



Variability and Association Study of Yield and Nutritive Quality Traits in Pearl Millet (*Pennisetum glaucum* L. R Br)

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ABSTRACT

Background: Micronutrient deficiency poses a significant global health challenge, affecting more than two billion individuals, with a pronounced impact on women, children and infants, principally in developing nations. Implementing agricultural strategies, such as incorporating micronutrient-rich crop-based foods and bio-fortified crop varieties containing elevated levels of iron and zinc, emerges as economical and viable solution. The study aimed to determine the extent of variability in the accessible germplasm collection from varied origins and consider the potential for bio-fortifying pearl millet with essential micronutrients.

Methods: A field research was executed with 103 pearl millet genotypes using randomized block design at Millet breeding station, TNAU, Coimbatore for three seasons of summer and rainy seasons of 2022 and 2023, aiming to find the variation and the relation of two major micronutrients with yield-related traits. The collected data was subjected for analysis by using WINDOSTAT software version 7.1.

Result: The genotypes, PT 6476, PT 6583, PTB 7079, PTB 7095, PT 6679, PT 7054, PTB 7082, PT 7062 and ICMB 98222 and PMC 23B, PT 5315, PTB 7086, DMR 3/1, PT 6476, PTB 7098, PT 5188, ICMB 99222 and PT 6676 were exhibited the higher reports of >80 mg/kg and >50 mg/kg Fe and Zn contents respectively with considerable agronomic back ground across the seasons and they were permissible for the bio-fortification programs. Also the trial revealed that high genetic and phenotypic coefficient of variation for yield linked traits. The traits such as girth of single panicle, test weight, leaf breadth, leaf length, length of single panicle, leaf sheath length and grain iron revealed the highly significant association with kernel yield. Additionally, a positive highly significant correlation coefficient ($r = 0.66$) between micronutrient contents (Fe and Zn) along with seed yield ($r = 0.18$) was observed, suggesting the probability of concurrent improvement of micronutrients without altering the grain yield.

Key words: Correlation, Path Analysis, Pearl millet genotypes, Variability.

INTRODUCTION

The global health challenge of micronutrient deficiency, particularly in developing nations, has been extensively documented. Over two billion individuals worldwide, especially children and women of reproductive age, experienced the insufficient intake of iron (Fe) and zinc (Zn), from which iron deficiency being a leading cause of anemia (Boncompagni *et al.*, 2018). This issue is most pronounced in resource-limited regions, especially among communities heavily dependent on staple cereals for their energy and nutritional requirements. Various approaches have been suggested to address micronutrient malnutrition, including medical supplementation, industrial fortification of food, dietary diversification and crop biofortification, which involves developing crop varieties with elevated micronutrient levels. Biofortification holds significant importance for populations who were reliant on agriculture, providing a cost-effective and sustainable strategy that prioritizes those most vulnerable to deficiencies (Finkelstein *et al.*, 2017).

Pearl millet, a vital coarse grain cereal and forage crop grown in arid and semi-arid regions of the Indian subcontinent and Africa, plays a crucial role in ensuring dietary energy and nutritional security (Bhat *et al.*, 2018; Srivastava *et al.*, 2020; Aribam *et al.*, 2024). Known for its resilience to drought conditions, pearl millet thrives in marginal areas where other major cereals often struggle

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to yield substantial crops (Kumawat *et al.*, 2019; Rasitha *et al.*, 2024). Pearl millet has a significant contribution to cereal consumption in specific regions of India, serving as an economical source of grain iron (Fe) and zinc (Zn) (Datir *et al.*, 2018). Many of the studies have confirmed the effectiveness of iron-biofortified pearl millet in improving iron status,

