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Genetic Mechanisms Associated with Physiological, Nutritional Traits and Grain Yield in Pearl Millet (*Pennisetum glaucum* L.)

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Abstract— *One hundred genotypes of pearl millet including three checks were tested during* kharif *2024 in an Alpha Lattice design to understand the genetic mechanisms associated in governing the inheritance of grain yield, nutritional (iron, zinc, and protein content in seeds), and physiological traits (harvest index, relative water content, and SPAD chlorophyll meter reading). Higher variability for iron and zinc; moderate variability for grain yield, harvest index, and protein; and low variability for relative water content and SPAD chlorophyll meter reading were recorded. High heritability and high genetic advance as percent of mean were noted for iron content, zinc content, grain yield per plant, protein content, and harvest index, indicating predominance of additive gene action, and an early and simple selection would be advisable. High heritability coupled with moderate genetic advance over percent mean registered for relative water content indicated the operation of additive gene actions and might consistently manifest in future generations, resulting in increased effectiveness of the breeding program. Moderate heritability along with low genetic advance for SPAD chlorophyll meter reading revealed governance of non-additive genes and can be improved by heterosis breeding as simple selection might not be effective.*

Keywords— Pearl millet, Variability, Physiological traits, Nutritional traits, Genetic advance, Heritability, Iron content, Zinc content, Protein content, Biofortification.

I. INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is a coarse cereal and ranks sixth among major cereal crops in terms of area in the world after rice, wheat, maize, barley, and sorghum. The protogynous nature of its hermaphrodite flowers makes pearl millet extensively cross-pollinated. Pearl millet has become a preferred crop for growing in arid and semi-arid regions because of its drought tolerance and low inorganic fertilizer requirement. It is also nutritionally superior and rich in micronutrients such as iron and zinc and can mitigate malnutrition and hidden hunger. Genetic variability, heritability, and genetic advance offer insights into the kind and degree of genetic control over significant agronomic and economic variables. Heritability estimates indicate the observed variation that is genetically inherited, whereas genetic variability provides the basis for selection. Heritability along with genetic advance helps breeders to adopt specific selection procedures. The study in pearl millet was conducted to estimate genetic parameters for physiological, nutritional traits, and grain yield so as to infer the gene actions associated in governing the traits.

II. MATERIALS AND METHODS

The experimental material for the present study comprised of 97 pearl millet inbred lines and three checks i.e., ABV04 (Composite variety), SBH 888 (Hybrid), and Pittaganti (local variety). The experiment was laid out in an Alpha Lattice Design with two replications. All the genotypes were sown in nursery in July 2024 and transplanted to the main field in August 2024 at ARS, Ananthapuramu. Each genotype was sown in one row of four meters length with a spacing of 45 cm between rows and 15 cm between the plants within the rows. The crop was provided with 60 N + 30 P_2O_5 + 20 K_2O kg ha^{-1}. Half of the N and the entire P and K were applied as a basal dose, and the second half of N was applied as top dressing after 35 days of sowing. All the recommended cultural and agronomic practices were followed for raising a healthy crop during the crop period.

Observations on grain yield and harvest index were recorded on five randomly selected competitive plants of each genotype in each replication. The harvest index was calculated for each genotype by applying the formula of Donald (1962). The RWC was calculated by the formula of Weatherley (1950) and expressed in percentage. Estimation of seed iron and zinc content was done as per the procedure given by Tandon (1999). The nitrogen content of the pearl millet genotypes was determined by the Kjeldahl method using a KEL PLUS distillation unit. The crude protein content of the sample was calculated as 6.25 times its nitrogen content and expressed as percentage.

The genotype means for each trait over two replications were subjected to statistical analysis. The statistical package used was R. The differences among genotypes for different traits were tested for significance by using analysis of variance technique on the basis of model proposed by Panse and Sukhatme (1961). The genotypic and phenotypic variances, genotypic coefficient of variation (GCV), and phenotypic coefficient of variation (PCV) were calculated as per the formula proposed by Burton (1952). Categorization of the range of variation was done as proposed by Sivasubramanian and Madhavamenon (1973). Heritability in broad sense [$h^2(b)$] was calculated by the formula given by Lush (1940) and heritability estimates were categorized as suggested by Johnson et al. (1955b). The genetic advance was estimated by the formula given by Johnson et al. (1955a) and the range of genetic advance as per cent of mean was classified according to Johnson et al. (1955b).

III. RESULTS AND DISCUSSION

3.1 Mean Performance of the Pearl Millet Genotypes

The mean, range, and top 10 genotypes are presented in Table 1.

3.1.1 Grain Yield per Plant (g)

Among the 100 genotypes, highest grain yield per plant was recorded by SBS 888 (53.9 g) and lowest by API 2001 (18.5 g) with a general mean value of 29.59 g. The genotypes SBS 888 followed by API 2054 and API 2052 recorded high grain yield.

