dry fodder yield, and iron content, suggesting the effectiveness of selection for these traits due to additive gene action. Correlation analysis showed strong positive associations of grain yield with dry fodder yield and panicle length, iron and zinc content, indicating the possibility of simultaneous genetic improvement of yield and micronutrient traits. Path coefficient analysis revealed that days to flowering and plant height had the highest direct positive effects on grain yield, whereas days to maturity and iron content showed negative direct effects. Panicle diameter and length also contributed moderately and positively to yield. The findings suggest that selecting for early flowering, taller plants, and superior panicle traits can lead to improved productivity. The study offers valuable insights for breeding high-yielding, nutrient-rich pearl millet genotypes adapted to arid and semi-arid environments.

Key words: Pearl millet, genetic variability, heritability, path coefficient analysis and grain yield

Pearl millet (*Pennisetum glaucum* L.) is a highly adaptable cereal crop cultivated predominantly in arid and semi-arid regions of India, where it serves as a staple food and fodder source. It is known for its resilience to drought, heat, and poor soil conditions, making it crucial for food and nutritional security in marginal environments (Satyavathi *et al.,* 2021). In addition to its agronomic advantages, pearl millet is nutritionally superior among cereals, with high levels of essential micronutrients such as iron (Fe) and zinc (Zn), which makes it a valuable crop for biofortification programs aimed at combating micronutrient malnutrition (Pujar *et al.*, 2020, Govindaraj *et al.*, 2022). Genetic improvement of complex traits such as grain yield and micronutrient content requires a thorough understanding of the genetic variability, heritability, and the relationships among traits. Variability in agronomic and nutritional traits provides the foundation for selection and crop improvement. Estimating parameters such as genotypic and phenotypic coefficients of variation (GCV and PCV), heritability, and genetic advance facilitates the identification of traits governed by additive gene action and those that can be improved through simple selection (Govindaraj *et al.,* 2011, Deewan *et al.,* 2023). Correlation and path coefficient analyses further help in identifying key yield-contributing traits by distinguishing between direct and indirect effects, thus enabling breeders to formulate efficient selection indices (Talawar *et al.,* 2017, Beniwal *et al.,* 2020, Pallavi *et al.,* 2024). Particularly, understanding the associations among phenological, morphological, yield-related, and nutritional traits is vital for developing ideotypes with balanced productivity and nutritional quality. Given the challenges of climate variability and nutritional

deficiencies, this study aimed to assess the extent of genetic variability and trait interrelationships among diverse pearl millet genotypes. The results are expected to provide insights into selecting high-yielding, early-maturing, and nutrient-dense cultivars suited for dryland agriculture.

MATERIALS AND METHODS

The present investigation was carried out during the *Kharif* 2024 season at the experimental farm of Rajasthan Agricultural Research Institute (RARI), Durgapura, to evaluate genetic variability, trait associations, and their contribution to grain yield in pearl millet. A total of 158 genotypes representing diverse genetic backgrounds were used as experimental material. The experiment was laid out in a Randomized Block Design (RBD) with three replications to ensure uniform environmental exposure and minimize experimental error. Each genotype was sown in plots consisting of two rows of 4 m length, with a row-to-row spacing of 50 cm and plant-to-plant spacing of 15 cm. All recommended agronomic practices were followed uniformly across the field to ensure healthy crop growth. The trial was maintained under rainfed conditions, characteristic of the arid agro-climatic zone of Rajasthan. Data were recorded on ten important traits: days to 50% flowering, days to maturity, plant height (cm), number of productive tillers per plant, panicle length (cm), panicle diameter (cm), grain yield (g/plant), dry fodder yield (g/plant), iron content (ppm), and zinc content (ppm). Iron (Fe) and Zinc (Zn) levels were measured using an atomic absorption spectrophotometer (AAS) following the tri-acid mixture method outlined by Sahrawat *et al.* (2002) at the Central Analytical Services Laboratory, ICRISAT, Patancheru, Hyderabad. Statistical analyses including ANOVA, estimation of genetic parameters (GCV, PCV, heritability, genetic advance), correlation, and path coefficient analysis were conducted using standard biometrical methods (Burton and Devane, 1953; Johnson *et al.*, 1955; Al-Jibouri *et al.*, 1958; Dewey and Lu, 1959). All statistical computations were performed using R software.