especially in children. Hence there is a need to alter the micronutrient composition for the benefit of end-users by exploring the presence of variation for grain Fe and Zn content among different pearl millet varieties. A wide range of genetic variability has been reported in grains specifically, Iniari germplasm accessions exhibited 51-121 mg/kg Fe and 46-87 mg/kg Zn, inbred parents and hybrids derived from diverse inbreds showed 30.3–102.0 mg/kg of Fe and 27.4-84.0 mg/kg of Zn and 25.8-80.0 mg/kg of Fe and 22.0-70 mg/kg of Zn respectively (Govindaraj *et al.*, 2020). Selecting micronutrient-dense lines within existing breeding populations and varieties is a valuable approach for the success of crop improvement programs and also the understanding of the associations between yield attributes and the interrelation between nutritional quality traits is crucial for simultaneous crop improvement grain yield and nutritional traits or breed into on improved genetic background. The current investigation is concentrated on identifying micronutrient-dense pearl millet parental lines, marking a critical step in the development of micronutrient biofortified pearl millet hybrids or composites. Pooled analysis was applied since it has importance for a comprehensive evaluation of risk factors that are highly prevalent in the general population.

MATERIALS AND METHODS

Experimental materials

The experimental materials consisted of 100 lines, including 42 B lines, 47 R lines and 11 land races, obtained from the Department of Millets at TNAU, Coimbatore and they were evaluated in randomized block design along with three checks, Dhanasakthi, 86M38 and COH10 Table 1. The chosen inbred lines differed exclusively for grain iron (Fe) and zinc (Zn) content. They also varied in performance for key agronomic traits, such as flowering date, plant height, panicle size, earhead weight and thousand-grain weight.

Field evaluation

A field trial was executed during three different seasons (*Kharif* 2022, Summer 2023 and *Kharif* 2023) at Millets Breeding Station, Department of Millets, TNAU, Coimbatore, utilizing a randomized block design with two replications. The climatic description of each environment has given Table 1. Each entry was planted in two rows, each measuring 4 meters in length, with an intra-row spacing of 15 cm and an inter-row spacing of 50 cm. The whole crop period, all required agronomic practice were followed.

Soil and grain micronutrient analysis

Soil micronutrient levels were evaluated by DTPA extractable method (Lindsay and Norwell, 1978) at the time of planting showing deficient level of Fe and Zn using Atomic Absorption Spectrometry (AAS). The scanning based method was utilized to estimate iron (Fe) and zinc (Zn) for estimation of micronutrients. The grain samples from

respective entries, harvested at physiological maturity, underwent for micro nutrient analysis using Energy Dispersive X-rays Fluorescence (ED-XRF) at TRRI, Aduthurai.

Observations recorded

Data recorded for thirteen morphometric traits from five plants which were selected randomly at all the experimental material. Morphometric traits viz. days to 50% flowering (DFF), days to maturity (DTM), plant height (PH), leaf sheath length (LSL), length of leaf (LL), leaf breadth (LB), number of economic tillers per plant (NET), panicle length (PL), panicle girth (PG), thousand grain weight (TGW), grain Fe content (Fe), grain Zn content (Zn) and grain yield/single plant (SPY) were noted.

Statistical analysis

Ahead of combined analysis, Bartlett 't' test was performed to test the error variance for its homogeneity across the seasons. Analysis of variance across the seasons and the association of traits over the seasons was done by WINDOSTAT statistical software version 7.1. The genetic parameters such as PCV and GCV, heritability and GAM were computed by using following formula.

The phenotypic coefficient of variation facilitates the comparison of total variation within the experimental material across different characteristics and was computed using the following formula:

$$PCV = \frac{\sigma_p^2}{\bar{x}} \times 100$$

The genotypic coefficient of variation aids in assessing the extent of genotypic variation within the experimental material across different characteristics and was computed using the following formula:

$$GCV = \frac{\sigma_g^2}{\bar{x}} \times 100$$

Heritability is the inheritable portion of the phenotypic variance and is estimated by dividing the genotypic variance by the phenotypic variance (Lush, 1949), expressed as a percentage.

