

IDENTIFICATION OF PROMISING INDIGENOUS RICE LANDRACES FOR GRAIN PRODUCTIVITY AND FE–ZN ENRICHMENT THROUGH MULTI-TRAIT RANKING

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ABSTRACT

Indigenous rice (*Oryza sativa* L.) landraces represent valuable genetic resources for improving grain productivity and nutritional quality. This study aimed to identify promising landraces combining yield-related traits with grain iron (Fe) and zinc (Zn) concentrations using an unweighted multi-trait rank-sum approach. Sixty-six landraces and four standard checks (Chittimutyalu, DRR Dhan 45, BPT 5204 and Zincorice) were evaluated during *Kharif* 2024 at the Agricultural College Farm, Aswaraopet, Telangana, using an augmented block design. Six traits, number of panicles per plant (NPP), number of filled grains per panicle (NFP), 1000-grain weight (TGW), grain yield per plant (GYP) and grain Fe and Zn concentrations were ranked and individual ranks were summed with lower values indicating superior overall performance. Substantial variation was observed for NPP (2-14), NFP (38-142), TGW (2.11-29.25 g), GYP (12.09-34.20 g), Fe (3.87-15.30 ppm) and Zn (10.63-25.48 ppm). Assamchudi recorded the lowest rank sum (57.5), followed by Red jasmine (66.0) and Hembarbag (69.0). DRR Dhan 45 ranked fourth (77.5), Zincorice fifth (90.5), BPT 5204 ninth and Chittimutyalu fourteenth. Assamchudi combined favourable yield attributes with 14.30 ppm Fe and 20.98 ppm Zn. Red jasmine recorded the highest grain yield (34.20 g) and NPP (14), while Hembarbag combined high yield (31.97 g) with favourable grain micronutrient concentrations. These landraces represent promising parental resources for breeding rice varieties with improved productivity and grain Fe-Zn enrichment.

KEYWORDS: breeding potential; grain yield; iron; landraces; multi-trait; rank-sum; selection; zinc

INTRODUCTION

Rice (*Oryza sativa* L.) is a major staple crop that contributes substantially to global food security, particularly in Asia (Fukagawa et al., 2019; Mohidem et al., 2022). Despite considerable progress in improving grain productivity, micronutrient deficiencies remain a nutritional concern in populations dependent on cereal-based diets. Improving grain iron (Fe) and zinc (Zn) concentrations alongside productivity has therefore become an important objective of rice biofortification and nutritional breeding programmes (Trijatmiko et al., 2016; Garcia-Oliveira 2018; Senguttuvel et al., 2023). Traditional rice landraces represent valuable genetic resources for broadening the genetic base of cultivated rice and improving grain nutritional quality. The considerable variation present in these materials for yield components, grain yield and micronutrient concentrations provides opportunities to identify potential donor parents for developing nutritionally enhanced, productive cultivars. However, the selection of suitable parents remains challenging because genotypes exhibiting superior performance for individual traits may not possess favourable combinations of productivity and nutritional attributes (Nirosha et al., 2016; Sanghamitra et al., 2022).

Multi-trait selection approaches can address this challenge by evaluating genotypes simultaneously for several breeding objectives. Among these, rank-sum analysis provides a straightforward and transparent method for integrating trait-wise performance into a composite selection criterion. By summing the ranks assigned to individual traits, this approach facilitates the identification of genotypes with consistently favourable performance without requiring predetermined economic weights. It can therefore serve as a practical preliminary tool for prioritizing parental resources for rice improvement (Mulamba & Mock, 1978; Beavis et al., 2023). Although morphological characterization and genetic divergence analyses help elucidate the diversity of rice germplasm, they do not necessarily identify genotypes combining desirable productivity and grain micronutrient attributes. A complementary breeding-oriented evaluation is therefore required to prioritize landraces based on their combined performance for these traits. Along with traditional multi-trait evaluation, data-driven agricultural methods could offer opportunities to enhance the organization, analysis, and interpretation of crop-performance data. Precision farming systems focus on the application of agricultural information for resource management and production decisions (Geetanjali and Singh, 2025). These methods may be useful in rice germplasm evaluation to complement trait-based selection, and can be used to integrate phenotypic observations across environments, but their usefulness in identifying superior Fe- and Zn-enriched landraces needs to be specifically validated.

The present study aimed to evaluate 66 indigenous rice landraces and four standard checks for six traits

associated with productivity and grain nutritional quality, namely number of panicles per plant, number of filled grains per panicle, 1000-grain weight, grain yield per plant, and grain Fe and Zn concentrations. An unweighted multi-trait rank-sum approach was employed to identify promising landraces with favourable trait combinations and compare their performance with established check varieties. The findings are expected to support the preliminary selection of parental resources for rice breeding programmes targeting simultaneous improvement of grain productivity and Fe–Zn enrichment.