RESULTS AND DISCUSSION

The analysis of variance revealed highly significant differences among genotypes for all the studied traits, indicating substantial genetic variability among the pearl millet genotypes. This genetic variability is crucial for effective selection and improvement in breeding programs. The results are consistent with findings of Singh *et al.,* (2014) and Angel *et al.,* (2024), who also reported wide variation in similar traits among pearl millet genotypes. Significant differences in flowering and maturity durations among genotypes suggest that breeding for early or late-maturing cultivars is feasible to suit different agro-ecological zones. Similarly, the variability observed for morphological traits like panicle length and plant height is in agreement with the findings of Kumar *et al.*, (2024), indicating the potential for selecting desirable plant types. Moreover, significant genetic variation was recorded for iron and zinc content, supporting the potential of pearl millet for biofortification. This aligns with earlier reports by Govindaraj *et al.,* (2022), who emphasized pearl millet's role in addressing micronutrient malnutrition. The low error variance across all traits confirmed the precision of the experiment and the reliability of results. These findings underline the potential for simultaneous genetic improvement of yield and nutritional traits in pearl millet.

The extent of genetic variability among the genotypes was assessed using genotypic and phenotypic coefficients of variation (GCV and PCV), broad-sense heritability, and genetic advance as percent of mean. The results revealed considerable variability for all the studied traits, indicating the potential for selection and improvement. The GCV ranged from 6.06% (days to maturity) to 43.49% (grain yield), while the PCV ranged from 6.11% to 45.97% for the same respective traits. High GCV and PCV values were observed for grain yield, dry fodder yield, productive tillers, and Fe content, indicating the presence of substantial inherent variability and the potential for effective selection. These findings are consistent with earlier reports by Pujar *et al.,* (2020) and Deewan *et al.*, (2023), who observed similar patterns of high variability in pearl millet genotypes for yield and related traits. Notably, PCV values were consistently higher than GCV for all traits, suggesting some degree of environmental influence on trait expression. However, the narrow gap between GCV and PCV for most traits, especially days to flowering, maturity, and Fe and Zn contents, indicates that the environmental effect was relatively minimal, and the expression of these traits is largely controlled by genetic factors. This is supported by high heritability estimates for all traits, which ranged from 67.04% (panicle diameter) to 98.64% (days to 50% flowering). High heritability coupled with high

genetic advance as a percent of mean was observed for grain yield, dry fodder yield, productive tillers and Fe content. This combination suggests that these traits are governed predominantly by additive gene action and that simple selection methods could be effectively used for genetic improvement. Similar conclusions were drawn by Talawar *et al.,* (2017), Rani *et al.*, (2022) and Deewan *et al.,* (2023), where traits with high heritability and genetic advance showed promise for direct selection. On the other hand, traits such as days to maturity, days to 50% flowering, and panicle diameter, though having high *heritability*, exhibited relatively lower genetic advance. This implies that non-additive gene effects and environmental interactions may play a larger role in the expression of these traits, and hence, selection may be less effective in early generations. For these traits, recurrent selection or hybrid breeding strategies may be more appropriate. Overall, the presence of substantial genetic variability, high heritability, and high genetic advance in key traits like grain yield, fodder yield, and micronutrient content demonstrates the potential of the evaluated pearl millet genotypes for use in breeding programs aimed at yield enhancement and nutritional improvement.

A strong positive association was observed between days to 50% flowering and days to maturity, indicating that genotypes that flower earlier tend to mature earlier. This close relationship suggests that phenological traits can be jointly considered to develop early maturing varieties. Similar observations were made by Beniwal *et al.,* (2020), who highlighted the interdependence of flowering and maturity under arid zone conditions. Grain yield showed a positive correlation with dry fodder yield and panicle length, implying that these traits contribute significantly to productivity. This supports earlier findings by Patil *et al.*, (2021) and Govindaraj *et al.*, (2022), who emphasized the role of biomass production and panicle architecture in enhancing yield performance. However, grain yield was negatively associated with the number of productive tillers and days to flowering, indicating that early flowering genotypes with moderate tillering may allocate more resources to grain filling rather than vegetative growth, thus improving yield efficiency. Plant height was positively correlated with both panicle diameter and panicle length, reflecting the influence of overall plant vigor on panicle traits. This suggests that taller plants tend to have more robust yield-contributing structures. Pallavi *et al.,* (2024) also reported similar associations and emphasized the importance of plant architecture in breeding programs.

