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Genetic analysis of zinc rich landraces for yield, quality and nutritional traits in rice (*Oryza sativa* L.)

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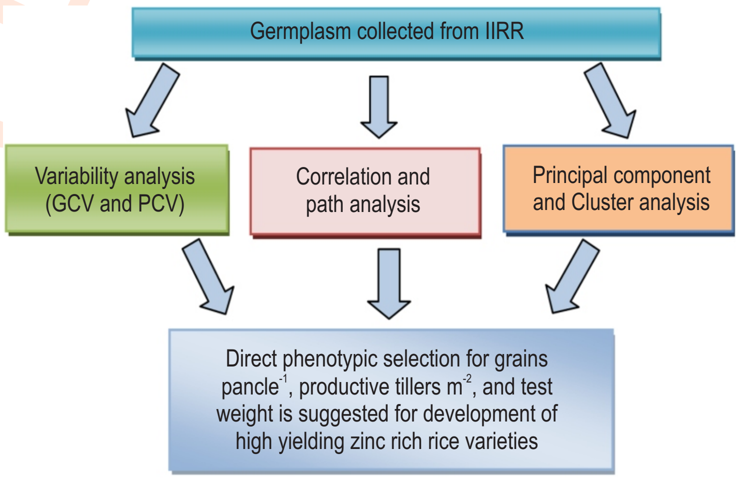
Abstract

Aim: To study genetic variability, correlation, path and Principal Component Analysis (PCA) in a set of 100 zinc rich rice landraces along with four checks.

Methodology: The study was carried out at the Regional Agricultural Research Station (RARS), Maruteru, during *Rabi* season, 2020-2021 in an Augmented Randomized Block Design.

Results: Grain yield per plant, grains per panicle, productive tillers m^{-2} and test weight showed moderate genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) coupled with high heritability and genetic advance as per cent mean. These traits also had positive and significant association coupled with high positive direct effect on grain yield per plant. They also contributed maximum variance to the total variability indicating the effectiveness of direct phenotypic selection for these traits for improving the grain yield per plant. Further, cluster analysis grouped the zinc rich rice landraces along with checks into three clusters. Cluster II had the highest genotypes (42), while Cluster I had 32 genotypes and Cluster III consisted of 30 zinc rich landraces along with three check varieties.

Interpretation: Grains per panicle, productive tillers and test weight were identified as effective selection criteria for the improvement of grain yield towards development of high yielding zinc-rich rice varieties to curtail micronutrient malnutrition in areas with rice as staple food.



Key words: Cluster analysis, Landraces, *Oryza sativa*, Path analysis, PCA, Zinc

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Introduction

Rice (*Oryza sativa* L.) is grown widely in the most diverse ecosystems of tropical and subtropical regions of the world. It is one of the staple cereal food crops for more than 2.70 billion people in Asia alone (Sarao *et al.,* 2016). Among the rice-cultivated countries, India occupies the largest area in the world i.e. 43.86 million hectares and production of 99.24 million tonnes and productivity of 2.49 t ha^{-1} (Sudeepthi *et al.,* 2020). Although high-yielding rice varieties have been developed, these cultivars have lower concentrations of micronutrients, proteins, and essential fats. Therefore, there is a need to develop high-yielding varieties with high level of nutrients. However, more than half of the world's population suffers from micronutrient malnutrition, often referred as "hidden hunger," which poses a major threat and enhances the mortality rate in children and women (Bekele *et al.,* 2013).

Zinc deficiency is a significant factor contributing to illness and diseases in regions where rice serves as a primary cereal food source, as stated by the World Health Organization (Raza *et al.,* 2020). This deficiency can lead to various health issues, including diarrhea, reduced appetite, skin problems, delayed wound healing, and hypogonadism. Additionally, it is linked to respiratory problems, as reported by Swami *et al.* (2016).

Every year millions of Disability-Adjusted Life Years (DALYs) would be saved if bio-fortified rice varieties are introduced globally. Zinc bio-fortification is a promising strategy to address micronutrient malnutrition and also enhance the levels of nutrient contents in staple food crops. The success of bio-fortification, however, relies on the existence of diversity of the target traits along with yield (Mingotte *et al.,* 2018). Screening of rice genotypes for grain zinc content is, therefore, the initial step in the plant breeding programme for the development of high yielding rice varieties along with high grain zinc content (Chandu *et al.,* 2020). Landraces, are important genetic material that possess potential characteristics for crop improvement and development programmes (Christina *et al.,* 2021) are essential. Evaluation of genetic variability is fundamental in rice breeding programmes for selection, conservation of different rice landraces, and proper utilization (Raza *et al.,* 2020). Further, genetic characters are predominantly governed by polygenes which are extremely influenced by the environment. Hence, heritability plays a key role in plant breeding since progeny from divergent parents exhibit greater heterosis and provide greater variability in segregating generations (Pratim *et al.,* 2018).

Heritability coupled with genetic advance offers the most effective condition for the selection of a specific character. Grain yield, however, is a complex trait that depends on various component characters. The relationship between the yield, quality and nutritional traits can be determined through correlation with one another (Bhargavi *et al.,* 2022). Additionally, path coefficient analysis aids in the efficient division of the correlation coefficients into direct and indirect measures, assisting the plant breeder in determining the genuine selection criteria (Duppala *et al.,* 2022). Further, Principal Component Analysis is a multivariate tool that has been found to be effective for evaluating the phenotypic diversity (Singh *et al.,* 2020) and identification of the traits that help in distinguishing selected genotypes which contribute maximum variability. However, correlation and path analysis reveal the strength of relationship between different traits (Ravikumar *et al.*, 2020). Studies on zinc rich landraces are, however, limited. In this context, the present study, comprising of 100 rice landraces rich in zinc was taken up to assess the genetic diversity and to identify superior landraces for yield, yield attributing, quality and nutritional traits for use in breeding programs aimed at tackling the problem of zinc malnutrition in areas with rice as staple food by developing high-yielding rice varieties with greater zinc content.

Materials and Methods

Plant material: The experimental material comprised of 100 zinc-rich rice landraces as well as four checks (DRR Dhan 48, DRR Dhan 49, MTU 7029 and Chittimuthyalu (zinc-rich)) obtained from ICAR-Indian Institute of Rice Research (IIRR), Rajendranagar and Regional Agricultural Research Station (RARS), Maruteru, India. These genotypes were assessed to study the genetic variability, correlation, path coefficient analysis and PCA for yield, yield components, quality and nutritional traits. Details of the genotypes used in the study are presented in Table 1. The present study was carried out at the Regional Agricultural Research Station (RARS), Maruteru, during *Rabi,* 2020-2021 in an Augmented Randomized Block Design. Twenty-one day old seedlings were transplanted in two rows of 4.5m length, with 20 cm between rows and 15 cm between plants. To attain a good crop, standard agronomic procedures and crop protection measures were implemented during the crop season.

Recording of observations: For grain yield and yield component traits, observations were taken on five randomly selected chosen plants. Observations on quality and nutritional traits, such as milling recovery per cent, hulling recovery per cent, head rice recovery per cent, water uptake, volume expansion ratio, amylose content, protein content, zinc and iron contents were obtained using standard procedures from randomly drawn grain samples from each plot in each genotype and replication. However, data on days to 50 per cent flowering was recorded on plots basis.