MATERIALS AND METHODS

Experimental site and plant material

The field experiment was conducted during *Kharif* 2024 at the College Farm, Agricultural College, Aswaraopet, Professor Jayashankar Telangana Agricultural University (PJTU), Telangana, India. Micronutrient estimation was carried out during Rabi 2024 at the Central Instrumentation Cell (CIC), College of Agriculture, Rajendranagar, Hyderabad. The experimental material comprised 66 indigenous rice (*Oryza sativa* L.) landraces collected by farmers from different geographical regions of India and four standard check varieties, namely BPT 5204, Chittimutyalu, DRR Dhan 45 and Zincorice (Table 1).

Table 1. List of 66 genotypes and 04 checks

Treatments	Entry name
Checks	
01	Chittimutyalu
02	DRR Dhan 45
03	BPT-5204
04	Zincorice
Genotypes	
01	Bhajana
02	Kalalangad
03	Kudrath
04	Saphari
05	Tarang
06	Kandasagar
07	Panchatantra
08	Budamalu
09	Ghalima
10	Bammagutni
11	Sugandhi
12	Haladhichudi
13	Dhimidi
14	Barhavahi
15	Sonamali
16	Gadakodimamahi
17	Rahikanda
18	Agmakunda
19	Indrani
20	Methimahal
21	Sannajajulu
22	Red jasmine
23	Bahurupi
24	Daddiga
25	Kiatampeta sannalu
26	Zeerashankar
27	Kundadam
28	Chandro gadah
29	Bhalududium
30	Kantamuguni
Treatments	Entry name
31	Tikkimisri
32	Kalajeel
33	Assamchudi
34	Kalimuch
35	Ramkul
36	Ambemohar
37	Gedikahiye

38	Illapusamba
39	Javapoola
40	302
41	Hembarbag
42	Kakirekkalu
43	Karamguruvay
44	Birodlu
45	Mudimurangi
46	Ramjeera
47	Hallabatta
48	Vedurusanna
49	Pohaki
50	Nagara
51	Lathisali
52	Esakarvad
53	Radhajigil
54	Kumargorla
55	Thonda
56	Jajudhan
57	Ambemohar-2
58	Raktasali
59	Siddhasanna
60	Aasudhi
61	Kouthrimaharaj
62	Kujipabali
63	Chintabarisannalu
64	Manipur black
65	Red rice
66	Kalabatti

Experimental design and crop management

The genotypes were evaluated using an augmented block design with two blocks, following the procedure described by (Federer, 1961). Seedlings were raised in a nursery and transplanted at 30 days after sowing. Each genotype was planted in three rows of 1.0 m length, maintaining 20 cm spacing between rows and 15 cm between plants within rows. The four check varieties were replicated in each block, whereas the landraces were evaluated as unreplicated test entries.

The crop was raised following the recommended package of practices for transplanted rice under the agro-climatic conditions of Telangana. Fertilizers were applied at a recommended rate of **120:60:40 kg ha⁻¹ N:P₂O₅:K₂O**, with nitrogen supplied in split doses at appropriate crop growth stages. Irrigation was provided according to crop requirements and prevailing weather conditions. Weed, insect-pest and disease management practices were followed as recommended for rice cultivation. Uniform crop management practices were maintained across the experimental entries.

Recording of observations

Observations were recorded on five randomly selected plants from the middle rows of each entry to minimize border effects. Six traits were considered for the present analysis: number of panicles per plant (NPP), number of filled grains per panicle (NFP), 1000-grain weight (TGW, g), grain yield per plant (GYP, g), grain iron concentration (Fe, ppm) and grain zinc concentration (Zn, ppm). Grain yield was recorded from individually harvested plants after drying the grain to approximately 12–14% moisture.

Estimation of grain iron and zinc concentrations

Representative grain samples from each genotype were cleaned to remove adhering dust and foreign material, oven-dried to constant weight and finely ground using a stainless-steel grinder. Approximately 0.5 g of powdered grain sample was weighed accurately and subjected to wet-acid digestion using concentrated nitric acid (HNO₃) and perchloric acid (HClO₄). The samples were heated gradually until a clear digest was obtained. After cooling, the digest was filtered, and the volume was made up to a known volume using deionized water.

Iron and zinc concentrations in the digested samples were determined using a flame atomic absorption spectrophotometer (PerkinElmer PE4000) at the CIC, College of Agriculture, Rajendranagar, Hyderabad. Reagent blanks were processed alongside the samples, and standard Fe and Zn solutions were used for instrument calibration. Selected samples were analysed repeatedly for quality control. The concentrations of both micronutrients were expressed as parts per million (ppm).

Multi-trait rank-sum analysis

Statistical analyses were performed using R statistical software (version 4.3.2). Genotype means for the six selected traits were used to calculate the unweighted rank-sum index. Genotypes were ranked in descending order for each trait, assigning rank 1 to the highest value. The rank sum for the *i*th genotype was calculated as:

$$RS_i = \sum_{j=1}^6 R_{ij}$$

Where RS_i is the total rank sum of the i^{th} genotype, and R_{ij} is its rank for the j^{th} trait.

