Received: 16 Jul 2022 | Revised: 01 Jan 2023 | Accepted: 01 Jan 2023

Electronic Journal of Plant Breeding

Research Article

# Principal component analysis of yield and quality traits in Zinc rich landraces of rice (*Oryza sativa* L.)

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**Abstract**
Principal Component Analysis (PCA) was carried out to find the genetic divergence among 35 zinc-rich landraces of rice along with two checks for yield and quality traits. Three principal components with Eigen value more than one explained maximum variation with a total contribution of 78.33 per cent of the total variability. Principal Component 1 (PC 1) contributed a maximum of 51.71 per cent, while PC 2 contributed to 18.71 per cent and PC 3 contributed to 7.96 per cent towards the total variability. Yield and quality traits *such as* days to 50 per cent flowering, number of productive tillers plant$^{-1}$, grain yield plant$^{-1}$, head rice recovery per cent, iron content and volume expansion ratio explained the maximum variance in PC 1. The results of the 2D scatter diagram revealed GM-120 and GM-173 landraces to be the most diverse. These genotypes were identified to be high yielding and nutritionally rich, compared to BPT 5204. Hybridization of these genotypes is expected to result in desirable transgressive segregants for yield, quality and nutritional traits.

**Keywords:** Principal component analysis, Yield components, Quality traits, Zn, Fe.

## INTRODUCTION

Rice (*Oryza sativa* L.) is the staple cereal food crop of more than half of the world's population and hence, it is considered as a Global grain. Among the rice-producing countries, India is the largest producer next to China. In India, it is grown in an area of 43.78 million hectares with an annual production of 118.43 million tones and productivity of about 2705 kg/ha (Agricultural Statistics at a Glance- 2021). Rice crop accounts for about 30% of the calories needed for the country's population (Maclean, 2002).

Among the essential micronutrients, zinc (Zn) and iron (Fe) are vital for maintaining the growth and development of human beings and plants. Recent studies have indicated that 17.3% of the world's population is zinc-deficient (Hefferon 2019). Malnutrition in humans also referred to as hidden hunger, is caused by a deficiency of essential nutrients like zinc and iron. It leads to several health disorders such as dwarfism, anorexia, weak immunity, growth retardation, loss of appetite, hair loss, diarrhoea, weight loss, and delayed healing of wounds (Wang and Busbey 2005). Therefore, improving the bio-availability of nutrients such as zinc and iron in rice grain *via* genetic selection through plant breeding can provide a sustainable solution to hidden hunger. Knowledge on the nature and degree of genetic diversity of high zinc and iron landraces is essential for planning an efficient bio-fortification program.

Principal Component Analysis (PCA) has been used frequently for genetic diversity studies in several crops such as rice (Bharadwaj *et al*., 2001 and Francis and Packiaraj, 2020) and wheat (Hailu *et al*., 2006), etc. The main advantage of PCA over cluster analysis is that each genotype can be assigned to one group only (Mohammadi, 2002). Further, PCA allows the natural grouping of the genotypes and is an accurate indicator of differences among genotypes and PCA scores are important in drawing conclusions for selecting promising genotypes. The present study was undertaken in this context to identify the nature and magnitude of genetic diversity among 35 zinc-rich landraces along with two checks for their yield and quality traits using Principal Component Analysis.

## MATERIALS AND METHODS

The experimental material consisted of 35 zinc-rich rice landraces from all over India. The seed of these accessions was collected from the Indian Institute of Rice Research (IIRR), Hyderabad. Two local checks obtained from Regional Agricultural Research Station (RARS), Maruteru *viz.,* MTU 7029 and BPT 5204 were grown together with the 35 zinc rich landraces (**Table 1**) during *Kharif* 2021 in a Randomized Block Design (RBD) with two replications. Seedlings were transplanted 28 days after sowing with a spacing of 20×15 cm. All the recommended practices were adopted to ensure a good crop stand. Morphological observations were recorded on yield, yield attributing and quality traits in five randomly selected plants for grain yield plant$^{-1}$ (g), plant height (cm), the number of productive tillers plant$^{-1}$, panicle length (cm), the number of grains panicle$^{-1}$ and test weight (g). Days to 50 per cent flowering were recorded on a plot basis.

Energy-dispersive X-ray Fluorescence Spectrometry (ED-XRF) was used for analyzing the grain zinc and iron content in brown rice at IIRR Hyderabad. All remaining grain quality parameters, *namely,* hulling recovery (%), milling recovery (%), head rice recovery (%), water uptake (ml) and volume expansion ratio were estimated at RARS, Maruteru, Andhra Pradesh. Principal component analysis was carried out using the software Window Stat Version 8.5.