Estimation of iron and zinc concentration: Iron and zinc concentration in rice samples was estimated using non-destructive, energy-dispersive X-ray fluorescence spectrometry (EDXRF) instrument (model X-Supreme 8000; Oxford Instruments plc, Abingdon, UK) at IIRR, Hyderabad. Ten gram of well dried paddy sample from each genotype was de husked using non-metallic de-husker (Krishi international 810 de-husker) having roller made of polymer to avoid iron and zinc contamination. De-husked rice was cleaned by removing broken grains and debris and 5 g of each sample was weighed and transferred to sample cups. The sample cups were gently shaken for uniform distribution of samples and kept for analysis. The concentration of Zn and Fe was expressed in parts per million (ppm) as per the procedure detailed by Paltridge *et al.* (2012).

Table 1: Details of zinc rich rice landraces studied

Code	Entry Name	Source/Origin
GM-1	Chakhao Paiterin	Manipur, India
GM -3	Binnidhan	Bangladesh
GM -7	Lalmala	Maharashtra, India
GM -8	Indrayani	Maharashtra, India
GM -9	Improved sambhamashuri	Telangana , India
GM -10	Samba Mashuri	Andhra Pradesh, India
GM -11	Mahisagar	Gujarat, India
GM -12	Raj Bangalo-1	West Bengal, India
GM -13	Raj Bangalo	West Bengal, India
GM -16	Futuyu-Red	China
GM -17	Futuyu	China
GM -18	Lalkada-1	Gujarat, India
GM -19	Nana bokra	Bangladesh
GM -22	Pokhali-1	Bangladesh
GM -23	Karma mashuri	Chhattisgarh, India
GM -25	Narmada	West Bengal, India
GM -29	Pusa basmati-1	New Delhi, India
GM -32	Ranbir basmati	Dehradhun, India
GM – 33	Kasturi basmati	Uttrakhand, India
GM – 34	Basmati-370	New Delhi, India
GM – 35	Type-3 basmati	Uttrakhand, India
GM – 36	Tarori basmati	Haryana, India
GM – 38	Nagaland selection-30	Nagaland, India
GM – 42	Nagaland selection-12	Nagaland, India
GM – 44	Nagaland selection-8	Nagaland, India
GM – 45	Nagaland selection-7	Nagaland, India
GM – 46	Nagaland selection-6	Nagaland, India
GM – 47	Nagaland selection-5	Nagaland, India
GM – 49	Nagaland selection-3	Nagaland, India
GM – 50	Selection from Gujarat	Gujarat, India
GM – 53	Selection form Madhya Pradesh	Madhya Pradesh, India
GM – 54	Selection from Punjab	Punjab, India
GM – 55	Selection from Gujarat	Gujarat, India
GM – 56	Selection from Gujarat	Gujarat, India
GM – 57	Selection from Gujarat	Gujarat, India
GM – 58	Selection from Gujarat	Gujarat, India
GM – 59	Selection from Gujarat	Gujarat, India
GM – 60	Selection form Madhya Pradesh	Madhya Pradesh, India
GM – 67	Selection from Punjab	Punjab, India
GM – 68	Selection from Gujarat	Gujarat, India
GM – 69	Selection from Madhya Pradesh	Madhya Pradesh, India
GM – 72	Selection from Madhya Pradesh	Madhya Pradesh, India
GM – 73	Selection from Gujarat	Gujarat, India
GM – 74	Selection from Gujarat	Gujarat, India
GM – 76	Selection from Madhya Pradesh	Madhya Pradesh, India
GM – 79	Selection from Madhya Pradesh	Madhya Pradesh, India
GM – 80	Selection from Gujarat	Gujarat, India
GM – 86	Selection from Maharashtra	Maharashtra, India
GM – 88	Selection from Punjab	Punjab, India
GM – 89	Selection from Gujarat	Gujarat, India
GM – 91	Selection from Maharashtra	Maharashtra, India
GM – 93	Selection from Gujarat	Gujarat, India
GM – 94	Selection from Gujarat	Gujarat, India
GM – 96	Selection from Kerala	Kerala, India
GM – 99	Selection from Gujarat	Gujarat, India
GM – 100	Selection from Maharashtra	Maharashtra, India

Table continu

GM – 103	Selection from Gujarat	Gujarat, India
GM – 107	Selection from Gujarat	Gujarat, India
GM – 115	Selection from Gujarat	Gujarat, India
GM – 116	Selection from Gujarat	Gujarat, India
GM – 117	Selection from Maharashtra	Maharashtra, India
GM – 119	Selection from Madhya Pradesh	Madhya Pradesh, India
GM – 120	Selection from Gujarat	Gujarat, India
GM – 122	Selection from Kerala	Kerala, India
GM – 124	Selection from Gujarat	Gujarat, India
GM – 125	Selection from Punjab	Punjab, India
GM – 127	Selection from Madhya Pradesh	Madhya Pradesh, India
GM – 128	Selection from Madhya Pradesh	Madhya Pradesh, India
GM – 129	Selection from Madhya Pradesh	Madhya Pradesh, India
GM – 139	Selection from Gujarat	Gujarat, India
GM – 142	Selection from Maharashtra	Maharashtra, India
GM – 144	Selection from Gujarat	Gujarat, India
GM – 146	Selection from Gujarat	Gujarat, India
GM – 148	Selection from Madhya Pradesh	Madhya Pradesh, India
GM – 149	Selection from Madhya Pradesh	Madhya Pradesh, India
GM – 150	Selection from Gujarat	Gujarat, India
GM – 151	UBKVR-1	West Bengal, Inda
GM – 155	Chakho selection	Manipur, India
GM – 156	Panval-1	Maharashtra, India
GM – 157	Leelabati	West Bengal, India
GM – 163	Shalimar	Jammu Kashmir, India
GM – 165	Quadir	Uttar Pradesh, India
GM – 167	Kamad	Chhattisgarh, India
GM – 169	Dehradun basmati 3-6	Dehradun, India
GM – 170	Dehradun basmati 3-7	Dehradun, India
GM – 171	Dehradun basmati 2-3	Dehradun, India
GM – 172	Dehradun basmati 2-2	Dehradun, India
GM – 173	Dehradun basmati 1-10	Dehradun, India
GM – 175	Dehradun basmati 1-8	Dehradun, India
GM – 176	Dehradun basmati 1-7	Dehradun, India
GM – 177	Dehradun basmati 1-6	Dehradun, India
GM – 178	Dehradun basmati 1-5	Dehradun, India
GM – 179	Dehradun basmati 1-4	Dehradun, India
GM – 180	Dehradun basmati 1-3	Dehradun, India
GM – 181	Dehradun basmati 1-2	Dehradun, India
GM – 187	IET -27933	Telangana, India
GM-191	IET -27985	Telangana, India
GM-194	IET -27578	Telangana, India
GM-198	IET-26895	Telangana, India
GM-200	IET-26881	Telangana, India
Checks	DRR Dhan-48	Telangana, India
	DRR Dhan-49	Telangana, India
	MTU-7029	Andhra Pradesh, India
	Chittimuthyalu	Andhra Pradesh, India

Statistical analyses: Genetic variability parameters namely, phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) were calculated using the procedure of Burton (1952). Broad sense heritability was computed according to the formula given by Allard (1960) and genetic advance as per cent of mean (GAM) was estimated as per the procedure suggested by Johnson *et al.* (1955). Further, correlation coefficients were computed in accordance with Falconer and Mackay (1964). Additionally, the direct and indirect effects of various components on grain yield were assessed by path coefficient analysis, as described by Dewey and Lu (1959). PCA analysis was carried out following the formulae provided by Gomez and Gomez (1984). Statistical analysis was performed using the R software version 4.2.1 to examine the relationships among the grain yield and its related traits. Genetic variability analysis was done by using R software, while cluster analysis was done by using DARwin version 1.62 (Perrier and Jacquemoud-Collet, 2006) based on Unweighted Pair Group Method Using

Arithmetic means (UPGMA) for yield, yield attributes and quality traits in zinc-rich rice landraces.