All 70 genotypes, including the four check varieties, were ranked together to enable direct comparison between indigenous landraces and established checks. Genotypes were ordered according to their total rank-sum values, with lower values indicating more favourable relative performance across the six traits. The index was used as a preliminary selection tool to identify landraces combining desirable productivity attributes and grain Fe and Zn concentrations. The rankings represent relative performance within the evaluated germplasm set and do not directly estimate genetic merit or breeding value.

RESULTS

Variation in productivity and grain micronutrient traits

The 70 rice genotypes exhibited considerable variation for all six traits considered in the multi-trait analysis (Table 2). The NPP ranged from 2 to 14, with Red jasmine recording the maximum. The NFP ranged from 38 to 142, with Bahurupi recording the highest value. TGW varied from 17.23 to 29.25 g, with Zeerashankar exhibiting the maximum. GYP ranged from 12.09 to 34.20 g, with Red jasmine recording the highest yield, followed by Vedorusanna (33.02 g), Hembarbag (31.97 g), Kundadam (30.57 g) and Siddhasanna (30.54 g). Grain Fe concentration ranged from 3.87 to 15.30 ppm, whereas Zn concentration varied from 10.63 to 25.48 ppm. DRR Dhan 45 recorded the highest Fe concentration (15.30 ppm), while Kumargorla exhibited the highest Zn concentration (25.48 ppm). The observed variation provided opportunities to identify landraces with favourable combinations of productivity and grain micronutrient traits.

Table 2. Mean performance of 70 rice genotypes for the six traits included in the multi-trait rank-sum index

No.	Genotype	NPP	NFP	TGW (g)	GYP (g plant ⁻¹)	Fe (ppm)	Zn (ppm)
1	Bhajana	8	81	17.63	20.94	8.97	17.28
2	Kalalangad	5	53	26.23	13.64	10.37	16.48
3	Kudrath	7	75	20.93	18.04	8.17	18.98
4	Saphari	10	109	23.23	29.44	6.97	17.68
5	Tarang	7	54	22.45	13.19	10.42	16.63
6	Kandasagar	4	46	21.75	12.59	11.32	17.03
7	Panchatantra	11	102	17.65	24.69	4.72	10.63
8	Budamalu	8	97	20.11	20.59	5.93	11.13
9	Ghalima	5	53	17.85	15.39	10.62	20.63
10	Bammagutni	10	108	21.85	24.09	9.93	15.73
11	Sughandi	9	63	17.45	20.49	7.63	13.53
12	Haladichudi	7	102	24.85	18.29	4.72	10.73
13	Dhimidi	13	88	17.75	30.39	8.23	14.43
14	Barhavahi	6	53	20.65	13.69	12.73	18.03
15	Sonamali	5	86	21.25	15.09	14.42	25.03
16	Gadakodimamahi	7	62	20.85	28.09	7.83	13.03
17	Rahikanda	6	64	20.75	19.69	6.93	14.63
18	Agmakunda	8	93	22.65	12.09	5.03	11.63
19	Indrani	11	81	23.45	25.29	9.63	15.53
20	Methimahahal	6	46	27.55	19.39	6.33	12.23
21	Sannajajulu	8	51	20.45	21.19	10.83	16.73
22	Red jasmine	14	112	24.45	34.20	11.63	17.23
23	Bahurupi	10	142	20.15	25.09	14.42	23.53
24	Daddiga	6	67	22.05	17.39	8.33	13.03
25	Kistampetasannalu	5	47	20.85	13.99	8.03	14.63
26	Zeerashankar	4	75	29.25	14.89	5.73	12.73
27	Kundadam	10	82	28.52	30.57	8.80	14.88
28	Chandrogadah	5	74	22.93	18.67	6.40	12.98
29	Baludhudium	7	61	20.23	18.47	8.20	14.68
30	Kantamuguni	6	56	20.63	15.77	10.50	17.18
31	Tikkimisri	8	64	17.72	15.97	12.20	16.98
32	Kalajeel	10	70	20.33	23.67	8.70	14.38
33	Kalimuch	11	79	19.93	28.07	7.20	14.78
34	Ramkul	3	61	20.43	15.37	8.10	14.98
35	Ambemohar	12	83	20.53	30.47	9.60	16.28
36	Gedikahiye	10	39	20.73	27.47	11.50	16.98