TABLE 1
Analysis of variance for quantitative and micronutrient traits in pearl millet

Source	DF	Grain Yield	Dry Fodder Yield	Days to 50% Flowering	Days to Maturity	Plant Height	Productive Tillers	Panicle Length (cm)	Panicle Diameter (cm)	Fe Content (PPM)	Zn Content (PPM)
Sum of squares											
Replication	2	35.599	272.1	0.127	0.699	74.12	1.152	1.264	0.001	111.2	9.111
Genotype	158	294.902**	1690.86**	63.346**	66.054**	2243.93**	0.77**	29.846**	0.233**	523.08**	153.406**
Error	317	11.081	90.95	0.289	0.332	88.21	0.049	2.431	0.033	3.88	3.342

*& **, significant at the 0.05 and 0.01 probability level, respectively.

TABLE 2
Genetic variability, heritability, and genetic advance for different traits in pearl millet

Traits	Max	Min	Mean	GCV (%)	PCV (%)	H^2 (BS)	GA (% Mean)
Grain Yield (g/p)	65.00	3.50	22.364	43.49	45.97	89.52	84.77
Dry Fodder Yield (g/p)	205.00	10.00	69.042	33.45	36.19	85.43	63.69
Days to 50% Flowering	66.00	40.00	47.619	9.63	9.69	98.64	19.70
Days to Maturity	95.00	70.00	77.182	6.06	6.11	98.51	12.40
Plant Height (cm)	237.00	71.00	179.439	14.94	15.83	89.07	29.04
Productive Tillers	4.30	1.00	1.507	32.50	35.69	82.94	60.98
Panicle Length (cm)	32.00	11.00	20.993	14.40	16.20	78.98	26.36
Panicle Diameter (cm)	3.50	1.70	2.678	9.64	11.78	67.04	16.26
Fe Content (PPM)	104.00	30.00	55.232	23.82	24.08	97.81	48.53
Zn Content (PPM)	64.00	25.00	44.259	15.98	16.51	93.74	31.87