## RESULTS AND DISCUSSION

The Analysis of Variance (ANOVA) for yield and quality traits showed highly significant differences among the genotypes for all the characters under study, indicating the existence of adequate variation in experimental material. The mean performance of the zinc rich landraces with respect to yield, yield attributes and quality traits is presented in **Table 2**. Days to 50 per cent flowering varied from 66 (GM-163) to 119 days (MTU 7029), with an overall mean value is 76 days. The plant height ranged from 93cm (MTU 7029) to 170 cm (GM 22), with an overall mean value of 139 cm. The number of productive tillers plant$^{-1}$ varied from 11 (GM-122) to 16 (GM-169), with an overall mean value of (13). The panicle length ranged from GM-18 (21.59 cm) to GM-94 (32.71 cm), with an overall average of 26.42 cm. One of the important yield influencing traits is the number of filled grains panicle$^{-1}$. It was noticed to be minimum in GM-127 (185) and maximum in GM-163 (319) with an overall average of 246. Maximum test weight was recorded in GM-178 (24.79g) while minimum in BPT-5204 (13.89 g), with an overall mean of 21.57g. Grain yield plant$^{-1}$ was observed to range from 14.59g (GM-129) to 29.09g (GM-120) with an overall mean value of 20.44g, indicating high variability among the genotypes for grain yield. A perusal of the results also revealed significantly higher grain yield plant$^{-1}$ in a few zinc rich landraces *viz.*, GM-120, GM-173, GM-88 and GM-18 compared to the best high yielding check, MTU 7029 (23.58g).

Among the micronutrients, zinc (Zn) and iron (Fe) are vital nutrients that improve human health and curtail the risk of malnutrition. In the present investigation, the highest zinc content was observed for GM-163 (35.77 ppm), while the lowest zinc content was recorded in MTU-7029 (19.25 ppm) with an overall mean value of 27.07 ppm. Further, iron content varied from MTU-7029 (6.95 ppm) to GM-163 (15.92 ppm) with an average value of 11.46 ppm. A perusal of the results revealed significantly greater zinc and iron content compared to the check, BPT 5204 (Zn=20.36 ppm; Fe=7.99 ppm) in all the landraces studied. The highest Hulling recovery percentage was noticed in GM-173(64.91) while lowest in GM-91 (82.13) with an overall mean value of 75.04. The maximum milling recovery percentage was recorded for GM-91 (74.84) and minimum in GM-120 (57.98) with an overall average of 67.40. Head rice recovery ranged from 53.88 per cent (GM-173) to 63.53 per cent (MTU-7029) with a mean of 59.20 per cent. The lowest water uptake value was recorded in GM-125 (115.25) and the highest in MTU-7029 (181.25) with an overall mean value of 145.96. The maximum volume expansion ratio was recorded in GM-117(3.04) and minimum in BPT-5204 (4.65) with an overall mean value is 3.56. Based on the above *per se* performance four landraces were identified as potential zinc rich landraces with significantly high yield, compared to the checks and are presented in **Table 3 and Fig.1.**

PCA revealed 78.33 per cent contribution of the first three principal components to the total variability (**Table 4**) indicating that the fundamental features of the data set are represented in the first three principal components. The principal components with the Eigen values less than one were considered non-significant. The first principal component (PC 1) contributed 51.71 per cent to the total variability. The characters days to 50 (%) flowering (0.364), the number of productive tillers/ plant (0.356), head rice recovery (%) (0.297), volume expansion ratio (0.290), water uptake (ml) (0.271), and iron content (0.282) represented the maximum variance in this component. Hence, the selection of lines and traits from this PC will be useful. The second principal