Results and Discussion

The analysis of variance (ANOVA) revealed highly significant differences among 100 zinc rich rice landraces along with four checks for yield, yield components, quality and nutritional traits indicating the presence of adequate amount of variability (Table 2). Results on mean performance and range of the yield, yield components, quality and nutritional attributes are shown in Table 3 and Fig. 1. The magnitude of variation between genotypes was reflected by high values of mean and range (Rahangdale *et al.,* 2019). The findings of this study showed a maximum range for number productive tillers m^{-2} (412-244) with a mean value of 351.19 and a minimum range for volume expansion ratio (2.65-4.28) with a mean value of 3.45. Grain yield per plant showed more variation, ranging from 15.25g to 26.85 g, with an average value of 20.79 g. The quality characteristics, namely, head rice recovery percent ranged from 48.05 to 75.86% with a mean value of 63.12, and amylose content ranged from 3.81 to 27.59% with a mean value of 20.63%.

Nutritional characteristics included zinc content ranging from 17.7 to 37.6 ppm with an average of 24.53 ppm, iron content ranged from 6.5 to 16.8 ppm with an average of 10.59 ppm, and protein content ranged from 3.5 to 9.68% with an average of 7.90%. In this study, the number of productive tillers, grains per panicle, plant height, hulling per cent, milling per cent, head rice recovery per cent and water uptake showed high range which corroborates with the earlier findings (Singh *et al.*, 2022; Sameera *et al.*, 2016). The nutritional traits namely, zinc and iron content also showed higher range, which is similar to the reports Akshay *et al*. (2022). The magnitude of GCV and PCV difference predicted the level of environmental influences on the characteristics. PCV estimation was greater than GCV estimation for all characteristics, confirming the impact of environment on genotype performance. The results on genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) are presented in Table 3. Results revealed that slightly higher value of PCV for all the characters studied than GCV. Among the traits, volume expansion ratio showed large difference between the values of GCV and PCV, indicating a high environmental effect on trait expression and poor heredity.

For all characteristics, except volume expansion ratio, a small difference was observed between GCV and PCV values, indicating that environmental impacts were minimal and that genetic factors had a greater role in character expression (Singh *et al.*, 2020). Low GCV and PCV (<10%) estimates were recorded for volume expansion ratio followed by milling per cent, which is hulling per cent and head rice recovery per cent, in conformity with the reports of Bhargavi *et al*. (2022). Moderate PCV and GCV (10-20%) estimates were noticed for amylose content, grain yield per plant, protein content, test weight, days to 50 per cent flowering, water uptake, zinc content, plant height, iron content, productive tillers per m^2 and panicle length, while grains per panicle recorded low GCV and moderate PCV. The values of PCV and GCV were moderate for days to 50 per cent flowering (Sri Lakshmi *et al.,* 2021), plant height, productive tillers per m^2,

Table 2: Analysis of variance for yield, yield components, quality and nutritional traits in zinc rich rice landraces

		Yield components					
Source of Variation	df	Days to 50 per cent flowering	Plant height (cm) Sum of squares	Number productive tillers m^{-2}	Panicle length (cm)	Grains per panicle	Test weight (g)
Blocks	4	6.17	3.17	97.82	3.03	182.08	3.27
Genotypes	103	234.54**	435.43**	2913.95**	11.7**	1017.23**	11.3**
Checks	3	338.85**	2713.78**	3485.92**	4.07	737.62*	38.88**
Checks Vs genotypes	1	4642.6**	3499.58	21828.6**	260.24**	66530.65**	0.14
Error	12	3.14	10.41	293.29	1.73	130.65	2.6

		Quality traits					Nutritional traits				
Source of Variation	df	Hulling (%)	Milling (%)	Head rice recovery (%)	Amylose content (%)	Water Uptake (ml)	Volume expansion ratio	Zinc content (ppm)	Iron content (ppm)	Protein content (%)	Grain yield per plant (g)
Blocks	4	44.07	23.09	22.17	0.32	30.11	0.17	0.37	1.02	1.65	2.81
Genotypes	103	35.05**	34.94	39.94**	12.91**	681.33**	0.36*	15.1**	2.97**	2.05**	12.4**
Checks	3	114.74**	150.03	165.19**	14.19	284.98	0.16*	35.94**	11.56**	0.31	28.15**
Checks Vs genotypes	1	970.92**	689.21**	596.6**	41.16**	4542.73**	0.14	58.61**	46.15**	8.76**	6.36
Error	12	3.87	9.06	7.61	0.63	15.31	0.08	2.54	0.47	0.53	1.7

*, ** Significant at 5 and 1 per cent levels.

Table 3: Genetic parameters for yield, yield components, quality and nutritional traits in rice landraces

Characters	Mean	Range		Genotypic coefficient of variation (GCV)	Phenotypic coefficient of variation (PCV)	Heritability (%)	Genetic Advance as percent of mean (GAM)
		Minimum	Maximum				
Yield component traits							
Days to 50 per cent flowering	91.70	78.00	117.00	14.98	15.10	98.32	30.64
Plant height	137.48	85.60	178.20	13.11	13.32	96.90	26.63
Number of productive tillers per m^2	351.19	244.00	412.00	11.50	12.18	89.19	22.41
Panicle length	26.42	19.52	34.66	10.52	11.65	81.67	19.62
Number of grains per panicle	169.79	120.00	235.00	9.98	11.22	65.40	15.84
1000 seed weight	19.55	13.00	25.62	14.39	16.57	75.44	25.78
Grain quality traits							
Hulling recovery	74.80	62.85	85.60	5.88	6.44	83.32	11.08
Milling recovery	68.89	55.51	80.27	5.78	7.24	63.56	9.50
Head rice recovery	63.12	48.05	75.86	7.60	8.77	75.06	13.57
Amylose content	20.63	3.81	27.59	16.76	17.19	94.98	33.69
Water uptake	179.50	125	254.00	14.07	14.24	97.66	28.69
Volume expansion ratio	3.45	2.65	4.28	5.73	9.99	32.88	6.77
Nutritional traits and Grain yield							
Zinc content	24.53	17.70	37.60	13.82	15.27	81.92	25.81
Iron content	10.59	6.50	16.80	12.66	14.20	79.46	23.28
Protein content	8.09	3.50	9.68	15.44	17.99	73.80	27.36
Grain yield per plant	20.79	15.25	26.85	15.60	16.84	85.79	29.81

panicle length, zinc content, iron content, and protein content (Akshay *et al.*, 2022), test weight and grain yield per plant (Lingaiah *et al.,* 2020), amylose content (Singh *et al.*, 2020) and water uptake (Bhargavi et al., 2022) and are in agreement with the reports of earlier workers. Sameera *et al.* (2014) reported that heritability estimates provided along with genetic advance estimates are of practical importance. All the characters showed high broad sense heritability (>60 %) except for volume expansion ratio which recorded moderate heritability (30-60 %). Further, high heritability (>60 %), coupled with high genetic advance as per cent of mean (>20%) was recorded for days to 50 per cent flowering, plant height, productive tillers, test weight, amylose content, water uptake, zinc content, iron content, protein content and grain yield per plant suggesting the predominance of additive gene action.