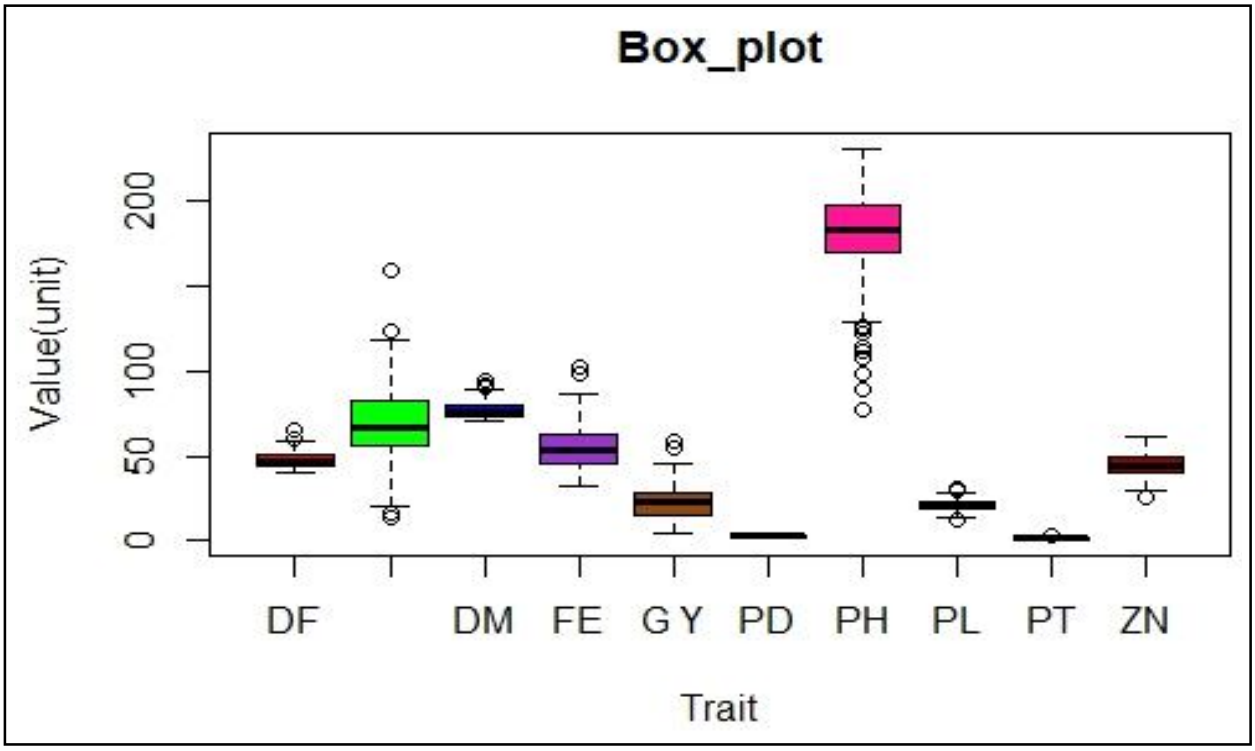

Fig. 1. Box plot representation of genetic variability for different traits in pearl millet.

In terms of nutritional traits, a strong positive correlation was observed between iron and zinc content, suggesting that simultaneous improvement of these micronutrients is feasible through genetic selection. This is consistent with the findings of Govindaraj *et al.*, (2011) who reported that both iron and zinc could be co-enhanced in pearl millet genotypes. Notably, the non-significant correlations between grain yield and micronutrient content indicate that nutritional improvement can be pursued without adversely affecting yield potential. He also emphasized the importance of integrating biofortification into mainstream breeding without compromising productivity. Overall, the results highlight key traits, such as panicle length, dry fodder yield, and micronutrient content as valuable indicators for simultaneous improvement of yield and nutritional quality in pearl millet. These relationships offer a scientific basis for informed selection strategies in breeding programs aimed at developing high-yielding, nutrient-rich cultivars.

Path coefficient analysis provided a deeper understanding of the contribution and interrelationships among traits influencing yield. Among all traits, days to flowering showed the most prominent positive direct influence on grain yield. This suggests that a longer flowering period may enhance the crop's ability to accumulate assimilates, thus supporting better grain

development. Extended flowering durations can lead to improved spikelet fertility and grain filling, especially under favourable environmental conditions. Such traits are vital in optimizing reproductive efficiency, particularly in dryland agriculture (Talawar *et al.*, 2017, Beniwal *et al.*, 2020). Plant height also exhibited a substantial positive direct effect, highlighting the role of vegetative growth and plant vigor in improving yield. Taller plants generally indicate greater biomass accumulation, which may enhance source capacity for grain production. Positive effects were also observed for panicle diameter and panicle length, indicating that traits related to panicle architecture contribute meaningfully to yield by improving sink strength and grain number. On the other hand, traits such as days to flowering and days to maturity displayed negative direct effects on grain yield. These findings imply that prolonged vegetative or maturity phases may not favor yield under water-limited or stress-prone conditions. Early maturity is often advantageous for drought escape, allowing the crop to complete its life cycle before the onset of terminal stresses. Similarly, iron content showed a negative direct effect, possibly due to physiological trade-offs between nutrient enrichment and yield performance in certain genotypes or environments. Other traits such as productive tillers and zinc content showed negligible direct effects on yield, indicating that their contribution may be more pronounced through indirect pathways or under specific environmental conditions. Although these traits are important from a nutritional or structural standpoint, their direct role in influencing grain yield appears limited in the current study. The overall model explained a substantial proportion of the variability in grain yield, suggesting that the included traits captured a significant share of yield-related variation. However, the residual effect also indicates that several other factors such as environmental interactions, physiological processes, or unmeasured traits may influence grain yield.