**Table 1. Details of the experimental material studied**

| S.No | Code | Entry Name | Source/ Origin |
|---|---|---|---|
| 1 | GM-7 | Lalmala | Jammu Kashmir, India |
| 2 | GM-12 | Raj Bangalo-1 | West Bengal, India |
| 3 | GM-16 | Futuyu-Red | China |
| 4 | GM-17 | Futuyu | China |
| 5 | GM-18 | Lalkada-1 | Gujarat, India |
| 6 | GM-22 | Pokkali-1 | Kerala, India |
| 7 | GM-32 | Ranbir basmati | Jammu Kashmir, India |
| 8 | GM-42 | Nagaland selection-12 | Nagaland, India |
| 9 | GM-44 | Selection form Madhya Pradesh | Madhya Pradesh, India |
| 10 | GM-79 | Selection form Madhya Pradesh | Madhya Pradesh, India |
| 11 | GM-80 | Selection form Gujarat | Gujarat, India |
| 12 | GM-86 | Selection form Maharashtra | Maharashtra, India |
| 13 | GM-87 | Selection form Madhya Pradesh | Madhya Pradesh, India |
| 14 | GM-88 | Selection form Punjab | Punjab, India |
| 15 | GM-91 | Selection form Maharashtra | Maharashtra, India |
| 16 | GM-93 | Selection form Gujarat | Gujarat, India |
| 17 | GM-94 | Selection form Gujarat | Gujarat, India |
| 18 | GM-117 | Selection form Maharashtra | Maharashtra, India |
| 19 | GM-120 | Selection form Gujarat | Gujarat, India |
| 20 | GM-122 | Selection form Kerala | Kerala, India |
| 21 | GM-124 | Selection form Gujarat | Gujarat, India |
| 22 | GM-125 | Selection form Madhya Pradesh | Madhya Pradesh, India |
| 23 | GM-127 | Selection form Madhya Pradesh | Madhya Pradesh, India |
| 24 | GM-128 | Selection form Madhya Pradesh | Madhya Pradesh, India |
| 25 | GM-129 | Selection form Madhya Pradesh | Madhya Pradesh, India |
| 26 | GM-155 | Chakho selection | Manipur, India |
| 27 | GM-156 | Panval-1 | Maharashtra, India |
| 28 | GM-157 | Leelabati | West Bengal, India |
| 29 | GM-163 | Shalimar | Jammu Kashmir, India |
| 30 | GM-167 | Kamad | Chhattisgarh, India |
| 31 | GM-169 | Dehradun basmati 3-6 | Uttarakhand, India |
| 32 | GM-172 | Dehradun basmati 2-2 | Uttarakhand, India |
| 33 | GM-173 | Dehradun basmati 1-10 | Uttarakhand, India |
| 34 | GM-175 | Dehradun basmati 1-8 | Uttarakhand, India |
| 35 | GM-178 | Dehradun basmati 1-5 | Uttarakhand, India |
| 36 | | MTU-7029 © | Andhra Pradesh, India |
| 37 | | BPT-5204 © | Andhra Pradesh, India |

component (PC 2) contributed to 18.716 per cent of the total variance. The characteristics such as grain yield/ plant and grains panicle$^{-1}$ (0.204) described the highest loadings in this component. The third principal component (PC 3) was illustrated by 7.90 per cent contribution toward the total variability. The characters, test weight (0.330), water uptake (ml) (0.134), and grain yield plant$^{-1}$ (0.034) recorded maximum variance in this component.

The maximum contributing traits towards the genetic diversity of the zinc rich landraces are identified as, days to 50% flowering, productive tillers plant$^{-1}$, grain yield plant$^{-1}$, the number of grains panicle$^{-1}$, test weight, iron content, head rice recovery, water uptake, hulling recovery (%) and volume expansion ratio. Similar results were noted earlier by Tiwari *et al*. (2022) for days to 50% flowering and grain yield plant$^{-1}$; Sudeepthi *et al*. (2020)

Table 2. Mean performances for yield, yield components and quality traits in zinc-rich landraces of rice