Hence, direct phenotypic selection would be effective for improvement of these traits even in early generations. Similar results were reported earlier by Kishore *et al.* (2015) for days to 50 per cent flowering; Rahangdale *et al.* (2019) for productive tillers, test weight and grain yield per plant[1]; Singh *et al.* (2020) for zinc, iron, protein and amylose content; and Devi *et al.* (2020) for water uptake. The results on correlation analysis among the yield, yield components, quality and nutritional characters are presented in Table 4 and Fig. 2. Results revealed a positive and significant relationship between grain yield and the yield component characteristics, such as number of productive tillers, grains per panicle, and test weight, indicating the potential for their simultaneous improvement with grain yield per plant (Neethu *et al.*, 2018). In contrast, amylose concentration showed negative significant relationship with grain yield per plant. Hence, balanced selection needs to be adopted while effecting simultaneous improvement for this trait. The results on path coefficient analysis (Table 5) revealed a low residual effect of 0.37, indicating that variables studied in the present investigation explained approximately 63.00 per cent of variability for grain yield per plant and therefore, other attributes, besides the characters studied also contributed for grain yield per plant.

The perusal of data revealed, that the number of productive tillers had positive direct effect (0.54) on grain yield per plant followed by test weight (0.32) and grains per panicle (0.13). Direct highest positive effect on yield was exerted by number of productive tillers and test weight, indicating the effectiveness of direct selection of these traits in the improvement of grain yield per plant. Similar inferences were drawn by Jasmine *et al.* (2022). In contrast, amylose content showed a negative direct effect on grain yield per plant. Principal component analysis identifies the minimum number of components which can elucidate maximum variability out of the total variability (Anderson, 1972). The results of PCA revealed a total of sixteen Principal Components (PCs) accounting for total variability in the experimental material. Among these, six principal components exhibited Eigen value more than 1.00 and contributed to 69.77 per cent of the total cumulative variability. The details of Eigen values, variability and cumulative variability of six Principal Components are presented in Table 6 and 7. The Scree plot elucidated the percent of variation contributed by each PC (Fig. 3). PC1 accounted for maximum variability of 20.73 per cent with the highest Eigen value of 3.31. Traits like grains per panicle, grain yield per plant and days to 50

Table 4: Character associations of yield, yield components, quality and nutritional traits in zinc rich rice landraces

Characters	Plant height	Number of productive tillers m^{-2}	Panicle length	Grains per panicle	Test weight	Hulling recovery per cent	Milling recovery percent	Head rice recovery Per cent	Zinc content	Iron content	Protein content	Amylose content	Water uptake	Volume expansion raito	Grain per yield
Days to 50 per cent flowering	0.034	-0.252**	0.077	0.203*	0.026	-0.148	-0.117	-0.120	-0.016	-0.121	-0.031	0.018	-0.078	0.179	-0.020
Plant height		0.079	0.349**	-0.138	-0.002	0.152	0.206*	0.219*	0.259**	0.23*	-0.015	-0.123	0.219*	0.155	0.038
Number of productive tillers m^{-2}			-0.146	0.281**	0.560**	-0.044	-0.038	-0.033	0.120	0.086	-0.152	-0.172	0.135	-0.045	0.759**
Panicle length				-0.401**	-0.224*	0.190	0.217*	0.257**	0.015	0.144	0.213*	0.103	0.227	0.091	-0.157
Grains per panicle					0.196*	-0.332**	-0.377**	-0.440**	0.162	0.056	-0.281**	-0.185	-0.321**	0.083	0.379**
Test weight						0.043	0.031	0.002	0.025	-0.086	-0.076	-0.013	-0.083	-0.182	0.624**
Hulling recovery per cent							0.953**	0.907**	-0.065	0.120	0.141	-0.076	0.030	-0.069	-0.059
Milling recovery percent								0.960**	-0.065	0.103	0.098	-0.029	0.100	-0.076	-0.060
Head rice recovery per cent									-0.092	0.072	0.091	-0.033	0.188	-0.082	-0.056
Zinc content										0.494**	-0.182	-0.116	0.049	0.158	0.057
Iron conten											-0.059	-0.176	0.257**	0.165	0.037
Protein content												0.064	0.050	0.144	-0.108
Amylose content													-0.022	-0.087	-0.213*
Water uptake														0.037	0.037
Volume expansion ratio															0.043

*, ** Significant at 5 % and 1 % levels, respectively

Table 5: Direct and indirect effects of yield, yield components, quality and nutritional traits in zinc rich rice landraces

Characters	Days to 50 per cent flowering	Plant height	Number of productive tillers m^{-2}	Panicle length	Grains per panicle	Test weight	Hulling recovery per cent	Milling recovery percent	Head rice recovery Per cent	Zinc content	Iron content	Protein content	Amylose content	Water uptake	Volume expansion ratio	Grain per yield
Days to 50 percent flowering	0.0536	-0.0008	-0.1382	0.0038	0.0388	0.0083	0.0168	0.0143	-0.0312	0.0010	-0.002	-0.0094	-0.0016	-0.0011	0.0176	-0.020
Plant height	0.0018	-0.0258	0.0435	0.0171	-0.0262	-0.0088	-0.0172	-0.0252	0.0569	-0.0160	0.004	-0.0004	0.0109	0.0003	0.0153	0.038
Number of productive tillers m^{-2}	-0.0135	-0.0020	0.5468	-0.0071	0.0537	0.1799	0.0050	0.0046	-0.0085	-0.0074	-0.0016	-0.0045	0.0153	0.0002	-0.004	0.759**
Panicle length	0.0041	-0.0090	-0.0802	0.0490	-0.0764	-0.0721	-0.0215	-0.0264	0.0668	-0.0009	0.0028	0.0063	-0.0092	0.0003	0.0090	-0.157
Grains per panicle	0.0109	0.0035	0.1541	-0.0196	0.1905	0.0630	0.0378	0.0460	-0.1143	-0.0100	0.0011	-0.0083	0.0165	-0.0004	0.0082	0.379**
Test weight	0.0013	0.0007	0.3063	-0.0110	0.0374	0.3211	-0.0049	-0.0038	0.0005	-0.0015	-0.0016	-0.0022	0.0012	-0.0001	-0.0179	0.624**
Hulling recovery per cent	-0.0079	-0.0039	-0.0240	0.0093	-0.0634	0.0138	-0.1082	-0.1218	0.2355	0.0040	0.0023	0.0042	0.0067	0.0004	-0.0068	-0.059
Milling recovery percent	-0.0063	-0.0053	-0.0209	0.0106	-0.0719	0.0101	-0.1082	-0.1218	0.2492	0.0040	0.0020	0.0029	0.0026	0.0015	-0.0075	-0.060
Head rice recovery per cent	-0.0064	-0.0056	-0.0180	0.0126	-0.0839	-0.0839	0.0006	-0.1031	-0.1171	0.2594	0.0057	0.0014	0.0027	0.0002	-0.0081	-0.056
Zinc content	-0.0009	-0.0067	0.0658	0.0007	0.0309	0.0081	0.0074	0.0080	-0.0240	-0.062	0.0096	-0.0053	0.0103	0.0007	0.0155	0.057
Iron content	-0.0065	-0.0059	-0.0473	0.0070	0.0107	-0.0278	-0.0137	-0.0126	0.0188	-0.0306	0.0195	-0.0017	0.0156	0.0003	0.0163	0.037
Protein content	-0.0017	0.0004	-0.0835	0.0104	-0.0535	-0.0244	-0.0161	-0.0120	0.0238	0.0113	-0.0011	0.0295	-0.0057	0.0007	-0.0142	-0.108
Amylose content	0.0009	0.0031	-0.0942	0.0050	-0.0354	-0.0044	0.0086	00035	-0.0087	0.0072	-0.0034	0.0019	-0.0890	-0.0003	0.0086	-0.213*
Water uptake	-0.0041	-0.0056	0.0741	0.0111	-0.0611	-0.02676	-0.0034	-0.0122	0.0488	-0.0030	0.0050	0.0014	0.0020	0.0014	0.0099	0.037
Volume expansion ratio	0.0096	-0.0040	-0.0246	0.0045	0.01591	-0.0584	0.0078	0.0093	-0.0216	-0.0098	0.0032	0.0042	0.0077	0.0001	0.0985	0.043