37	Illapusamba	2	38	19.93	23.57	8.00	14.88
38	Javapoola	5	53	17.72	28.57	6.60	12.98
39	Assamchudi	11	116	25.03	26.57	14.30	20.98
40	302	7	61	17.23	18.27	8.90	15.78
41	Hembarbag	12	127	21.03	31.97	12.70	18.98
42	Kakirekkal	9	102	20.43	28.07	12.50	19.28
43	Karamguruvay	7	127	20.23	20.57	12.00	18.58
44	Birodalu	3	40	20.03	18.07	13.50	19.78
45	Mudimurangi	7	127	25.63	25.47	10.50	20.78
46	Ramjeera	4	72	24.42	14.77	9.90	18.68
47	Hallabatta	3	53	20.03	18.07	7.30	17.88
48	Vedurusanna	10	88	24.03	33.02	8.70	18.48
49	Pohaki	8	99	22.23	25.94	8.08	17.98
50	Nagara	7	84	20.83	19.94	8.47	16.78
51	Latisali	3	46	20.43	13.24	9.37	19.78
52	Esakarvad	10	121	20.83	24.64	3.97	20.68
53	Radhajigil	11	111	20.73	27.44	8.37	21.78
54	Kumargorla	8	95	20.53	22.94	4.67	25.48
55	Thonda	12	105	22.63	28.64	8.47	16.98
56	Jajudhan	9	118	20.83	20.24	3.87	17.88
57	Ambemohar-2	8	110	20.83	22.14	8.07	16.98
58	Raktasali	5	65	24.23	15.94	12.17	20.48
59	Siddhasanna	13	84	20.23	30.54	13.87	21.88
60	Aasudhi	8	57	20.93	19.24	8.57	14.68
61	Kouthrimaharaj	7	83	20.33	18.04	7.27	12.78
62	Kujipabali	10	84	28.83	24.94	5.17	13.78
63	Chintabarisannalu	9	95	18.03	21.44	8.97	15.78
64	Manipur black	8	97	24.13	23.94	8.17	16.78
65	Red rice	5	74	21.43	16.24	7.07	14.28
66	Kalabatta	11	92	20.43	24.54	8.17	18.68
67	Chittimutyalu	11	101	17.40	25.17	14.47	20.30
68	DRR Dhan 45	10	102	28.47	24.43	15.30	21.37
69	BPT 5204	11	103	20.13	25.37	14.47	21.70
70	Zincorice	12	102	21.40	24.50	14.47	20.57

Trait-wise performance of superior genotypes

The superior performing genotype differed among the six traits. Red jasmine recorded the highest NPP and GYP, whereas Bahurupi and Zeerashankar exhibited the highest NFP and TGW, respectively (Figure 1). DRR Dhan 45 recorded the maximum Fe concentration (15.30 ppm), while Chittimutyalu, BPT 5204 and Zincorice each contained 14.47 ppm Fe. Bahurupi and Sonamali also exhibited relatively high Fe concentrations (14.42 ppm). Kumargorla recorded the highest Zn concentration (25.48 ppm), followed by Sonamali (25.03 ppm), Bahurupi (23.53 ppm), Siddhasanna (21.88 ppm), Radhajigil (21.78 ppm), BPT 5204 (21.70 ppm) and DRR Dhan 45 (21.37 ppm). These results indicated that individual trait superiority was distributed across different genotypes, supporting the use of an integrated selection approach.

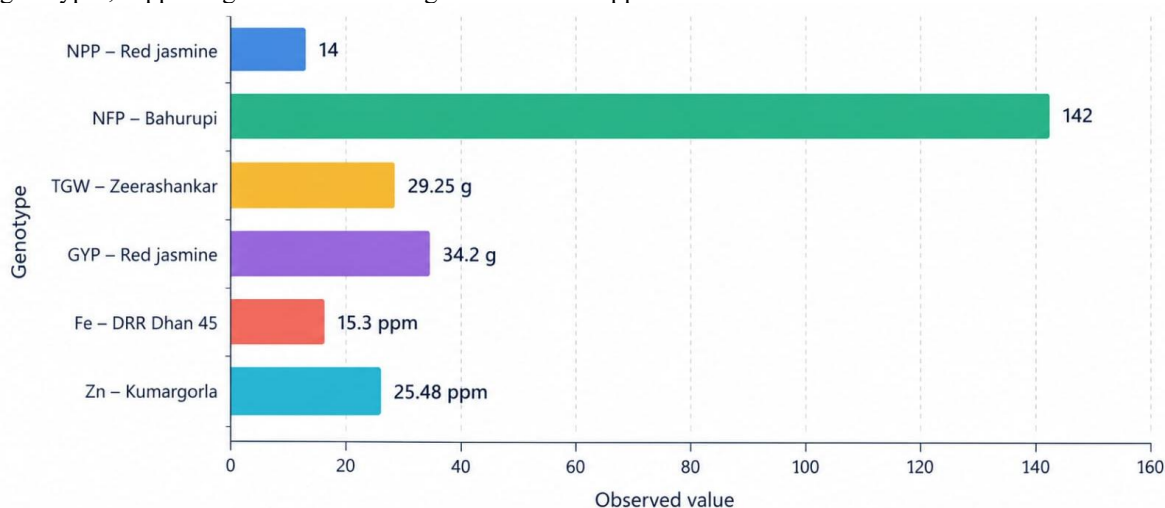


Figure 1. Trait-specific superiority among indigenous rice landraces and standard checks

Multi-trait rank-sum analysis

The unweighted rank-sum index provided an integrated assessment of the 70 genotypes for NPP, NFP, TGW, GYP, Fe and Zn (Table 3). Assamchudi recorded the lowest rank sum (57.5) and was ranked first, followed by Red jasmine (66.0) and Hembarbag (69.0) (Figure 2). Among the standard checks, DRR Dhan 45 ranked fourth (77.5), Zincorice fifth (90.5), BPT 5204 ninth (108.5) and Chittimutyalu fourteenth. Other high-ranking landraces included Mudimurangi (rank sum 103.0; sixth), Siddhasanna (103.5; seventh), Bahurupi (106.0; eighth) and Radhajigil (118.0; tenth). The three highest-ranked genotypes were indigenous landraces, indicating their favourable relative performance across the six selection traits compared with the evaluated checks.