| S.No | Genotypes | Days to 50% flowering | Plant height (cm) | Number of productive tillers plant$^{-1}$ | Panicle length (cm) | Grains panicle$^{-1}$ | Grain yield plant$^{-1}$ (g) | Thousand seed weight (g) | Zinc content (ppm) | Iron content (ppm) | Hulling recovery percent | Milling recovery percent | Head rice recovery | Water Uptake (ml) | Volume expansion ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | GM-7 | 69 | 152.00 | 15 | 24.00 | 205 | 16.84 | 19.93 | 31.62 | 10.32 | 70.88 | 64.41 | 59.06 | 132.38 | 3.78 |
| 2 | GM-12 | 76 | 129.50 | 12 | 26.60 | 219 | 21.08 | 18.19 | 25.30 | 11.03 | 71.74 | 64.76 | 60.06 | 129.00 | 3.85 |
| 3 | GM-16 | 67 | 134.50 | 15 | 26.62 | 231 | 24.21 | 22.54 | 27.18 | 10.29 | 74.99 | 65.67 | 56.99 | 115.25 | 3.84 |
| 4 | GM-17 | 75 | 133.00 | 13 | 24.72 | 262 | 21.12 | 22.48 | 31.69 | 11.28 | 74.82 | 69.19 | 59.45 | 160.25 | 3.71 |
| 5 | GM-18 | 75 | 128.50 | 15 | 21.59 | 227 | 26.80 | 21.51 | 30.59 | 11.25 | 74.57 | 64.06 | 59.81 | 135.50 | 3.38 |
| 6 | GM-22 | 70 | 170.00 | 13 | 24.11 | 242 | 24.62 | 24.12 | 31.37 | 11.07 | 80.41 | 73.75 | 60.19 | 141.50 | 3.35 |
| 7 | GM-32 | 81 | 156.50 | 13 | 27.81 | 201 | 18.15 | 20.24 | 25.76 | 11.32 | 71.51 | 65.19 | 58.54 | 165.25 | 3.56 |
| 8 | GM-42 | 68 | 149.00 | 13 | 25.43 | 222 | 24.79 | 23.35 | 25.22 | 11.86 | 71.78 | 65.90 | 57.99 | 166.75 | 3.21 |
| 9 | GM-44 | 67 | 127.00 | 12 | 24.33 | 209 | 18.98 | 20.67 | 24.12 | 10.99 | 71.69 | 63.54 | 55.55 | 136.25 | 3.15 |
| 10 | GM-79 | 76 | 149.50 | 15 | 30.12 | 197 | 21.24 | 21.67 | 31.54 | 10.71 | 80.50 | 71.84 | 57.95 | 163.50 | 3.63 |
| 11 | GM-80 | 77 | 151.50 | 15 | 29.95 | 214 | 18.63 | 21.31 | 27.62 | 12.59 | 76.51 | 72.68 | 63.31 | 161.00 | 3.10 |
| 12 | GM-86 | 92 | 153.00 | 14 | 23.66 | 238 | 20.98 | 24.26 | 31.72 | 11.89 | 76.34 | 65.76 | 57.98 | 121.00 | 4.08 |
| 13 | GM-87 | 76 | 118.00 | 13 | 26.22 | 253 | 18.60 | 19.96 | 25.54 | 11.84 | 81.50 | 72.54 | 63.85 | 136.50 | 3.44 |
| 14 | GM-88 | 89 | 149.50 | 13 | 23.33 | 264 | 26.24 | 22.16 | 30.73 | 11.96 | 71.35 | 65.08 | 57.63 | 143.00 | 3.04 |
| 15 | GM-91 | 74 | 144.00 | 14 | 23.70 | 256 | 17.13 | 18.71 | 27.21 | 12.76 | 82.13 | 74.84 | 59.78 | 170.25 | 3.11 |
| 16 | GM-93 | 67 | 133.50 | 13 | 23.66 | 243 | 24.14 | 23.13 | 25.86 | 13.54 | 81.06 | 72.48 | 58.69 | 122.50 | 3.34 |
| 17 | GM-94 | 75 | 130.00 | 14 | 32.71 | 219 | 17.01 | 21.13 | 26.52 | 12.16 | 74.70 | 65.40 | 60.11 | 162.00 | 3.77 |
| 18 | GM-117 | 78 | 130.50 | 13 | 23.37 | 192 | 16.95 | 20.67 | 26.49 | 13.18 | 75.46 | 67.55 | 54.63 | 174.61 | 3.04 |
| 19 | GM-120 | 74 | 156.50 | 15 | 23.61 | 271 | 29.09 | 24.62 | 27.69 | 11.01 | 65.34 | 57.98 | 55.59 | 115.25 | 3.43 |
| 20 | GM-122 | 76 | 151.00 | 11 | 26.54 | 310 | 22.88 | 21.49 | 28.01 | 11.36 | 70.19 | 64.81 | 59.10 | 118.50 | 3.14 |