$$h^2 = \frac{\sigma_g^2}{\sigma_p^2} \times 100$$

Genetic advance mean signifies the percentage improvement in the genotypic mean value of the selected progenies compared to their parental population after the process of selection. The calculation and classification were carried out following the method outlined by Johnson *et al.* (1955).

$$GAM = \frac{\text{Genetic advance}}{\text{Grand mean}} \times 100$$

RESULTS AND DISCUSSION

A significant portion of the universal population experiences the shortage of micronutrients such as with iron affecting

60-80% and zinc affecting thirty per cent of the population being particularly prevalent. These deficiencies have severe social impacts, leading to conditions such as anemia (due to iron deficiency) and stunted growth (due to zinc deficiency), which have devastating effects on countries (Yadav *et al.*, 2023). Ensuring these essential micronutrients are available through staple diets is a reliable way to enhance global human health. To meet out this micronutrient needs, evolving nutrient-rich and agronomically superior cultivars is a crucial goal in plant breeding. The biofortification breeding focuses on creating lines that produce hybrids and commercial varieties with higher iron and zinc content than currently available. To meet these ambitious breeding targets, leveraging that genetic diversity found in available material is a rapid method for identifying mineral-rich accessions. In this regard, one hundred and three bajra genotypes evaluated for their variability for yield and nutritive quality traits and the results described below.

Combined analysis of variance Table 2 disclosed that existence of variation among 103 genotypes for studied morphometric and nutritive quality traits under except leaf breadth for environmental variance (Anuradha *et al.*, 2020) over the seasons. The examination of mean values and various heritable variability parameters Table 3 indicated the significant variations for most of the studied traits and it could be utilized to develop hybrid varieties with simultaneous improvement in yield and former yield traits (Rajpoot *et al.*, 2023).

Variability studies for yield and nutritive quality traits

Higher phenotypic coefficient of variation (PCV) was observed Table 3 and it indicating that the impact of environment on the observed traits. Notably, the yield traits including test weight and leaf sheath length exhibited higher PCV and GCV, suggesting significant variability amid the genotypes for these traits (Rajpoot *et al.*, 2023). These high variability estimates indicated that presence of ample variation for the studied traits and it could be used for further

Table 1: Soil and weather parameters prevailed during three different crop periods.

Seasons	Soil parameters					Weather parameters				Rainfall (mm)
	Fe	Zn	pH	EC	Soil type	Mean temp. (°C)		Relative humidity (%)		
	(mg/kg)	(mg/kg)		(dS m ⁻¹)		Max.	Min.	07:22 hrs.	14:22 hrs.	
Kharif' 2022	3.36	0.74	8.01	0.37	Clay loam	31.4	22.7	82.2	55	605
Summer' 2023	3.21	0.68	8.00	0.39		33.12	21.82	82.36	39.62	221.9
Kharif' 2023	3.05	0.63	7.98	0.41		27.93	58.74	50.08	33.49	60.6

Table 2: Pooled analysis of variance of three seasons for 16 yield and nutritive quality traits.

Traits	Mean sum of squares					
	Environments (df=2)	Genotypes (df=102)	Genotypes × Environment (df =204)	Pooled error (df = 306)	Mean (pooled)	CV (%)
DFF	289.46**	31.51**	2.08**	0.79	50.62±0.60	2.92
DTM	617.24**	26.52**	1.96**	0.69	83.46±0.58	1.69
PH	467.08**	2417.03**	51.25**	60.03	151.03±3.58	5.81
LSL	2.05**	20.30**	2.51**	0.96	12.09±0.66	13.48
LL	26.99**	137.16**	20.99**	10.94	55.55±1.97	8.69
LB	0.12	1.22**	0.15**	0.1	4.03±0.17	10.53
NET	1.16**	0.83**	0.27**	0.1	4.08±0.21	12.91
PL	29.25**	66.17**	4.18**	2.25	21.97±1.02	11.34
PG	0.64**	5.51**	0.16**	0.12	8.53±0.30	8.61
TGW	6.03**	14.36**	0.42**	0.07	9.98±0.25	6.15
Fe	585.21**	472.25**	17.22**	8.39	43.30±1.27	7.20
Zn	748.52**	88.53**	8.46**	4.93	66.66±3.43	12.58
SPY	17,718.96**	558.33**	65.36**	44.46	60.75±1.77	7.14