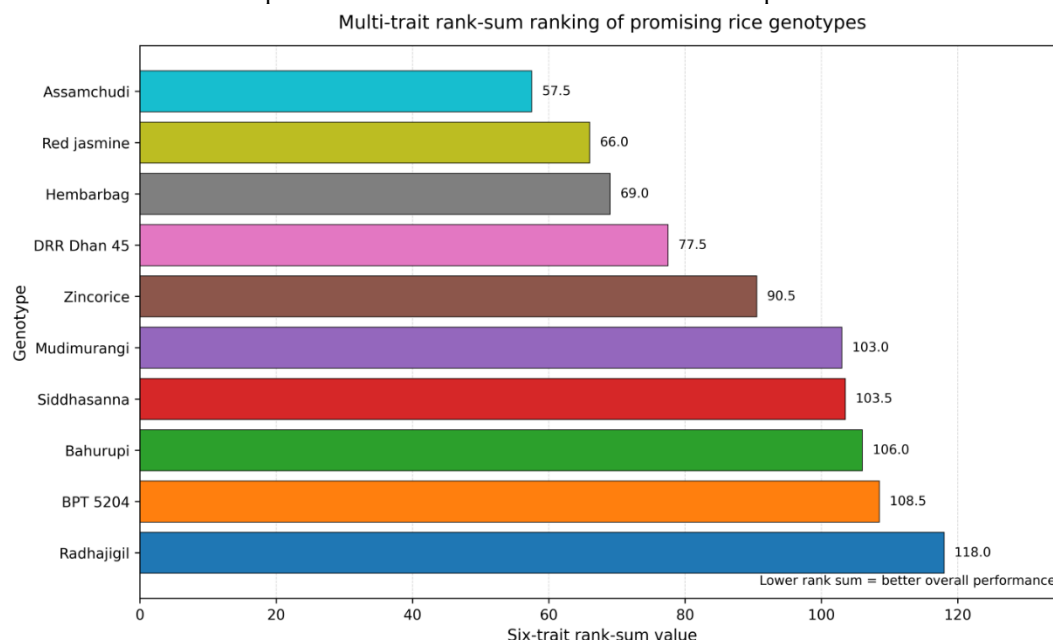


Figure 2. Multi-trait rank-sum ranking of promising indigenous rice landraces and standard checks based on six productivity and grain micronutrient traits.

Table 3. Rank-sum analysis of all 70 rice genotypes based on six productivity and micronutrient traits

Overall rank	Genotype	NPP rank	NFP rank	TGW rank	GYP rank	Fe rank	Zn rank	Rank sum	Type
1	Assamchudi	11.5	7	8	16	7	8	57.5	Landrace
2	Red jasmine	1	8	10	1	16	30	66.0	Landrace
3	Hembarbag	5.5	3	28	3	11	18.5	69.0	Landrace
4	DRR Dhan 45	20.5	17	4	28	1	7	77.5	Check
5	Zincorice	5.5	17	26	27	3	12	90.5	Check
6	Mudimurangi	44.5	3	7	18	21.5	9	103.0	Landrace
7	Siddhasanna	2.5	32	52	5	8	4	103.5	Landrace
8	Bahurupi	20.5	1	54	22	5.5	3	106.0	Landrace
9	BPT 5204	11.5	14	55	19	3	6	108.5	Check
10	Radhajigil	11.5	9	38.5	15	39	5	118.0	Landrace
11	Thonda	5.5	13	19	9	37.5	34.5	118.5	Landrace
12	Vedurusanna	20.5	28.5	14	2	34.5	23	122.5	Landrace
13	Kakirekkalu	27.5	17	46.5	12.5	12	17	132.5	Landrace
14	Chittimutyalu	11.5	20	68	21	3	14	137.5	Check
15	Saphari	20.5	11	16	8	57	28	140.5	Landrace
16	Kundadam	20.5	36	3	4	33	48.5	145.0	Landrace
17	Bammagutni	20.5	12	23	29	25	45	154.5	Landrace
18	Indrani	11.5	37.5	15	20	27	46	157.0	Landrace
19	Ambemohar	5.5	34.5	42.5	6	28	42	158.5	Landrace
20	Esakarvad	20.5	5	34.5	25	69	10	164.0	Landrace
21	Pohaki	34.5	21	21	17	47	25	165.5	Landrace
22	Kalabatta	11.5	27	46.5	26	44	20.5	175.5	Landrace
23	Karamguruvay	44.5	3	52	39	15	22	175.5	Landrace
24	Manipur black	34.5	22.5	13	30	44	37.5	181.5	Landrace
25	Sonamali	58.5	30	27	61	5.5	2	184.0	Landrace
26	Gedikahiye	20.5	69	38.5	14	17	34.5	193.5	Landrace
27	Ambemohar-2	34.5	10	34.5	34	48	34.5	195.5	Landrace