3.1.2 Iron Content (ppm)

Iron content among the 100 genotypes ranged from 24.1 ppm (API 1087) to 223.5 ppm (API 1012) with a general mean of 86.94 ppm. Iron content was observed to be high in API 1012 followed by API 1039 and API 1018. Hence, these can be utilized in development of biofortified pearl millet varieties. The mean values of 42 genotypes were found to be significantly higher than the general mean value. A total of 52 genotypes outperformed the superior check, SBS 888 (66.8 ppm).

3.1.3 Zinc Content (ppm)

Maximum zinc content was recorded in API 1039 (80.3 ppm) and minimum in API 2018 (10.4 ppm). The general mean value for zinc content was 80.3 ppm. Among the 100 genotypes, API 1039 followed by API 1018 and API 1111 recorded highest zinc content which can be further exploited in breeding programmes. Twenty-eight genotypes registered significantly higher zinc content than the general mean value while 65 genotypes showed more zinc content than the superior check, ABV 04 (18.9 ppm).

3.1.4 Protein Content (%)

Mean values of protein content in grain ranged from 5.4% (API 2035) to 15.0% (API 1106) with a general mean of 9.09%. The genotypes API 1106 followed by API 1045 and API 2012 displayed highest protein content. Forty-nine genotypes registered significantly more protein content than the general mean value. Seventeen genotypes recorded more mean protein content than the best check, ABV 04 (10.3%).

3.1.5 Harvest Index (%)

Among the 100 genotypes, harvest index varied between 24.3% (API 2001) and 56.2% (SBS 888) with a general mean value of 40.19%. The superior performance was exhibited by SBS 888 followed API 2007 and API 1058. Thirty-five genotypes showed significantly higher harvest index compared to the general mean value (40.19%). None of the genotypes recorded higher mean value for harvest index than the best check, SBS 888 (56.2%).

3.1.6 Relative Water Content (%)

Among the 100 genotypes, API 1073 (62.5%) registered the lowest relative water content while API 1007 (89.6%) recorded the highest. The general mean for relative water content was 76.12%. The genotypes API 1007, API 1045, and API 1011 exhibited superior performance for the trait. Thirty-three genotypes were found to be significantly superior to the general mean value. Thirty-four genotypes outperformed the best check, ABV 04 (79.0%).

3.1.7 SPAD Chlorophyll Meter Reading at 60 DAS

The mean values of SPAD chlorophyll meter readings at 60 days after sowing (DAS) ranged from 50.5 (API 1029) to 67.2 (API 1084) with a mean of 58.92. Higher SCMR readings were observed in API 1084 followed by API 2056 and API 1083. Two genotypes recorded SCMR readings significantly exceeding the general mean. Nine genotypes recorded higher SCMR readings compared to the superior check, SBS 888 (62.7).

TABLE 1
MEAN PERFORMANCE, RANGE, AND TOP PERFORMING GENOTYPES FOR GRAIN YIELD, NUTRITIONAL, AND PHYSIOLOGICAL TRAITS IN PEARL MILLET

Trait	Range	General Mean	Top Performing Genotypes
Grain Yield (g/plant)	18.5 – 53.9	29.59	SBS 888, API 2054, API 2052
Iron Content (ppm)	24.1 – 223.5	86.94	API 1012, API 1039, API 1018
Zinc Content (ppm)	10.4 – 80.3	80.3	API 1039, API 1018, API 1111
Protein Content (%)	5.4 – 15.0	9.09	API 1106, API 1045, API 2012
Harvest Index (%)	24.3 – 56.2	40.19	SBS 888, API 2007, API 1058
Relative Water Content (%)	62.5 – 89.6	76.12	API 1007, API 1045, API 1011
SPAD Chlorophyll Reading	50.5 – 67.2	58.92	API 1084, API 2056, API 1083

3.2 Genetic Variability Parameters

In the present study, the differences between the phenotypic coefficient of variation and genotypic coefficient of variation were low for all the traits, indicating the less effect of environment on the expression of the traits.

The traits viz., zinc content (GCV = 54.03%; PCV = 54.07%) followed by iron content (GCV = 50.96%; PCV = 50.98%) showed higher estimates of coefficients of variation demonstrating the presence of enormous amount of innate variability among the genotypes that remained unaffected by environmental factors. Hence, a simple selection for these traits would be effective for further improvement. Similar findings were reported by previous workers for zinc content by Anuradha et al. (2018), Subbalakshmi et al. (2018a), Priyanka et al. (2019), and Jaiswal et al. (2025); and for iron content by Anuradha et al. (2018), Subbalakshmi et al. (2018a), Priyanka et al. (2019), Andhale et al. (2024), Thomas et al. (2018), Goswami et al. (2023), and Jaiswal et al. (2025).

