

## Evaluation and stability analysis for yield and related traits in rice under humid south-eastern plain zone of Rajasthan

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### Abstract

**Aim:** A total of 15 rice (*Oryza sativa* L.) varieties were evaluated in three different seasons representing different environments under Humid South-eastern Plain Zone in Rajasthan during kharif 2019, 2020 and 2021 to assess the stability of grain yield.

**Methodology:** Additive main effect and multiplicative interaction (AMMI) and stability model were employed to study the G×E interaction. ANOVA revealed significant G×E interaction and variety and environment effect.

**Results:** The mean grain yield varied among the varieties from 40.20 to 56.80 q ha<sup>-1</sup>, with a general mean of 46.57 q ha<sup>-1</sup>. Variety MTU1010 was identified to have a higher mean grain yield than the general mean and was stable across the years. AMMI analysis revealed that the first two IPCA scores together explained 87.26 % of the total interaction variance.

**Interpretation:** Both linear and non-linear components contributed towards G×E interaction. Biplot graphical analysis showed variety DR46 exhibited the best overall yield performance. Varieties DR46 and NDR359 recorded a better performance in environments E1 and E3, while KARJAT performed well in E1 and E2 environments; hence, it could be identified for specific climatic conditions. These varieties could be utilized for direct cultivation as well as for the development of other cultivars.

**Key words:** AMMI analysis, G × E interaction, Rice, Stability

Selection of high yielding rice varieties from diverse ecologies



Multi-environmental trials (Years/season)



Evaluation of 15 rice varieties for three years (2019-E1, 2020-E2, 2021-E3)



Identification of varieties with high mean yield and stability of target traits (DR46, NDR359 and KARJAT)

## Introduction

Rice (*Oryza sativa* L.) plays a pivotal role in nourishing the global population, reigning supreme as a top-tier staple among stable food crops. It holds indispensable significance in the dietary habits of billions across the world. The potential scarcity of rice supplies in various regions raises the alarming prospect of widespread hunger. Globally, 776 million tons of rice are produced from 166 million ha of land to meet the needs of the world's rapidly growing population (FAO, 2022). This underscores the profound impact of rice cultivation in meeting the nutritional needs of diverse communities. Elevating the grain yield per unit area of rice stands as a crucial strategy in alleviating poverty. This pivotal objective necessitates the cultivation of rice varieties renowned for their robust yield potential, coupled with the implementation of well-suited agricultural management techniques. By adopting these measures, we not only enhance food production but also pave the way for economic upliftment, particularly in communities where poverty is a persistent challenge.

This holistic approach contributes to sustainable agricultural practices and bolsters food security, thereby fostering positive socio-economic outcomes. In India, rice is cultivated over about 44.1 million ha area with the production of 165.3 million tons paddy with the productivity of 3.78 t ha<sup>-1</sup>. India is the second largest rice-growing country in the world (Government of India, 2023). Rajasthan occupies an area of 2.34 lakh hectares with a production of 6.61 lakh tonnes and productivity of 2.86 t ha<sup>-1</sup>; whereas, in Kota, rice is cultivated on an area of 1.37 lakh ha with a production of 4.36 lakh tonnes and productivity of 3.18 t ha<sup>-1</sup> (Government of Rajasthan, 2022). India possesses an extensive range of rice varieties, reflecting a vast diversity that thrives across various growing environments. Despite the release of numerous rice varieties over time, a significant number of them have faded from cultivation within a short span. The primary reason for this decline is the inconsistent performance of many varieties in diverse environmental conditions. Only a handful of rice varieties have demonstrated stable and reliable performance, standing the test of time to remain in cultivation over the years.