28	Dhimidi	2.5	28.5	62	7	41	55	196.0	Landrace
29	Kujipabali	20.5	32	2	23	64	58	199.5	Landrace
30	Raktasali	58.5	47	12	57	14	13	201.5	Landrace
31	Kumargorla	34.5	24.5	42.5	33	68	1	203.5	Landrace
32	Jajudhan	27.5	6	34.5	41	70	26.5	205.5	Landrace
33	Chintabarisannalu	27.5	24.5	60	35	30.5	43.5	221.0	Landrace
34	Kalimuch	11.5	39	58.5	12.5	55	50	226.5	Landrace
35	Nagara	44.5	32	34.5	42	37.5	37.5	228.0	Landrace
36	Ramjeera	64	44	11	63	26	20.5	228.5	Landrace
37	Kudrath	44.5	40.5	29.5	52.5	44	18.5	229.5	Landrace
38	Bhajana	34.5	37.5	66	37	30.5	29	234.5	Landrace
39	Sannajajulu	34.5	63	44	36	19	39	235.5	Landrace
40	Kalajeel	20.5	45	49.5	31	34.5	56	236.5	Landrace
41	Gadakodimamahi	44.5	51	31.5	11	51	60.5	249.5	Landrace
42	Tikkimisri	34.5	48.5	63.5	56	13	34.5	250.0	Landrace
43	Barhavahi	52	60	40	65	10	24	251.0	Landrace
44	Aasudhi	34.5	55	29.5	45	36	51.5	251.5	Landrace
45	Tarang	44.5	57	20	68	23	40	252.5	Landrace
46	Haladichudi	44.5	17	9	48	66.5	69	254.0	Landrace
47	Panchatantra	11.5	17	65	24	66.5	70	254.0	Landrace
48	Kalalangad	58.5	60	6	66	24	41	255.5	Landrace
49	Kantamuguni	52	56	41	58	21.5	31	259.5	Landrace
50	Birodalu	67.5	68	56.5	50.5	9	15.5	267.0	Landrace
51	Ghalima	58.5	60	61	59	20	11	269.5	Landrace
52	Kandasagar	64	66	24	69	18	32	273.0	Landrace
53	Daddiga	52	46	22	54	40	60.5	274.5	Landrace
54	Agmakunda	34.5	26	18	70	65	67	280.5	Landrace
55	Chandrogadah	58.5	42.5	17	46	60	62.5	286.5	Landrace
56	Baludhudium	44.5	53	52	47	42	51.5	290.0	Landrace
57	302	44.5	53	69	49	32	43.5	291.0	Landrace
58	Latisali	67.5	66	46.5	67	29	15.5	291.5	Landrace
59	Rahikanda	52	48.5	37	43	58	53.5	292.0	Landrace
60	Methimahal	52	66	5	44	61	66	294.0	Landrace
61	Red rice	58.5	42.5	25	55	56	57	294.0	Landrace
62	Budamalu	34.5	22.5	70	38	62	68	295.0	Landrace
63	Sughandi	27.5	50	67	40	52	59	295.5	Landrace
64	Zeerashankar	64	40.5	1	62	63	65	295.5	Landrace
65	Kouthrimaharaj	44.5	34.5	49.5	52.5	54	64	299.0	Landrace
66	Javapoola	58.5	60	63.5	10	59	62.5	313.5	Landrace
67	Hallabatta	67.5	60	56.5	50.5	53	26.5	314.0	Landrace
68	Ramkul	67.5	53	46.5	60	46	47	320.0	Landrace
69	Kistampetasannalu	58.5	64	31.5	64	49	53.5	320.5	Landrace
70	Illapusamba	70	70	58.5	32	50	48.5	329.0	Landrace

Performance of promising landraces

The trait profiles of the highest-ranked landraces revealed complementary strengths (Table 4). Assamchudi, ranked first with a rank sum of 57.5, recorded 11 panicles per plant, 116 filled grains per panicle, a TGW of 25.03 g and a GYP of 26.57 g. Its grain Fe and Zn concentrations were 14.30 and 20.98 ppm, respectively. Although it did not record the maximum value for any individual trait, its favourable combined performance resulted in the lowest rank sum.

Red jasmine ranked second (66.0) and combined the highest grain yield (34.20 g) and NPP (14) with 112 filled grains per panicle and a TGW of 24.45 g. Its Fe and Zn concentrations were 11.63 and 17.23 ppm, respectively. Hembarbag ranked third (69.0), with 12 panicles per plant, 127 filled grains per panicle, a GYP of 31.97 g, Fe concentration of 12.70 ppm and Zn concentration of 18.98 ppm.