** Represents significance at 1% probability level.

DFF - Days to 50% Flowering; DTM - Days to maturity; PH - Plant height; LSL - Leaf sheath length; LL - Length of leaf; LB - Breadth of leaf; NET - Number of economic tillers per plant; PL - Panicle length, PG - Panicle girth; TGW - Thousand grain weight; Fe - Grain Fe content; Zn - Grain Zn content; SPY - Grain yield/Single plant.

Table 3: Estimation of genetic parameters for 16 yield and nutritive quality traits across three seasons.

Parameters	DFF	DTM	PH	LSL	LL	LB	NET	PL	PG	TGW	Fe	Zn	SPY
Minimum	40.63	73.75	84.55	5.34	38.78	2.39	2.98	13.11	5.06	5.33	37.10	27.80	45.11
Maximum	60.13	91.00	223.00	19.17	69.29	5.98	5.68	36.10	12.59	15.96	92.27	58.62	110.96
GCV (%)	6.29	3.49	18.64	20.46	11.64	15.20	11.79	19.95	14.15	21.79	20.47	12.19	18.22
PCV (%)	6.94	3.88	19.53	24.50	14.53	18.49	17.48	22.94	16.56	22.64	21.66	14.16	22.15
Heritability (bs)	0.82	0.81	0.91	0.69	0.64	0.68	0.45	0.76	0.73	0.93	0.89	0.74	0.68
GAM	11.77	6.48	36.67	35.20	19.21	25.75	16.39	35.73	24.91	43.19	39.76	21.63	30.89

GCV- Genotypic coefficient of variation; PCV - Phenotypic coefficient of variation; hbs - Broad sense heritability; GAM - Genetic Advance as per centage of Mean ; DFF - Days to 50% flowering; DTM - Days to maturity; PH - Plant height; LSL - Leaf sheath length; LL - Length of leaf; LB - Leaf breadth; NET - Number of economic tillers per plant; PL - Panicle length, PG - Panicle girth; TGW - Thousand grain weight; Fe - Grain Fe content; Zn - Grain Zn content; SPY - Grain yield / Single plant.

selection and crop improvement. In the sense of yield higher PCV and moderate GCV observed across the environments and also individual environments Supplementary Table 1. In contrast to this, Anuradha *et al.*, (2018) and Kumawat *et al.* (2019) reported higher variability. Considering nutritive traits higher variability observed for Fe content whereas moderate variability observed for Zn content.

Heritability of traits provides insights on the effectiveness of selection concerning inheritance. However, combining heritability with genetic advance (GAM) offers a more dependable estimate of selection. Most of the studied traits observed with high heritability (broad sense) and genetic advance as % of mean. These findings suggested that these characters governed by additive genes and direct selection strategies could effectively enhance these specific traits including grain micronutrients viz., Fe and Zn (Govindaraj *et al.*, 2020).

The genotypes viz., PT 6476, PT 6583, PTB 7079, PTB 7095, PT 6679, PT 7054, PTB 7082, PT 7062 and ICMB 98222 and PMC 23B, PT 5315, PTB 7086, DMR 3/1, PT 6476, PTB 7098, PT 5188, ICMB 99222 and PT 6676 were exhibited the higher reports of >80 mg/kg and >50 mg/kg Fe and Zn contents respectively Table 4 with considerable agronomic superiority across the three seasons. Hence these lines serves as key genotypes and it can be utilized for the bio-fortification programs.