| 21 | GM-124 | 68 | 139.00 | 12 | 25.55 | 304 | 20.23 | 19.27 | 27.93 | 10.06 | 74.72 | 69.62 | 58.03 | 172.16 | 3.64 |
| 22 | GM-125 | 70 | 132.50 | 13 | 30.07 | 210 | 18.24 | 22.90 | 27.83 | 10.57 | 69.58 | 62.01 | 55.10 | 158.90 | 3.51 |
| 23 | GM-127 | 76 | 146.50 | 13 | 30.31 | 189 | 16.23 | 21.07 | 26.20 | 10.35 | 74.95 | 65.38 | 59.08 | 118.00 | 3.55 |
| 24 | GM-128 | 74 | 139.00 | 14 | 26.06 | 253 | 17.69 | 23.25 | 25.80 | 10.70 | 74.42 | 65.52 | 58.16 | 134.01 | 3.35 |
| 25 | GM-129 | 69 | 130.00 | 15 | 26.44 | 304 | 14.59 | 19.46 | 27.29 | 11.04 | 80.79 | 71.24 | 60.29 | 125.50 | 3.77 |
| 26 | GM-155 | 76 | 128.50 | 14 | 25.32 | 244 | 19.07 | 20.07 | 26.13 | 11.76 | 81.97 | 72.24 | 58.88 | 125.18 | 3.77 |
| 27 | GM-156 | 75 | 150.50 | 13 | 27.36 | 271 | 16.86 | 21.55 | 24.61 | 12.03 | 74.83 | 66.40 | 56.17 | 155.60 | 3.21 |
| 28 | GM-157 | 67 | 144.50 | 14 | 26.80 | 263 | 18.78 | 19.71 | 25.90 | 12.01 | 75.11 | 68.23 | 60.77 | 124.50 | 3.34 |
| 29 | GM-163 | 66 | 120.00 | 15 | 23.97 | 321 | 16.76 | 24.17 | 35.77 | 15.92 | 74.22 | 68.28 | 63.56 | 142.25 | 3.95 |
| 30 | GM-167 | 78 | 150.50 | 15 | 27.20 | 312 | 17.26 | 22.99 | 26.23 | 13.51 | 81.04 | 72.91 | 62.78 | 146.50 | 3.72 |
| 31 | GM-169 | 75 | 161.50 | 16 | 25.62 | 254 | 18.88 | 24.39 | 25.61 | 11.11 | 72.07 | 64.58 | 59.25 | 144.25 | 3.29 |
| 32 | GM-172 | 84 | 150.50 | 15 | 27.34 | 278 | 18.11 | 22.41 | 26.38 | 11.49 | 70.93 | 63.58 | 56.46 | 149.25 | 3.48 |
| 33 | GM-173 | 86 | 149.00 | 15 | 26.62 | 315 | 28.28 | 24.06 | 25.51 | 11.84 | 64.91 | 60.32 | 53.88 | 174.25 | 3.30 |
| 34 | GM-175 | 81 | 160.50 | 14 | 30.54 | 224 | 25.14 | 22.84 | 24.95 | 12.68 | 75.14 | 70.72 | 62.00 | 180.50 | 3.61 |
| 35 | GM-178 | 79 | 141.00 | 15 | 31.59 | 226 | 15.57 | 24.79 | 25.32 | 11.56 | 80.88 | 72.31 | 61.26 | 125.25 | 4.25 |
| 36 | MTU 7029© | 119 | 92.50 | 14 | 28.22 | 225 | 23.58 | 20.13 | 19.25 | 6.95 | 76.57 | 66.92 | 63.53 | 181.25 | 4.37 |
| 37 | BPT 5204© | 110 | 94.00 | 14 | 26.64 | 243 | 21.86 | 13.89 | 20.36 | 7.99 | 77.13 | 66.09 | 61.24 | 173.00 | 4.65 |
| Range | Minimum | 66 | 93 | 11 | 21.59 | 189 | 14.59 | 13.89 | 19.25 | 6.95 | 64.91 | 57.98 | 53.88 | 115.25 | 3.04 |
| | Maximum | 119 | 170 | 16 | 32.71 | 321 | 29.09 | 24.79 | 35.77 | 15.92 | 82.13 | 74.84 | 64.53 | 181.25 | 4.65 |
| Mean | | 76 | 139.92 | 13.74 | 26.42 | 246 | 20.48 | 21.59 | 27.07 | 11.46 | 75.04 | 67.40 | 59.20 | 145.96 | 3.56 |
| SEm | | 0.69 | 1.03 | 1.08 | 0.65 | 3.26 | 0.81 | 0.86 | 0.58 | 0.4 | 0.85 | 0.77 | 0.88 | 1.65 | 0.04 |
| CD (0.05) | | 1.99 | 2.97 | 2.99 | 1.88 | 9.39 | 2.35 | 2.50 | 1.67 | 1.17 | 2.37 | 2.12 | 2.54 | 3.25 | 0.13 |
| CV (%) | | 1.27 | 1.94 | 11.00 | 3.50 | 1.87 | 5.64 | 5.68 | 3.04 | 5.02 | 1.55 | 1.61 | 2.10 | 1.10 | 1.80 |