Table 4. Breeding implications of promising landraces

Breeding objective	Priority genotype(s)	Main attribute
Overall productivity + Fe + Zn	Assamchudi	Lowest overall rank sum
High productivity + micronutrients	Hembarbag	High GYP, NFP, Fe and Zn
High grain productivity	Red jasmine	Highest GYP and NPP
High filled grains + Fe + Zn	Bahurupi	Maximum NFP; high Fe and Zn
High productivity + Zn	Mudimurangi	High NFP, TGW, GYP and Zn

High yield + Fe + Zn	Siddhasanna	High GYP, Fe and Zn
High Fe donor	DRR Dhan 45	15.30 ppm Fe
High Zn donor	Kumargorla	25.48 ppm Zn
High TGW donor	Zeeshankar	29.25 g TGW
Strong check/reference	Zincorice	Rank 5 overall

Other landraces also showed useful trait combinations. Mudimurangi combined 127 filled grains per panicle, a TGW of 25.63 g, a GYP of 25.47 g and 20.78 ppm Zn. Siddhasanna recorded 13 panicles per plant, a GYP of 30.54 g, 13.87 ppm Fe and 21.88 ppm Zn. Bahurupi was distinguished by the highest NFP (142), together with Fe and Zn concentrations of 14.42 and 23.53 ppm, respectively. Radhagil recorded a GYP of 27.44 g and 21.78 ppm Zn, while Vedurusanna combined a high GYP (33.02 g) with a TGW of 24.03 g and 18.48 ppm Zn.

Overall, the rank-sum analysis identified Assamchudi as the most balanced genotype according to the selected index, Red jasmine as a high-yielding landrace, and Hembarbag as a promising genotype combining productivity with grain micronutrient concentrations. Mudimurangi, Siddhasanna and Bahurupi offered additional combinations of yield components and nutritional traits for consideration in rice improvement programmes.

DISCUSSION

The identification of breeding materials combining high grain productivity with enhanced grain Fe and Zn concentration is an important requirement for developing nutritionally improved rice cultivars (Calayugan et al., 2020; Dhanyalakshmi et al., 2024; Nayak et al., 2026). Although individual trait evaluation is useful for identifying specific donors, selection based on a single character may result in the loss of desirable attributes for other important traits (Duc et al., 2025). In the present study, a rank-sum approach integrating six target traits, namely NPP, NFP, TGW, GYP, grain Fe concentration and grain Zn concentration, was used to prioritize breeding materials with a favourable overall phenotype. The trait-wise results demonstrated considerable differences among the genotypes in the expression of individual traits, with Red jasmine recording the highest grain yield and NPP, Bahurupi the highest NFP, Zeeshankar the highest TGW, DRR Dhan 45 the highest Fe concentration and Kumargorla the highest Zn concentration. Such trait-specific superiority indicates that no single genotype was universally superior for all six attributes and highlights the value of simultaneous selection when the breeding objective involves both productivity and nutritional quality (Vieira et al., 2025).

The rank-sum analysis provided a complementary perspective by identifying genotypes with favourable combinations rather than extreme performance for individual traits (Kumar et al., 2026). Assamchudi occupied the first position, followed by Red jasmine and Hembarbag, demonstrating that the most useful breeding materials need not necessarily be the highest-ranking genotype for any one individual character. The favourable position of Assamchudi was associated with its relatively consistent performance across productivity and micronutrient traits, including 11 panicles per plant, 116 filled grains per panicle, 25.03 g 1000-grain weight, 26.57 g grain yield per plant, 14.30 ppm Fe and 20.98 ppm Zn. This balanced expression is particularly relevant to biofortification breeding, where improvement in grain micronutrient concentration needs to be achieved without compromising yield potential (Avnee et al., 2023). Similarly, the high overall ranking of Hembarbag reflected its combination of high grain yield and filled grain number with favourable Fe and Zn concentrations. These genotypes therefore represent promising sources for developing segregating populations aimed at simultaneous improvement of grain productivity and nutritional quality.

The performance of Red jasmine further illustrates the usefulness of integrating multiple traits into parent selection. It recorded the highest grain yield (34.20 g) and NPP (14), while also showing favourable performance for NFP and TGW. Although its Fe and Zn concentrations were not the highest among the evaluated genotypes, its strong productivity contributed substantially to its second overall position. This indicates that the rank-sum approach does not favour micronutrient concentration at the expense of productivity but instead identifies genotypes with a favourable overall balance (Venmuhil et al., 2020). Such materials may be particularly valuable in breeding programmes where enhanced Fe and Zn are required while maintaining or increasing yield potential (Anusha et al., 2021; Singh et al., 2025). Other landraces, including Mudimurangi, Siddhasanna, Bahurupi, Radhagil and Vedurusanna, also exhibited complementary combinations of yield components, grain yield and micronutrient concentration. Their value therefore extends beyond their overall rank, as specific attributes may make them useful donors in crosses designed for particular breeding objectives.