Association studies for yield and nutritive quality traits

Selecting superior genotypes by yield as such will not be effective (Bikash *et al.*, 2013). Correlation of distinct traits provides the idea on being inherited together from generations. It helps in rambling selection for the multifaceted trait like grain yield by selection through other biometrical traits which are closely and positively associated. This association is by cause of pleiotropic gene action or linkage or more likely both (Dapke *et al.*, 2014).

Correlations between yield characters and quality components were examined and the resultant correlation coefficients are presented in Table 5. The correlation coefficient due to genotypic was more than that phenotypic for the studied characters which denoted that existence of considerable inherent association of the traits. Yield per plant expressed the significant positive correlations with the traits panicle girth, thousand grain weight, leaf breadth, leaf length, leaf sheath length, length of single panicle and grain Fe. These results inferred that choice of these traits would lead to simultaneous improvement in yield/plant. Grain Fe exhibited an optimistic relation with yield, suggesting ample progress of both yield and micronutrient (Fe) content simultaneously. This study concludes that selecting for high yield and Fe will be achieved without adversely affecting grain yield whereas Chakraborti *et al.* (2010) reported a noteworthy negative relationship among Fe content and grain yield in maize. No correlation was exhibited among kernel iron and test weight, in contrast

Pujar *et al.*, 2020 found significant associations for both micronutrients.

The current investigation emphasizes a substantial positive correlation of micronutrients across the seasons and as well in individual seasons, indicating concurrent selection of these interrelated traits to enhance nutritional quality. Earlier reports in pearl millet by Govindaraj *et al.* (2013) and Rai *et al.* (2014) have consistently revealed the strong association between grain nutritive contents and these likely due to shared physiological mechanism or localized quantitative trait loci (QTLs) for iron and zinc accumulation, as reported in pearl millet (Kumar, 2011). This suggests that selecting for both micronutrients simultaneously could be effective. The consistent association across diverse environments allows to rank the genotypes for micronutrients which are expected to be less affected by environmental factors. Since both micronutrients are additively inhibited, it is crucial to

incorporate these qualities into parents to produce hybrids with high Fe/Zn content and high yields.

Although negative correlation was identified between zinc and yield and Pujar *et al.* (2020) reported the same relationships in pearl millet. Comparable negative correlations between kernel zinc and yield have been observed in sorghum (Ashok Kumar *et al.*, 2009), wheat (Morgounov *et al.*, 2007) and Maize (Chakraborti *et al.* 2010). These negative linkages can be overcome through intentional assortment in the populations drawn from crosses between high-Fe and high-yielding parents.

Estimation of associations of traits alone not be sufficient because of reciprocated cancellation of related traits, hence there is a call for to estimate the path coefficients, which takes into account, the cause of relationship in addition to the degree of relationship. The trait test weight (TGW) and grain Fe showed moderate optimistic direct effect on grain yield whereas grain Zn

Table 4: Top performing genotypes for grain micronutrients and the range of their agronomic performance.

Trait	Top 10 genotypes	Days to 50% flowering	Thousand seed weight (g)	Grain yield (g)
Fe (>80 mg/kg)	PT 6476, PT 6583, PTB 7079, PTB 7095, PT 6679, PT 7054, PTB 7082, PT 7062, ICMB 98222,	47-60	7.33-13.20	58.65-95.30
Zn (>50 mg/kg)	PMC 23B, PT 5315, PTB 7086, DMR 3/1, PT 6476, PTB 7098, PT 5188, ICMB 99222, PT 6676	45-56	7.29-12.21	51.09-100.79