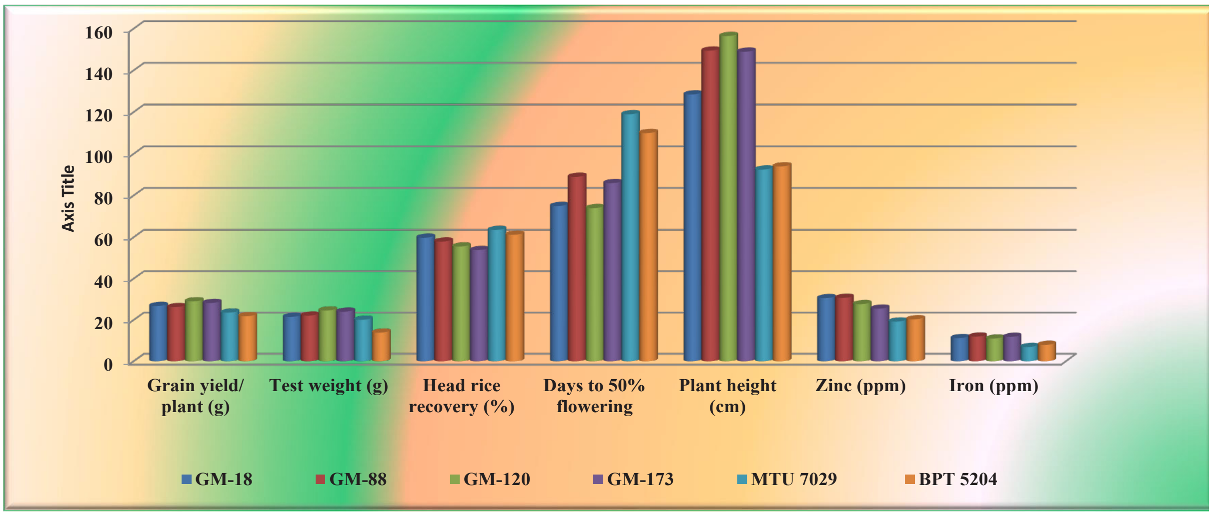


**Fig. 1. Promising Zinc rich landraces**

**Table 3. Promising zinc- rich landraces identified in the study**

| S.No | Zinc rich landraces | Grain yield/ plant (g) | Test weight (g) | Head rice recovery (%) | Days to 50% flowering | Plant height (cm) | Zinc (ppm) | Iron (ppm) |
|---|---|---|---|---|---|---|---|---|
| **Landraces** | | | | | | | | |
| 1 | GM-18 | 26.80 | 21.51 | 59.81 | 75 | 128.50 | 30.59 | 11.25 |
| 2 | GM-88 | 26.24 | 22.16 | 57.98 | 89 | 149.50 | 30.73 | 11.96 |
| 3 | GM-120 | 29.06 | 24.62 | 55.59 | 74 | 156.50 | 27.69 | 11.01 |
| 4 | GM-173 | 28.28 | 24.06 | 53.88 | 86 | 149.00 | 25.51 | 11.84 |
| **Checks** | | | | | | | | |
| 1 | MTU 7029 | 23.58 | 20.13 | 63.53 | 119 | 92.50 | 19.25 | 6.95 |
| 2 | BPT 5204 | 21.86 | 13.89 | 61.24 | 110 | 94.00 | 20.36 | 7.99 |

**Table 4. Component loading of different characters in rice for yield and quality traits**

| | | Canonical Roots Analysis (PCA) | | |
|---|---|---|---|---|
| | **Components** | **1 Vector** | **2 Vector** | **3 Vector** |
| | Eigene Value (Root) | 7.24024 | 2.62036 | 1.10614 |
| | % Variance | 51.71597 | 18.71688 | 7.90102 |
| | Cumulative% | 51.71597 | 70.43284 | 78.33385 |
| **S.No** | **Characters** | **PC1** | **PC2** | **PC3** |
| 1 | Days to 50% flowering | 0.36432 | 0.00224 | 0.08822 |
| 2 | Plant Height (cm) | -0.31696 | 0.00563 | -0.091 |
| 3 | Number of productive tillers plant$^{-1}$ | 0.35604 | 0.00533 | 0.00704 |
| 4 | Panicle length (cm) | -0.27687 | -0.18411 | -0.01459 |
| 5 | Grains panicle$^{-1}$ | -0.12429 | 0.2046 | -0.81049 |
| 6 | Grain yield plant$^{-1}$ (g) | -0.10904 | 0.47412 | 0.03449 |
| 7 | Thousand seed weight (g) | -0.26115 | -0.21792 | 0.33063 |
| 8 | Zinc content (ppm) | -0.34172 | -0.002 | -0.10989 |
| 9 | Iron content (ppm) | 0.28266 | -0.19213 | -0.32098 |
| 10 | Hulling recovery (%) | -0.15509 | -0.48254 | -0.13813 |
| 11 | Milling recovery (%) | 0.02652 | -0.58344 | -0.09586 |
| 12 | Head rice recovery (%) | 0.2972 | -0.18229 | -0.23091 |
| 13 | Water uptake (ml) | 0.27147 | -0.02941 | 0.13409 |
| 14 | Volume expansion ratio | 0.29051 | 0.08745 | -0.04007 |