*, ** Significant at 5 % and 1 % level respectively, Diagonal values indicate direct effects, Residual effect = 0.367

Table 6: Eigen values, variability and cumulative variability of principal components

Principal Components (PC)	Eigen value	Variability (%)	Cumulative variability (%)
PC1	3.316	20.726	20.726
PC2	2.241	14.011	34.738
PC3	1.946	12.164	46.902
PC4	1.320	8.250	55.153
PC5	1.241	7.756	62.913
Pc6	1.098	6.868	69.778
PC7	0.992	6.200	75.979
PC8	0.840	5.256	81.235
PC9	0.743	4.647	85.883
PC10	0.662	4.141	90.024
PC11	0.564	3.528	93.553
PC12	0.457	2.859	96.412
PC13	0.411	2.569	98.981
PC14	0.079	0.499	99.481
PC15	0.058	0.367	99.848
PC16	0.024	0.151	100.00

Table 7: Principal component loadings of different characters for first six principal components

Characters	PC1	PC2	PC3	PC4	PC5	PC6
Days to 50 per cent flowering	0.195	0.085	-0.009	-0.100	-0.788	-0.365
Plant height	-0.401	0.247	0.423	-0.110	-0.224	-0.086
Number of productive tillers m^{-2}	-0.255	0.115	0.330	-0.162	-0.253	0.400
Panicle length	-0.453	0.387	-0.061	-0.293	-0.251	0.111
Number of grains per pancle	0.364	-0.118	-0.108	0.504	-0.514	0.093
Grain yield per plant	0.195	-0.728	0.527	-0.315	-0.038	-0.026
Test weight	0.099	-0.763	0.490	-0.305	-0.047	-0.016
Hulling recovery percent	-0.883	-0.327	-0.121	0.141	-0.024	-0.107
Milling recovery percent	-0.905	-0.317	-0.113	0.147	-0.096	-0.053
Head rice recovery percent	-0.908	-0.284	-0.127	0.127	-0.105	-0.020
Zinc content	-0.031	0.243	0.719	0.238	-0.001	0.053
Iron content	-0.291	0.381	0.565	0.256	0.178	0.085
Protein content	-0.221	0.136	-0.293	-0.619	0.168	-0.154
Amylose content	0.071	-0.022	-0.290	-0.271	-0.270	0.709
Water uptake	-0.306	0.334	0.176	-0.090	0.059	0.280
Volume expansion ratio	-0.064	0.508	0.195	-0.300	-0.119	-0.379

per cent flowering contributed the maximum variability for PC1. In PC2, volume expansion ratio, iron content, panicle length, water uptake, plant height, zinc content and protein content showed positive loadings whereas in PC3, the traits namely, zinc content, iron content, grain yield per plant, test weight, plant height, number of productive tillers, volume expansion ratio and water uptake contributed maximum to diversity. Characters, grains per panicle, iron content, zinc content, milling per cent, hulling per cent and head rice recovery showed positive loadings in PC4. Iron and protein content contributed to maximum variability in PC5, while traits like, amylase content, water uptake, number of productive tillers, panicle length and grains per panicle showed positive loadings in PC6. The analysis identified the maximum contributing traits for diversity as grain yield per plant, plant height, number of productive tillers, number grains per panicle, water uptake, volume expansion ratio, zinc and iron content, which is in line with the earlier findings of Christiana *et al.* (2021). The biplot diagram showed the interaction among the characters along with genotypes performing better for the traits (Fig. 3). The traits namely, grains per panicle1 and number of productive tillers per m^2 were identified as the most important contributors to the PC and were noticed to be highly correlated with grain yield per plant[1], in consonance with the reports of Basavaraj *et al.* (2022). Based on Euclidean distance, the clustering was carried out following the UPGMA.

Hundred zinc rich rice landraces along with four checks were grouped into three clusters based on yield, yield components, quality and nutritional traits (Fig. 4). Cluster II the had highest number of genotypes (42), Cluster I comprised of 32