Moderate estimates of coefficient of variation were recorded for grain yield per plant (GCV = 18.31%; PCV = 18.76%) followed by protein content (GCV = 17.14%; PCV = 17.19%) and harvest index (GCV = 15.59%; PCV = 15.88%). This suggested that there was enough variation among the genotypes under study for making selections to enhance these traits. These results resonated with Thomas et al. (2018), Priyanka et al. (2019), Swamynatham et al. (2019), Kedarnath et al. (2021), Yadav et al. (2022), Jain et al. (2023), and Kumar et al. (2023) for grain yield per plant; Thomas et al. (2018) and Goswami et al. (2023) for protein content; and Priyanka et al. (2019), Kedarnath et al. (2021), Yadav et al. (2022), and Goswami et al. (2023) for harvest index.

Lower estimates of coefficient of variation were noticed for SPAD chlorophyll meter reading (GCV = 3.94%; PCV = 6.40%) and relative water content (GCV = 7.46%; PCV = 7.73%) demonstrating a limited range of variability for these traits constraining the potential for selection. Lower estimates of coefficient of variation were reported previously for relative water content by Singh et al. (2018) and for SPAD chlorophyll meter readings by Naik et al. (2022).

3.3 Heritability in Broad Sense

Broad sense heritability (h^2b) is a measure of how much genetic variance contributes to the whole phenotypic variance of a variable. Estimates of heritability combined with the coefficient of variation would provide the clearest picture of the amount of advance that can be anticipated from selection. Higher estimates of heritability were recorded for iron content (99.95%) followed by zinc content (99.86%), protein content (99.41%), harvest index (96.35%), grain yield per plant (95.18%), and relative water content (93.02%). Higher heritability values imply that a larger genetic component may be responsible under a range of environmental circumstances. Early generation selection based on per se performance can be useful for these traits. These results are in accordance with the findings of Anuradha et al. (2018), Subbalakshmi et al. (2018a), and Andhale et al. (2024) for yield related and nutritional traits; Nehra et al. (2017), Sumathi and Revathi (2017), Rasitha et al. (2019), Rajpoot et al. (2023), and Singh et al. (2023) for yield related traits. SPAD chlorophyll meter reading (37.78%) recorded moderate heritability, and similar results were reported by Priyanka et al. (2019) and Kumar et al. (2023).

3.4 Genetic Advance

Heritability estimates by themselves do not offer dependable insights into the gene mechanisms influencing the expression of a specific trait and do not indicate the potential genetic improvement that could arise from selecting the top individuals. Johnson et al. (1955a) noted that combining heritability estimates with genetic advance provides greater utility than relying solely on heritability estimates for forecasting the response to selection. The higher estimates of genetic advance were observed for iron content (91.26) followed by zinc content (29.44) while harvest index (12.70) followed by relative water content (11.28) and grain yield per plant (10.89) recorded moderate genetic advance. This indicates that these traits are under the control of additive genes and for the improvement of these traits by selection will be rewarding. The traits viz; protein content (3.20) and SPAD chlorophyll meter reading (2.94) expressed low genetic advance implying that these traits are governed by non-additive gene action.

3.5 Genetic Advance as Per Cent of Mean

The higher estimates of genetic advance as percent of mean were recorded for iron content (111.23) followed by zinc content (104.96), grain yield per plant (36.79), protein content (35.21), and harvest index (31.51), while moderate estimates of genetic advance as percent of mean were displayed by relative water content (14.82). Low genetic advance as percent of mean was exhibited by SPAD chlorophyll meter reading (4.99).

TABLE 2
GENETIC VARIABILITY PARAMETERS FOR GRAIN YIELD, NUTRITIONAL, AND PHYSIOLOGICAL TRAITS IN PEARL MILLET

rait	Mean	Range	GCV (%)	PCV (%)	h^2b (%)	GA	GA as % of Mean
Grain Yield (g/plant)	29.6	18.5 – 53.9	18.31	18.76	95.18	10.9	36.79
Iron Content (ppm)	86.9	24.1 – 223.5	50.96	50.98	99.95	91.3	111.23
Zinc Content (ppm)	80.3	10.4 – 80.3	54.03	54.07	99.86	29.4	104.96
Protein Content (%)	9.09	5.4 – 15.0	17.14	17.19	99.41	3.2	35.21
Harvest Index (%)	40.2	24.3 – 56.2	15.59	15.88	96.35	12.7	31.51
Relative Water Content (%)	76.1	62.5 – 89.6	7.46	7.73	93.02	11.3	14.82
SPAD Chlorophyll Reading	58.9	50.5 – 67.2	3.94	6.4	37.78	2.94	4.99

IV. CONCLUSIONS

High heritability coupled with high genetic advance as percent of mean noted for iron content, zinc content, grain yield per plant, protein content, and harvest index signifies that these traits are predominantly governed by additive genes, and an early and simple selection is advisable. High heritability coupled with moderate genetic advance over percent mean registered for relative water content indicates that this trait is governed by additive genes and might consistently manifest in future generations, resulting in increased effectiveness of the breeding program. Moderate heritability coupled with low genetic advance for SPAD chlorophyll meter reading reveals that this trait is governed by non-additive genes and can be improved by heterosis breeding as simple selection might not be effective.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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