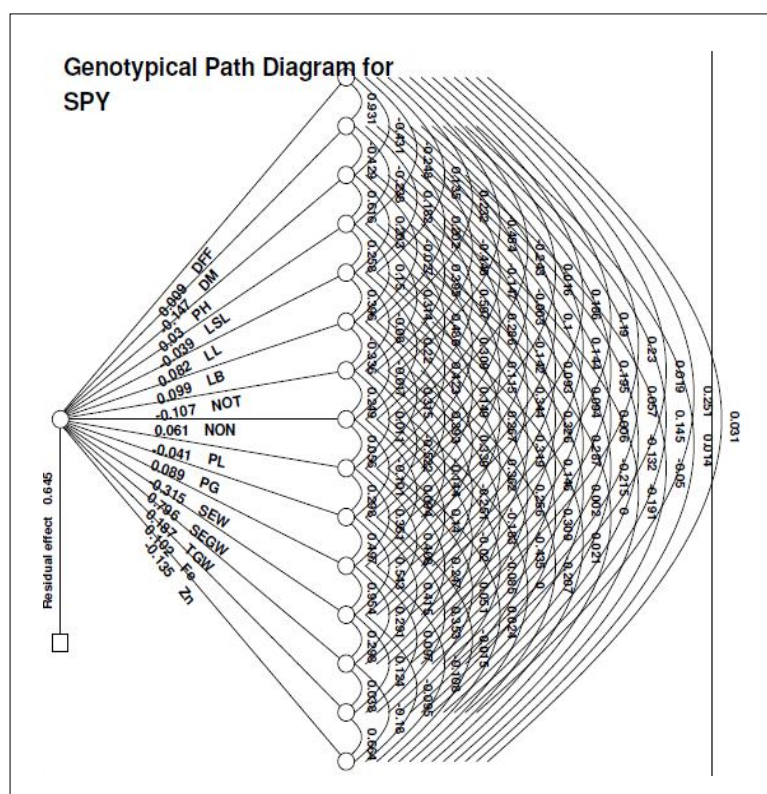


Fig 1: Genotypical path for yield and nutritive quality traits across seasons.

Supplementary Table 1: Genetic parameters for yield and nutritive quality traits of three individual seasons.

Traits	Genetic parameters											
	Phenotypic coefficient of variation				Genotypic coefficient of variation				Heritability (h^2)			
	K'22	S'23	K'23	S'23	K'22	S'23	K'23	S'23	K'22	S'23	K'23	S'23
DFF	7.13	7.13	6.50	6.93	6.90	6.24	93.81	94.61	92.23	13.77	92.23	13.89
DM	4.26	3.71	3.61	3.56	4.14	3.48	94.35	91.8	93.41	8.28	93.41	7.03
PH	19.89	19.33	19.36	18.46	19.33	18.73	94.45	91.21	93.63	38.7	93.63	36.32
LSL	27.84	23.78	22.32	23.23	27.11	19.96	94.82	95.43	73.96	54.39	73.96	46.75
LL	13.44	15.74	14.29	14.93	11.74	12.87	76.24	89.97	81.07	21.12	81.07	29.18
LB	18.37	17.04	19.99	13.03	17.42	19.18	89.93	58.44	92.04	34.03	92.04	20.51
NOT	21.08	12.28	18.04	9.57	20.12	15.42	91.13	60.73	73.03	39.57	73.03	15.36
NON	18.82	18.82	17.81	18.26	18.27	17.37	94.26	94.27	95.37	36.55	95.37	36.55
PL	22.10	22.46	24.58	20.93	21.39	23.76	93.66	86.85	93.48	42.65	93.48	40.18
PG	15.46	17.31	16.9	16.67	15.11	16.37	95.33	92.8	93.74	30.37	93.74	33.09
SEW	32.44	33.83	34.63	32.93	31.68	32.89	95.4	94.72	90.23	63.75	90.23	66.02
SEGW	33.19	29.77	30.62	29.07	31.37	29.89	89.33	95.38	95.47	61.08	95.47	58.49
TGW	21.19	22.94	23.68	22.78	20.92	23.64	97.45	98.78	99.59	42.54	99.59	46.68
Fe	20.53	22.44	21.8	22.11	19.76	21.25	92.71	97.09	94.96	39.21	94.96	44.88
Zn	13.45	15.01	13.71	14.33	11.96	12.86	79.18	91.15	87.88	21.93	87.88	28.18
SPY	24.89	23.22	21.06	21.37	22.17	19.01	79.35	84.73	81.38	40.68	81.38	40.53