**Table 5. PCA scores for Zinc-rich rice landraces**

| S.No. | Genotype | PCA I<br>X Vector | PCA II<br>Y Vector | PCA III<br>Z Vector |
|---|---|---|---|---|
| 1 | GM -7 | 60.727 | -47.539 | -33.591 |
| 2 | GM -12 | 61.679 | -45.316 | -35.891 |
| 3 | GM -16 | 53.093 | -39.269 | -36.365 |
| 4 | GM -17 | 54.409 | -42.466 | -39.073 |
| 5 | GM -18 | 52.884 | -39.222 | -35.384 |
| 6 | GM -22 | 52.708 | -48.06 | -37.878 |
| 7 | GM -32 | 64.249 | -47.538 | -32.807 |
| 8 | GM - 42 | 57.344 | -42.159 | -33.56 |
| 9 | GM - 44 | 56.233 | -43.323 | -32.207 |
| 10 | GM - 79 | 64.208 | -53.372 | -31.514 |
| 11 | GM - 80 | 62.254 | -52.575 | -35.537 |
| 12 | GM - 86 | 51.157 | -42.2 | -38.537 |
| 13 | GM - 87 | 52.408 | -50.593 | -40.094 |
| 14 | GM - 88 | 57.542 | -39.313 | -38.901 |
| 15 | GM - 91 | 56.4 | -53.217 | -39.37 |
| 16 | GM - 93 | 57.709 | -45.847 | -39.087 |
| 17 | GM - 94 | 56.89 | -46.076 | -35.106 |
| 18 | GM - 117 | 55.354 | -48.749 | -32.287 |
| 19 | GM - 120 | 50.556 | -30.28 | -38.011 |
| 20 | GM - 122 | 51.421 | -39.86 | -43.399 |
| 21 | GM - 124 | 61.618 | -45.915 | -41.792 |
| 22 | GM - 125 | 65.342 | -45.646 | -31.018 |
| 23 | GM - 127 | 48.584 | -46.903 | -33.592 |
| 24 | GM - 128 | 55.471 | -46.504 | -37.965 |
| 25 | GM - 129 | 57.874 | -46.702 | -44.676 |
| 26 | GM - 155 | 57.889 | -49.146 | -40.058 |
| 27 | GM - 156 | 57.13 | -45.312 | -40.583 |
| 28 | GM - 157 | 58.111 | -47.313 | -41.49 |
| 29 | GM - 163 | 57.246 | -42.816 | -47.008 |
| 30 | GM - 167 | 68.455 | -49.555 | -46.69 |
| 31 | GM - 169 | 64.342 | -44.585 | -38.827 |
| 32 | GM - 172 | 58.52 | -41.137 | -40.279 |
| 33 | GM - 173 | 71.572 | -34.435 | -39.895 |
| 34 | GM - 175 | 65.285 | -47.186 | -36.454 |
| 35 | GM - 178 | 71.439 | -52.872 | -37.723 |
| 36 | MTU-7029© | 109.333 | -45.96 | -28.403 |
| 37 | BPT-5204© | 104.354 | -43.651 | -32.271 |

**Table 6. Clustering pattern of zinc rich landraces in rice**

| Clusters | Number of Genotypes | List of Genotypes |
|---|---|---|
| 1 | 5 | GM-16, GM-18, GM-88, GM- 120 and GM-122 |
| 2 | 8 | GM-32, GM-79, GM-80, GM-125, GM-167, GM-169, GM-175 and GM-178 |
| 3 | 6 | GM-22, GM-87, GM-91, GM-117, GM-128 and GM-155 |
| 4 | 3 | GM-17, GM-86 and GM-127 |
| 5 | 12 | GM-7, GM-12, GM-42, GM-44, GM-93, GM-94, GM-124, GM-129, GM-156, GM-157, GM-163 and GM-172 |
| 6 | 1 | GM-173 |
| 7 | 2 | MTU-7029 and BPT-5204 |

https://doi.org/10.37992/2022.1304.169

**Table 7. Cluster mean values in PCA for yield and quality traits in rice**

| Clusters | Days to 50% flowering | Plant height (cm) | Number of productive tillers plant$^{-1}$ | Panicle length (cm) | Grains panicle$^{-1}$ | Grain yield / plant (g) | Thousand seed weight (g) | Zinc content (ppm) | Iron content (ppm) | Hulling recovery percent | Milling recovery percent | Head rice recovery | Water Uptake (ml) | Volume expansion ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 70.700 | 144.800 | 13.300 | 24.643 | 263.300 | 25.645 | 23.210 | 28.572 | 10.825 | 70.991 | 63.605 | 56.316 | 125.800 | 3.414 |
| 2 | 67.563 | 149.625 | 14.063 | 29.958 | 228.125 | 15.735 | 24.556 | 26.923 | 11.701 | 76.098 | 68.991 | 59.086 | 156.750 | 3.621 |
| 3 | 65.167 | 139.333 | 13.000 | 25.329 | 239.250 | 14.643 | 25.923 | 27.086 | 11.782 | 79.793 | 71.747 | 58.398 | 148.833 | 3.356 |
| 4 | 72.333 | 144.333 | 12.667 | 26.358 | 231.167 | 18.255 | 22.715 | 30.068 | 11.055 | 75.295 | 66.845 | 58.257 | 133.167 | 3.798 |
| 5 | 68.625 | 138.083 | 13.333 | 26.884 | 252.583 | 15.872 | 21.973 | 27.329 | 11.692 | 73.960 | 67.718 | 57.512 | 144.083 | 3.570 |
| 6 | 80.000 | 131.833 | 14.667 | 26.023 | 274.167 | 26.882 | 24.082 | 22.470 | 9.675 | 72.032 | 65.395 | 57.895 | 181.667 | 3.928 |
| 7 | 113.750 | 92.250 | 13.250 | 26.618 | 231.500 | 23.610 | 18.425 | 19.975 | 7.568 | 77.548 | 66.873 | 62.528 | 178.750 | 4.595 |