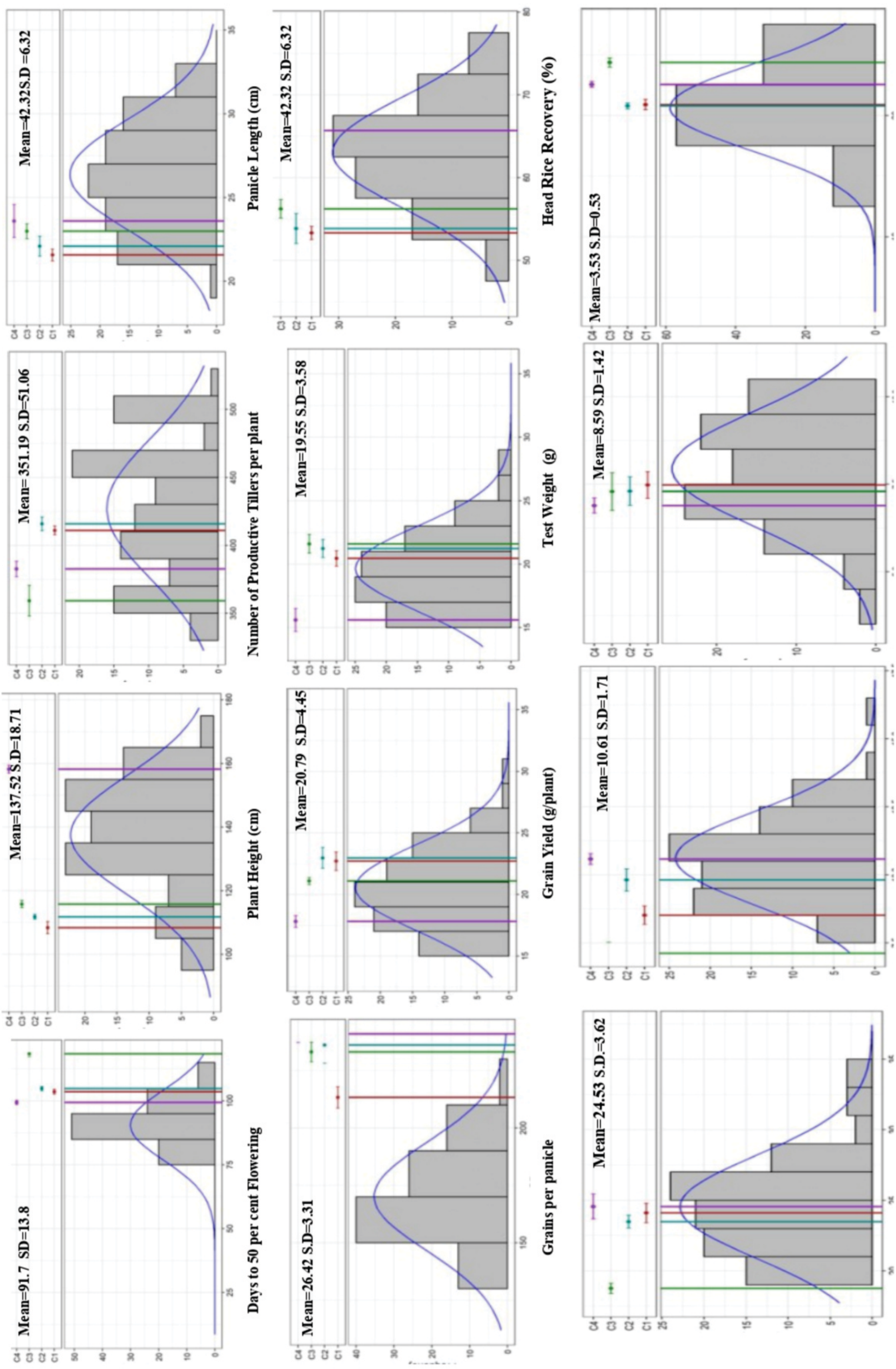


Fig 1: Frequency distribution of important traits for yield, yield components, quality and nutritional trait of zinc rich rice landraces.

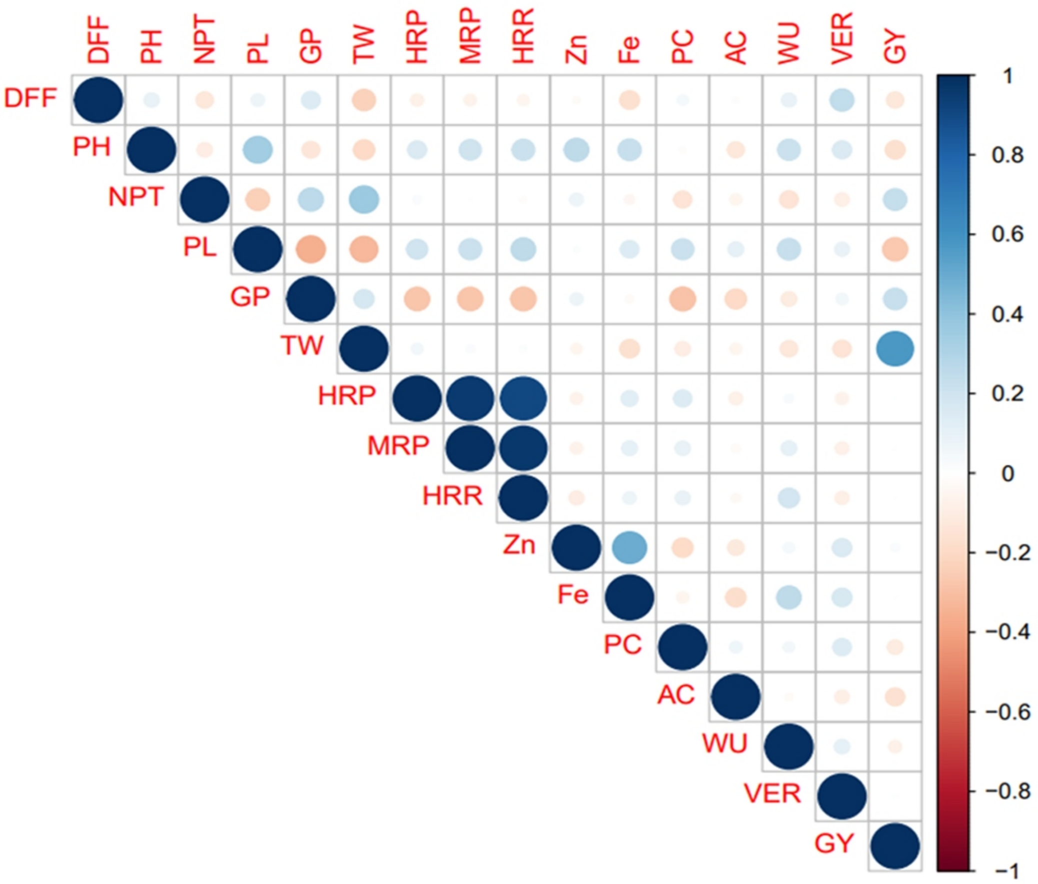
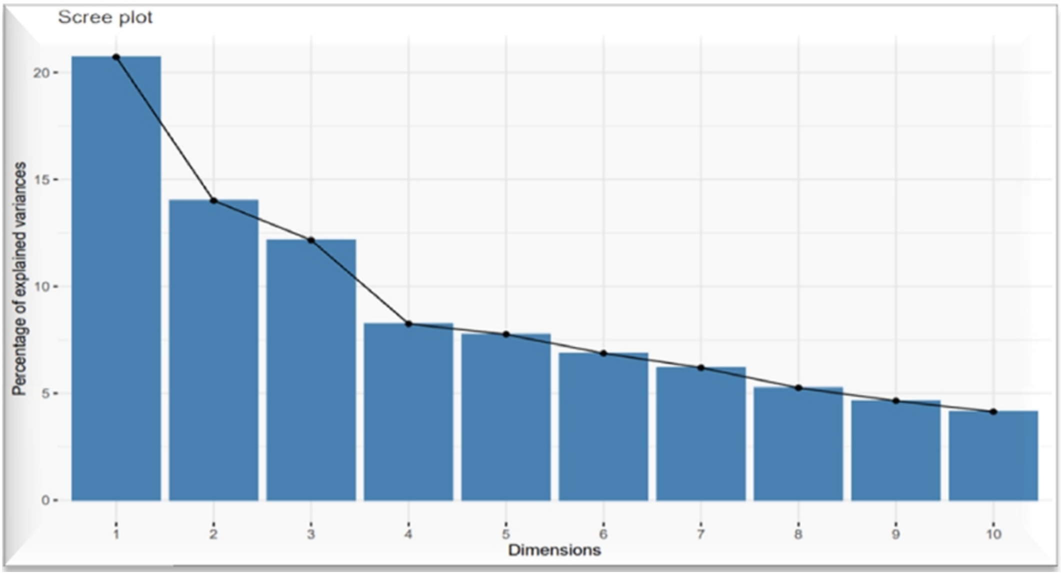
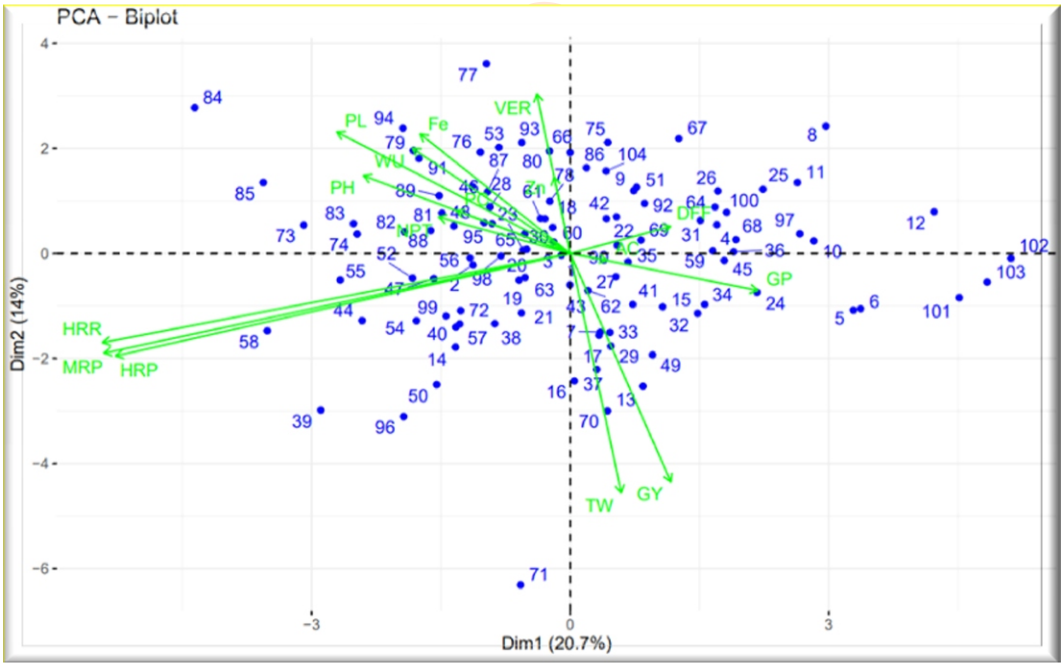