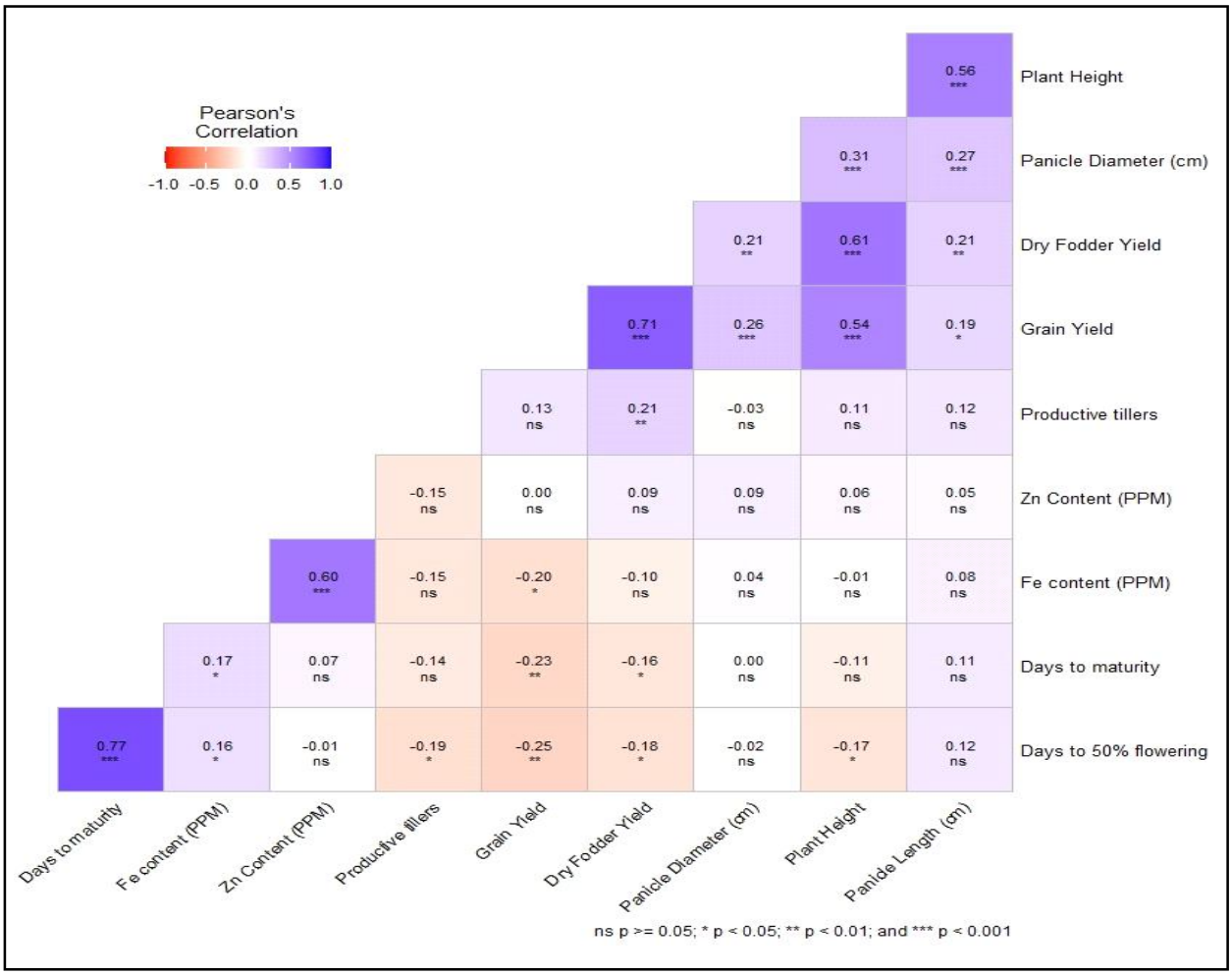

Fig. 2. Correlation Matrix of Agronomic and Nutritional Traits in Pearl Millet.