DFF- Days to 50% flowering; DM- Days to maturity; PH- Plant height; LSL- Leaf sheath length; LL- Leaf length; LB- Leaf breadth; NET- Number of economic tillers per plant; PL- Panicle length, PG- Panicle girth; TGW- Thousand grain weight; Fe- Grain Fe content; Zn- Grain Zn content; SPY- Grain yield/ - Single plant yield.

Table 5: Genotypic correlation coefficient matrix of individual and across three seasons for 16 yield and Nutritive quality traits.

Traits	Environment	DFF	DTM	PH	LSL	LL	LB	NET	PL	PG	TGW	Fe	Zn
DTM	Kharif' 22	0.84**											
	Summer'23	0.79**											
	Kharif' 23	0.90**											
	Pooled	0.93**											
PH	Kharif' 22	-0.41**	-0.45**										
	Summer'23	-0.40**	-0.38**										
	Kharif' 23	-0.41**	-0.37**										
	Pooled	-0.43**	-0.43**										
LSL	Kharif' 22	-0.16*	-0.26**	0.62**									
	Summer'23	-0.21**	-0.13	0.42**									
	Kharif' 23	-0.26**	-0.21**	0.64**									
	Pooled	-0.25**	-0.24**	0.62**									
LL	Kharif' 22	0.18**	0.18*	0.24**	0.25**								
	Summer'23	0.13	0.25**	0.02	0.13								
	Kharif' 23	-0.03	0.01	0.28**	0.29**								
	Pooled	0.14	0.18**	0.20**	0.26**								
LB	Kharif' 22	0.11	0.15*	0.01	0.20**	0.31**							
	Summer'23	0.30**	0.20**	-0.02	0.20**	0.36**							
	Kharif' 23	0.18*	0.13	-0.06	0.12	0.22**							
	Pooled	0.23**	0.20**	-0.03	0.15	0.40**							
NET	Kharif' 22	-0.16*	-0.28**	0.22**	0.13	-0.12	-0.26**						
	Summer'23	-0.45**	-0.36**	0.21**	0.17*	-0.06	-0.35**						
	Kharif' 23	-0.38**	-0.35**	0.53**	0.27**	-0.04	-0.15*						
	Pooled	-0.45**	-0.45**	0.40**	0.31**	-0.08	-0.34**						
PL	Kharif' 22	0.07	0.04	0.32**	0.33**	0.37**	0.24**	0.04					
	Summer'23	0.14*	0.05	0.17*	0.14*	0.22**	0.31**	-0.15*					
	Kharif' 23	0.03	-0.04	0.29**	0.21**	0.37**	0.19**	0.11					
	Pooled	0.02	0.00	0.29**	0.31**	0.42**	0.32**	0.01					
PG	Kharif' 22	0.16*	0.14	-0.13	0.20**	0.11	0.33**	-0.41**	0.17*				
	Summer'23	0.24**	0.07	-0.14	0.00	0.08	0.47**	-0.48**	0.27**				
	Kharif' 23	0.10	0.02	-0.12	-0.01	0.21**	0.31**	-0.36**	0.22**				
	Pooled	0.19*	0.10	-0.14*	0.11	0.15*	0.39**	-0.52**	0.30**				
TGW	Kharif' 22	0.03	0.14*	0.00	0.28**	0.19**	0.24**	-0.25**	0.23**	0.41**			
	Summer'23	0.00	0.01	0.01	0.22**	0.04	0.29**	-0.11	0.20**	0.35**			
	Kharif' 23	-0.03	-0.04	0.02	0.27**	0.17*	0.16*	-0.03	0.21**	0.38**			
	Pooled	0.02	0.06	0.01	0.29**	0.15*	0.26**	-0.18*	0.25**	0.42**			

Table 5: Continue...