Fig. 2: Correlation matrix of grain yield, yield components along with quality and nutritional characters in zinc rich rice landraces; DFF: Days to 50 per cent flowering; PH: Plant height; NPT: Number of productive tillers m^{-2}; PL: Panicle length; TW: Test weight (g); HRP: Hulling recovery percent; MRP: Milling recovery percent; HRR: Head rice recovery percent; Zn: Zinc (ppm); Fe: Iron (ppm); PC: Protein content (%); AC: Amylose content (%); WU: Water uptake (ml); VER: Volume expansion ratio; GY: Grain yield per plant.



A. Scree plot diagram using principal components of zinc rich rice landraces



B. Biplot diagram of principal components 1 and 2

Fig. 3: Principal component analysis for yield, yield components, quality and nutritional traits in zinc rich rice landraces.

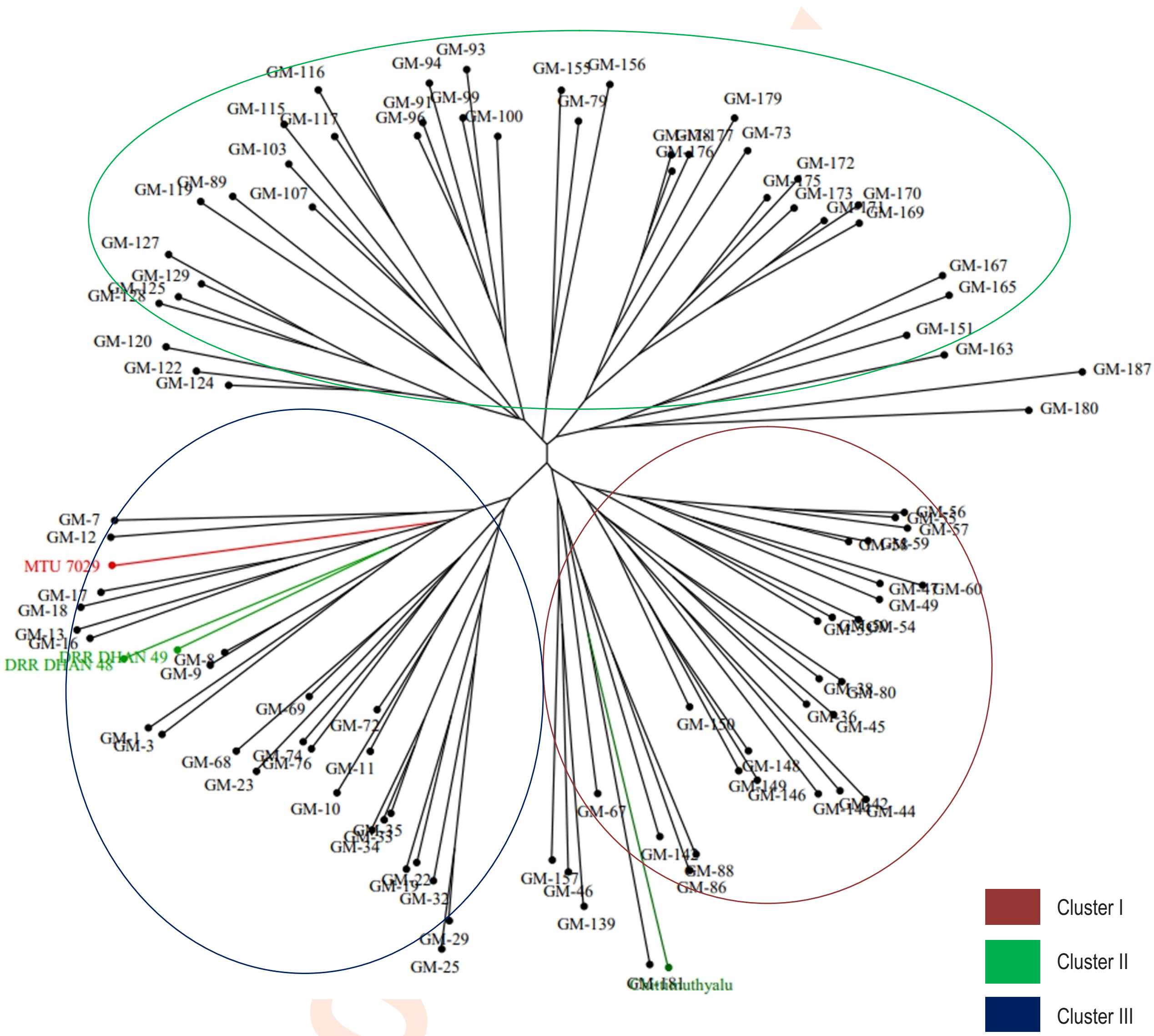


Fig. 4: UPGMA Cluster analysis of zinc rich rice landraces for yield, yield components quality and nutritional traits.

genotypes, while cluster IV had 30 genotypes. Cluster I and II were divided into two sub-clusters. Cluster III comprised of 30 genotypes (27 zinc rich rice landraces along with two zinc rich check varieties namely, DRR Dhan 48 and DRR Dhan 49 and one high yielding check variety MTU 7029). Cluster I consisted of 32 genotypes, out of which 31 were zinc rich rice landraces along with one check Chittimuthyalu (Zinc rich check variety) indicating their close relatedness.

Hybridization of genotypes from Cluster I and II, coupled with direct phenotypic selection for grains per panicle, productive tillers per square meter and test weight in the advance generations is recommended for the development of zinc rich rice varieties with high grain yield.

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References

Akshay, M., B.S. Chandra, K.R. Devi and Y. Hari: Genetic variability studies for yield and its attributes, quality and nutritional traits in rice (*Oryza sativa* L.). *Pharma. Innova. J.,* **11**, 167-172 (2022).

Allard, R.W.: Principles of Plant Breeding. John Willey and Sons Inc., New York (1960).

Anderson, T.W.: An Introduction to Multivariate Analysis. Wiley Eastem Private Limited, New Delhi (1972).

Basavaraj, P.S., C. Gireesh, M. Bharamappanavara, C.A. Manoj, L.V.G. Ishwarya, P. Senguttuvel, R.M. Sundaram, L.V. Subbarao and M.S. Anantha: Genetic analysis of introgression lines of *Oryza rufipogon* for improvement of low phosphorous tolerance in indica rice. *Indian J. Gene. Plant Breed.,* **82**, 135-142 (2022).