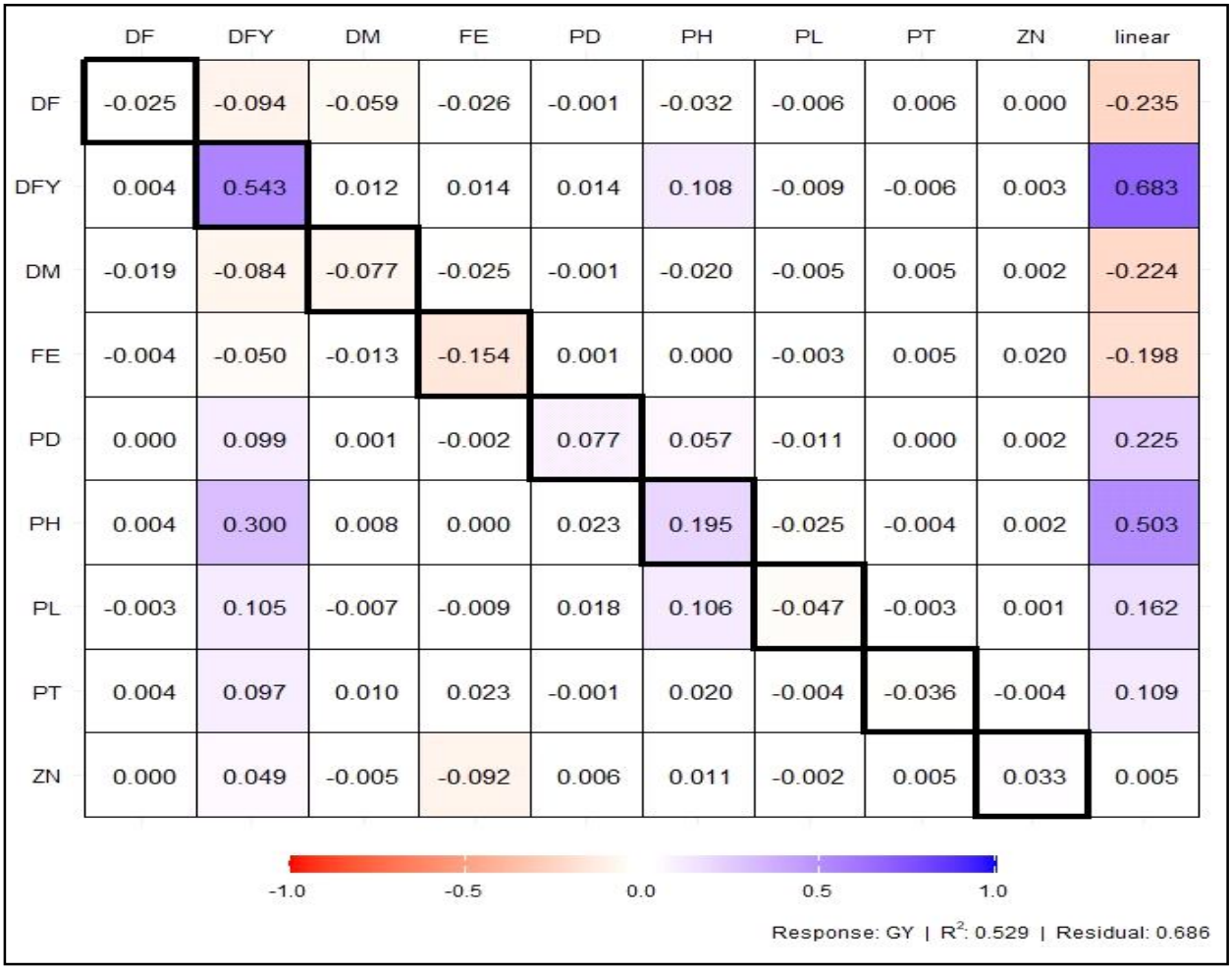

Fig. 3. Direct and indirect effects of yield contributing traits on grain yield.

CONCLUSION

In summary, days to flowering, plant height, and panicle traits emerged as key determinants of grain yield in pearl millet. These traits should be given priority in selection and breeding programs aimed at improving productivity. At the same time, balancing yield with nutritional traits like iron and zinc content will be crucial for developing high-yielding and nutritionally enriched cultivars suitable for arid and semi-arid regions. The study revealed significant genetic variability among pearl millet genotypes for key agronomic and nutritional traits, with high heritability and genetic advance for grain yield, fodder yield, and Fe content, indicating the potential for effective selection. Positive correlations among yield-contributing traits and between Fe and Zn content suggest the feasibility of simultaneous improvement in productivity and nutrition. Path analysis identified days to flowering, plant height, and panicle traits as major determinants of grain yield. These findings provide valuable insights for developing high-yielding, early-maturing, and nutrient-rich pearl millet cultivars tailored to diverse agro-ecological zones.

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