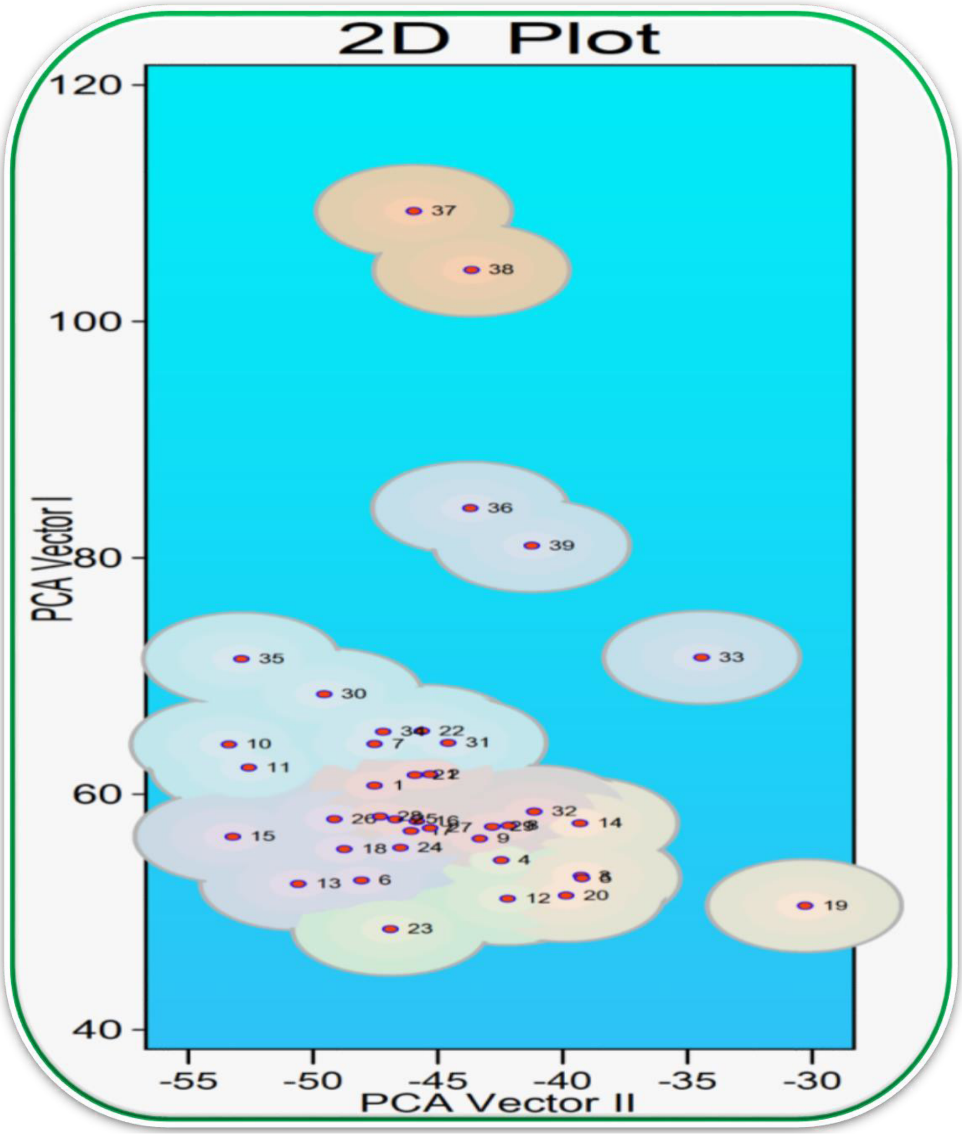


**Fig. 2. Two dimensional graph showing relative positions of zinc rich rice landraces based on PCA score**

for test weight; Christina *et al.* (2021) for productive tillers; Singh *et al*. (2020) for hulling recovery and head rice recovery (%) and grains panicle$^{-1}$ for Kumari *et al.* (2021). The PCA scores for zinc-rich rice landraces in the first three principal components were computed and were considered as three axes X, Y, and Z, and the squared distance of each genotype from these three axes was calculated. The results on PCA scores of the landraces for the three principal components are presented in **Table 5**. The PCA scores of zinc-rich rice landraces were also plotted in a graph to get a two-dimensional scatter diagram presented in **Fig. 2**. The land races under study were grouped into seven clusters (**Table 6**). Among these clusters, cluster VII had two genotypes *i.e* MTU 7029 and BPT 5204 (**Table 7**), while cluster IV had three genotypes such as GM-17, GM-86 and GM-127 with greater mean for grain zinc content (30.06 ppm) and cluster VI had one genotype (GM-173) with high mean for the number of productive tillers plant$^{-1}$ (14.66), grain yield plant$^{-1}$ (26.88g), and water uptake (181.66 ml). Hence, the selection of landraces from these clusters could be useful in the development of the high yielding and nutrient rich rice varieties

Based on the study, the landraces GM-173 and GM-120 have been identified to be genetically diverse, high yielding and nutrient rich . These genotypes could be exploited in rice bio-fortification programs.

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