Table 5: Continue...

Fe	Kharif' 22	0.14*	0.14*	0.14*	-0.13	-0.14	0.04	0.23**	-0.41**	-0.05	0.37**	0.11
	Summer'23	0.18**	0.37**	0.18**	-0.16*	-0.25**	-0.01	0.35**	-0.27**	0.08	0.34**	0.02
	Kharif' 23	0.11	0.19**	0.11	-0.08	-0.22**	-0.04	0.29**	-0.18*	0.02	0.29**	0.00
	Pooled	0.15*	0.25**	0.15*	-0.13	-0.22**	0.00	0.31**	-0.44**	0.05	0.35**	0.04
Zn	Kharif' 22	0.01	0.01	-0.03	-0.01	-0.12	0.08	0.07	-0.24**	0.00	0.08	-0.13
	Summer'23	0.13	0.13	0.12	-0.07	-0.18*	-0.03	-0.06	-0.07	-0.01	-0.08	-0.25**
	Kharif' 23	-0.06	-0.06	-0.09	-0.01	-0.10	-0.02	0.04	-0.12	-0.03	0.03	-0.10
	Pooled	0.03	0.03	0.01	-0.05	-0.19**	0.00	0.02	-0.21**	0.02	-0.02	-0.18
SPY	Kharif' 22	0.07	0.07	0.08	0.14*	0.29**	0.25**	0.42**	-0.18*	0.26**	0.52**	0.38**
	Summer'23	0.09	0.09	-0.02	0.07	0.15*	0.07	0.29**	-0.26**	0.25**	0.44**	0.13
	Kharif' 23	0.01	0.01	-0.04	0.05	0.15*	0.35**	0.17*	-0.19**	0.36**	0.45**	0.09
	Pooled	0.10	0.10	0.07	0.09	0.25**	0.31**	0.41**	-0.32**	0.31**	0.55**	0.42**

*, ** Represents significance at 5% and 1% probability level

DFF - Days to 50% Flowering; DM - Days to maturity; PH - Plant height; LSL - Leaf sheath length; LL - leaf length; LB - Leaf breadth; NET - Number of economic tillers per plant; PL

- Panicle length, PG - Panicle girth; TGW - Thousand grain weight; Fe - Grain Fe content; Zn - Grain Zn content; SPY - Grain yield/ - Single plant

exhibited negative effect on yield Fig 1 and these traits were important as component traits for form selection indices in future (Kalagare *et al.*, 2022).

CONCLUSION

The study showed considerable variability in critical nutrients and varied agronomic traits. Recovering different micronutrients and traits simultaneously is achievable if they are not negatively related with each other or with morphometric traits in tested lines, which are more probable to be use as future parents. The high estimates of hereditary parameters indicated that the minor influence of genotype-environment interactions, suggesting that simple selection-based breeding will be effective for genetic improvement. A strong correlation among grain micronutrient contents suggested that the opportunity of parallel improvement by conventional breeding. The positive relation among kernel iron and yield indicates that biofortification of Fe and Zn with competitive yields is feasible. The B lines such as PTB 7079, PTB 7095, PTB 7082, ICMB 98222, PMC 23B, PTB 7086, PTB 7098, ICMB 99222 along with the R lines such as PT 6476, PT 6583, PT 6679, PT 7054, PT 7062, PT 5315, DMR 3/1, PT 5188 and PT 6676 were identified with high level of micronutrients and the accessibility and use of these elite nutrient-dense breeding lines by breeding organizations could facilitate the introgression and mainstreaming of nutrition traits in commercial hybrid breeding in the near future.

Conflict of interest

All the authors declared that they have no conflicts of interest regarding the publication of this article. No funding or sponsorship influenced the design of the study, data collection, analysis, decision to publish or preparation of the manuscript.

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