This highlights the challenges in maintaining varietal diversity and underscores the importance of selecting and promoting rice varieties with resilient and consistent performance across different ecological contexts (Bose et al., 2014). Multi-location testing (MLTs) of genotypes stands as a key tool for plant breeders, providing a nuanced understanding of a genotype's adaptability and stability across diverse environments. This approach involves assessing how well a genotype performs in different geographical locations, offering valuable insights into its robustness under various climatic conditions. The performance of any character is a combined result of the genotype (G) of the variety, the environment (E) and the interaction between genotype and environment (GEI). To evaluate the consistency of rice grain yield and develop genotypes that respond optimally and consistently across years and geographic regions, it is necessary to research focus on yield stability and GE interactions (Blanche

et al., 2009). Grain yield (GY) is the economic determinant of the best-performing genotypes (Mehana et al., 2021). This quantitative trait is shaped by the additive main effects of both environment (E) and genotype (G), as well as the non-additive influence stemming from the interaction between genotype and environment (GEI) (Bocianowski et al., 2021). Breeders emphasize the impact of genotype-environment interaction (GEI) to assess the yield stability in genotypes across diverse conditions (Kumar et al., 2022). This stability is not apparent when considering the individual effects of either genotype or environment alone (Yue et al., 2022). Keeping the above in view, the present study was undertaken to determine the nature and magnitude of G × E interaction effects and to select the stable varieties for grain yield tested in consecutive three years.

## Materials and Methods

**Field experimentation:** The experimental material comprised of 15 rice varieties, which were evaluated in a randomized block design with three replications at the Agricultural Research Station, Ummedganj, Agriculture University, Kota, Rajasthan. The details of the diverse rice varieties, their origins and testing across three productive years/seasons are presented in Table 1. The field experiment was conducted in three different seasons of the year 2019, 2020 and 2021. The experimental site is situated at 25°13' N latitude and 75°54' E longitude, 259 m above mean sea level. The soil type at this location exhibits a clay texture and has a pH level of 7.5. Seeds of each variety were planted in a plot size of 5×2 m, maintaining a spacing of 20 × 10 cm. Observations were recorded on a plot basis for days to 50% flowering and days to maturity while on five randomly selected plants in each plot for plant height (cm), number of effective tillers per plant, panicle length (cm), number of panicle m<sup>-2</sup>, number of grains per panicle, test weight (g), amylose content (%), bran oil content (%) and grain yield (q ha<sup>-1</sup>).

**Statistical analyses:** All statistical analyses and graphical representation were performed in R 4.2 statistical software version 2022.12.0 with the help of the “metan”, “ggplot 2” and “dplyr” package. Combined ANOVA was carried out to test the presence of GEI. The AMMI and GGE biplots were computed using multi-environment trial analysis (Olivoto and Lúcio, 2020). Two multivariate analytical tools, AMMI and biplots (GGE) were also used to analyze G×E interaction and determine the stability and adaptability of each germplasm (Zobel et al., 1988; Yan and Kang, 2002). The GGE biplots and AMMI methods based on mega-environment assessment were used to plot the graphs of the following models: AMMI 1 and AMMI 2, which-won-where pattern of GGE, ranking of genotypes, mean performance vs. stability and discriminativeness vs. representativeness among test environments. They were used to visualize the presence of G × E interaction.

## Results and Discussion

The combined ANOVA for 15 rice varieties across multiple environments revealed significant differences for grain yield, underscoring the value of employing the AMMI analysis.