Behera, P.P., S.K. Singh, D.K. Singh, Y.S. Reddy, S. Habde, A. Khaire and M.A. Ashrutha: Genetic diversity analysis of rice (*Oryza sativa* L.) genotypes with high grain zinc content for yield and yield traits. *J. Pharmacog. Phytoche.,* **7**, 1319-1323 (2018).

Bekele, B.D., S. Rakh, G.K. Naveen, P.J. Kundur and H.E. Shashidhar: Estimation of genetic variability and correlation studies for grain zinc concentrations and yield related traits in selected rice (*Oryza sativa* L.) genotypes. *Asian J. Biol. Sci.,* **4**, 391-397 (2013).

Bhargavi, B., Y. Suneetha, J.K. Kumar, B. Violina, T.V. Ratnam and T. Srinivas: Genetic variability and trait associations for quality traits in high protein landraces of rice. *Scientist*, **1**, 861-872 (2022).

Burton, G.W.: Quantitative inheritance in grasses. Proceedings of 6th International Grassland Congress., **1**, 277-283 (1952).

Chandu, G., D. Balakrishnan, S.K. Mangrauthia and S. Neelamraju: Characterization of rice genotypes for grain Fe, Zn using energy dispersive X-Ray fluorescence spectrophotometer (ED - XRF). *J. Rice Res.,* **13**, 9-17 (2020).

Devi, K.R., V. Venkanna, Y. Hari, B.S. Chandra, N. Lingaiah and K.R. Prasad: Studies on genetic diversity and variability for yield and quality traits in promising germplasm lines in rice (*Oryza sativa* L.). *Pharma. Innova. J.,* **9**, 391-399 (2020).

Dewey, D.R and K.H.A. Lu: Correlation and path coefficient analysis of components of crested wheatgrass seed production. *Agron. J.,* **51**, 515-518 (1959).

Duppala, M.K., T. Srinivas, L.V. Subba Rao, Y. Suneetha, R.M. Sundaram and V.P. Kumari: Study of genetic variability and trait associations in F2 Population of YH3 x AKDRMS 21-54 intra-specific cross of rice. *Pharma. Innova.,* **11**, 1735-1742 (2022).

Falconer, D.S. and T.F.C. Mackay: Introduction to Quantitative Genetics. 4th Edn., Addison Wesley Longman, Harlow, 448 pages (1996).

Gomez, K.A. and A.A. Gomez: Statistical Procedures for Agricultural Research. 2nd Edn., John Wiley and Sons, New York, 680 pages (1984).

Jasmine, C., D. Shivani, P. Senguttuvel and D.S. Naik: Genetic variability and association studies in maintainer and restorer lines of rice [*Oryza sativa* (L.)]. *Pharma. Innova. J.,* **11**, 569-576 (2022).

Johnson, H.W., H.F. Robinson and R.W. Comstock: Estimates genetic and environment variability in soybean. *Agron. J.,* **47**, 314-318 (1955).

Kishore, N.S., T. Srinivas, U. Nagabhushanam, M. Pallavi and S.K. Sameera: Genetic variability, correlation and path analysis for yield and yield components in promising rice (*Oryza sativa* L.) genotypes. *SAARC J. Agricul.,* **13**, 99-108 (2015).

Lingaiah, N., C.B. Satish, V. Venkanna, K. Devi and Y. Hari: Genetic variability and correlation studies in yield traits of elite rice (*Oryza sativa* L.) genotypes. *Indian J. Pure Appl. Biosci.,* **8**, 359-363 (2020).

Mingotte, F.L.C., L.T.M. Revolti, U.H.S. Trevisoli, L.B. Lemos and D.F. Filho: Rice (Oryza sativa) breeding strategies for grain bio-fortification. *African J. Biotechnol.,* **17**, 466-477 (2018).

Neethu, F., D. Packiaraj, S. Geethanjali and K. Hemaprabha: Correlation and path coefficient analysis for yield contributing characters in rice (*Oryza sativa* L.) cultivars. *Int. J. Curr. Microbiol. Appl. Sci.,* **7**, 2292-2296 (2018).

Paltridge, N. G. , L. J. Palmer, P. J. Milham, G. E. Guild and J. C. R. Stangoulis: Energy-dispersive X-ray fluorescence analysis of zinc and iron concentration in rice and pearl millet grain. *Plant and Soil,* **361**, 251–260 (2012).

Perrier, X. and J.P. Jacquemoud-Collet: DARwin Software. http://darwin.cirad.fr/darwin (2006).

Rahangdale, S., Y. Singh, G.K. Koutu and S. Tiwari: Genetic variability, correlation and path coefficient studied for yield and quality traits in jnpt lines of rice (*Oryza sativa* L.). *Int. J. Curr. Microbiol. Appl. Sci.,* **8**, 1025-1037 (2019).

Ravikumar, B.N.V.S.R., P.N. Kumari, P.V. Rao, M.G. Rani, P.V. Satyanarayana, N. Chamundeswari, K.M. Vishnuvardhan, Y. Suryanarayana, M. Bharathalakshmi and A.V. Reddy: Principal component analysis and character association for yield components in rice (*Oryza sativa* L.) cultivars suitable for irrigated ecosystem. *Curr. Biotica.,* **9**, 25-35 (2015).

Raza, Q., A. Riaz, H. Saher, A. Bibi, S.S. Ali and M. Sabar: Grain Fe and Zn contents linked SSR markers based genetic diversity reveal perspective for marker assisted biofortification breeding in rice. *PLoS ONE,* **15**, e0239739 (2020).

Roy, S.C. and P. Shil: Assessment of genetic heritability in rice breeding lines based on morphological traits and caryopsis ultrastructure. *Scienti. Repo.,* **10**, 7830 (2020).

Sameera, S. and T. Srinivas: Variability, correlation and path analysis for grain yield and quality in rice (*Oryza sativa* L.). *Environ. Ecol.,* **34**, 755-761 (2016).

Sameera, S.K., A.P. Rajesh, V. Jayalakshmi, P.J. Nirmala and T. Srinivas: Assessment of variability for grain yield and quality characters in rice (*Oryza sativa* L.). *The Journal of Research PJTSAU,* **42**, 75-79 (2014).

Sarao, P.S. and J.S. Bentur: Antixenosis and tolerance of rice genotypes against brown planthopper. *Rice Sci.,* **23**, 96-103 (2016).

Singh, K.S., Y. Suneetha, D.S. Raja and T. Srinivas: Principal component analysis for yield and quality traits of coloured rice (*Oryza sativa* L.). *Pharma. Innova. J.,* **9**, 456-462 (2020).

Sri Lakshmi, M., Y. Suneetha and T. Srinivas: Genetic diversity analysis for grain yield and yield components in rice. *Int. J. Chemi. Stud.,* **9**, 1386-1389 (2021).

Sudeepthi, K., T. Srinivas, B.R, Kumar, D.P. Jyothula and S.N. Umar: Genetic variability, character association and path analysis for anaerobic germination traits in rice (*Oryza sativa* L.). *J. Pharmaco. Phytoche.,* **9**, 553-556 (2020).

Swamy, B.P.M., M.A.K. Rahman, M.N.I. Asilo, A. Amparado, C. Manito, P.C. Mohanty, R. Reinke and I.H.L.S. Loedin: Advances in breeding for high grain zinc in rice. *Rice*, **9**, 49 pages (2016).