Comparison with the established checks provided an additional perspective on the breeding value of the indigenous landraces. The first three positions in the overall six-trait ranking were occupied by indigenous landraces, while the highest-ranking check, DRR Dhan 45, occupied fourth position. This indicates that several indigenous landraces possessed combinations of productivity and micronutrient traits that were competitive with, or superior to, those observed in established cultivars. Nevertheless, the checks retained considerable breeding value because of their specific strengths. DRR Dhan 45 recorded the highest grain Fe concentration and also showed favourable performance for TGW, NFP and Zn concentration, whereas Zincorice combined relatively favourable micronutrient and productivity attributes. These results emphasize that indigenous landraces and improved cultivars should not be considered as mutually exclusive sources; rather, they can provide complementary parental resources for broadening the genetic base and assembling desirable trait combinations (Savitha & Usha Kumari, 2014). Systematically collecting phenotypic and environmental data

across locations and seasons would be beneficial for future evaluation of the selected landraces. Data-driven agriculture practices, such as machine learning analysis, have been proposed as a means to understand agricultural information and make decisions about crop management (Taqvi, 2025). If sufficient and reliable multi-environment data are available, these methods may be used to examine patterns in yield components and micronutrient levels in the grain of the present germplasm. These analyses should be used in addition to replicated field evaluation and appropriate statistical analysis of genotype and environmental effects.

An important outcome of the present analysis is the distinction between broad-spectrum breeding materials and trait-specific donors. Genotypes such as Assamchudi, Hembarbag, Mudimurangi, Siddhasanna, Bahurupi, Radhajigil and Vedurusanna displayed favourable combinations across several selection criteria and may therefore be considered broad-spectrum multi-trait resources. In contrast, certain genotypes were particularly valuable because of their exceptional performance for individual traits, such as Red jasmine for grain yield and NPP, Bahurupi for NFP together with favourable Fe and Zn, Zeerashankar for TGW, DRR Dhan 45 for Fe concentration and Kumargorla for Zn concentration. This distinction is relevant to practical breeding because parent selection depends on the specific objective of a crossing programme. A genotype with a moderate overall rank may still be highly valuable when a particular trait is deficient in another selected parent.

The identified materials can consequently be considered as potential parents for complementary crossing strategies. Crosses involving high-productivity and micronutrient-rich genotypes could be used to generate segregating populations with the expectation of recombining contrasting desirable attributes. For example, Red jasmine × Bahurupi could be explored for combining high productivity with enhanced Fe and Zn, Hembarbag × DRR Dhan 45 for combining productivity with high Fe concentration, Assamchudi × Kumargorla for combining balanced multi-trait performance with high Zn concentration, and Hembarbag × Bahurupi for improving yield components together with grain micronutrient concentration. These combinations should, however, be regarded as parent-selection hypotheses rather than predictions of superior progeny performance. Rank-sum values do not provide information on combining ability, heterosis, gene action or transgressive segregation; therefore, the usefulness of these proposed crosses must be established through hybridization, progeny evaluation and subsequent selection.

The present findings also highlight the importance of distinguishing preliminary germplasm prioritization from the identification of stable biofortification sources. Grain Fe and Zn concentration can be influenced by environmental conditions, soil properties, crop management and genotype × environment interactions. The significance of assessing the performance of crops under varying environmental conditions is also demonstrated in wheat, where combined salinity and heat stress had differential effects on physiological traits and yield attributes among wheat genotypes (Neelambari et al., 2024). While the study was conducted on wheat and not rice micronutrient enrichment, it further underscores the importance of evaluating the performance of the genotype under the relevant environmental conditions. Therefore, the rice landraces selected should be tested at several sites and seasons prior to determining yield stability and grain Fe–Zn performance. Consequently, the favourable ranking observed in the present evaluation may not necessarily remain unchanged across seasons or locations. The selected landraces should therefore be subjected to replicated multilocation and multiseason evaluation to determine the stability of grain yield and micronutrient concentration. Further studies should also assess grain micronutrient bioavailability and investigate the genetic basis of the favourable trait combinations identified in these landraces. Thus, the present rank-sum analysis provides a practical first-stage framework for prioritizing indigenous rice germplasm and identifying complementary parents for breeding programmes targeting simultaneous improvement of grain productivity and Fe–Zn nutritional quality. New image-analysis techniques could also provide future crop phenotyping opportunities. For instance, deep-learning techniques have been explored to detect soybean leaf conditions based on images (Ahmad, 2026). For future rice research, similar image-based methods could be used for specific measurable traits for which training data and validated methods exist. These would be used in addition to direct measurements of grain yield and Fe and Zn concentrations.

CONCLUSION

Multi-trait rank-sum analysis effectively prioritized indigenous rice landraces for simultaneous improvement of productivity and grain Fe–Zn concentration. Assamchudi ranked first, followed by Red jasmine and Hembarbag, with all three outperforming the standard checks in overall ranking. These genotypes, along with Mudimurangi, Siddhasanna, Bahurupi, Radhajigil and Vedurusanna, represent promising parental resources for rice breeding. Their breeding potential should be validated through progeny testing and multilocation evaluation.

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