**Table 1:** Details on rice cultivars, origin, parents and environment (code)

Name	Origin	Parents	Environment
DR42	IIRR, Hyderabad	NIL of IR 64	2019 (E1)
CR202	NRRI, Cuttack	IR 72022-4-6-23-2/IRRI 105	2020 (E2)
PR113	PAU, Ludhiana	Pusa 44/ PR 11	2021 (E3)
Dr46	IIRR, Hyderabad	IR 72022-4-6-23-2	-
MTU1010	RARS, ANGRAU, AP	Krishnaveni/ IR-64	-
NDR359	NDUA&T, UP	BG 90-2-4/OB 677	-
DR44	IIRR, Hyderabad	IR71700-247-1-1-2/IR03 L120	-
JAYA	NRRI, Cuttack	TN-1/T141	-
DR45	IIRR, Hyderabad	RP HP 3-IR 80463-B 39-3/IR 81421-B-B-66	-
IR-64	IRRI, Philippines	IR5657-33-2-1/IR2061-465-1-5-5	-
RATNA	NRRI Cuttack	TKM-6/IR 8	-
SURAKSHA	NRRI, Cuttack	Sasyasree x MR-1523	-
LALKADA	NAU, Gujarat	IR 833-6-2-2-1 x IR-2040	-
KARJAT-1	BSKVV Dapoli	Holamaldiga/IR-36	-
IR-28	IRRI, Philippines	IR833-6-2-1-1/ IR1561-149-1//IR24*4/O. nivara	-

**Table 2:** AMMI analysis of variance for grain yield and related traits over three years/seasons

DF		DM			PH			NET/P					
Source	Df	SS	MSS	PV	SS	MSS	PV	SS	MSS	PV	SS	MSS	PV
ENV	2	26.52	4.42	-	39.30	6.55	-	30.88	5.15	-	11.51	5.76	-
GEN	14	1482.86	105.92	-	3135.30	223.95	-	3898.36	278.45	-	219.78	15.70	-
GEN × ENV	28	129.72	4.63	-	179.81	6.42	-	262.51	9.38	-	54.04	1.93	-
PC1	15	116.46	7.76	89.8	134.83	8.99	75	235.96	15.73	89.9	44.09	2.94	81.6
PC2	13	13.26	1.02	10.2	44.97	3.46	25	26.55	2.04	10.1	9.95	0.77	18.4
Total	162	2325.62	14.36	-	4229.04	26.11	-	5155.74	31.83	-	443.62	2.74	-
Conti...													
PL		NP m <sup>2</sup>			NG/P			TW					
Source	Df	SS	MSS	PV	SS	MSS	PV	SS	MSS	PV	SS	MSS	PV
ENV	2	43.32	0.52	-	17612.55	209.67	-	12103.97	144.09	-	36.55	0.44	-
GEN	14	398.14	28.44	-	29334.19	2095.30	-	28937.77	2066.98	-	194.18	13.87	-
GEN × ENV	28	13.43	0.48	-	5853.90	209.07	-	8379.14	299.25	-	21.20	0.76	-
PC1	15	11.06	0.74	82.4	5542.30	369.49	94.7	8148.43	543.23	97.2	17.35	1.16	81.9
PC2	13	2.37	0.18	17.6	311.60	23.97	5.3	230.71	17.75	2.8	3.84	0.30	18.1
Total	162	482.56	2.98	-	62789.44	387.59	-	58005.26	358.06	-	284.13	1.75	-
Conti...													
AC		BOC			GY								
Source	Df	SS	MSS	PV	SS	MSS	PV	SS	MSS	PV			
ENV	2	32.08	0.38	-	13.56	0.16	-	179.81	2.14	-			
GEN	14	94.36	6.74	-	367.07	26.22	-	1994.44	142.46	-			
GEN:ENV	28	15.58	0.56	-	3.80	0.14	-	49.70	1.77	-			
PC1	15	13.84	0.92	88.8	3.09	0.21	81.5	41.58	2.77	83.7			
PC2	13	1.74	0.13	11.2	0.70	0.05	18.5	8.11	0.62	16.3			
Total	162	172.47	1.06	-	392.30	2.42	-	2285.72	14.11	-			
Conti...													

DF=Days to 50% flowering, DM= Days to maturity, PH= Plant height (cm), NET/P= Number of effective tillers per plant, PL=Panicle length (cm), NP= Number of panicle m<sup>2</sup>, NG/P= Number of grains per panicle, TW=Test weight (g), AC= Amylose content (%), BOC= Bran oil content (%), GY= Grain yield (q ha<sup>-1</sup>)

**Table 3:** Mean value for yield and related traits for 15 rice varieties over three years/seasons

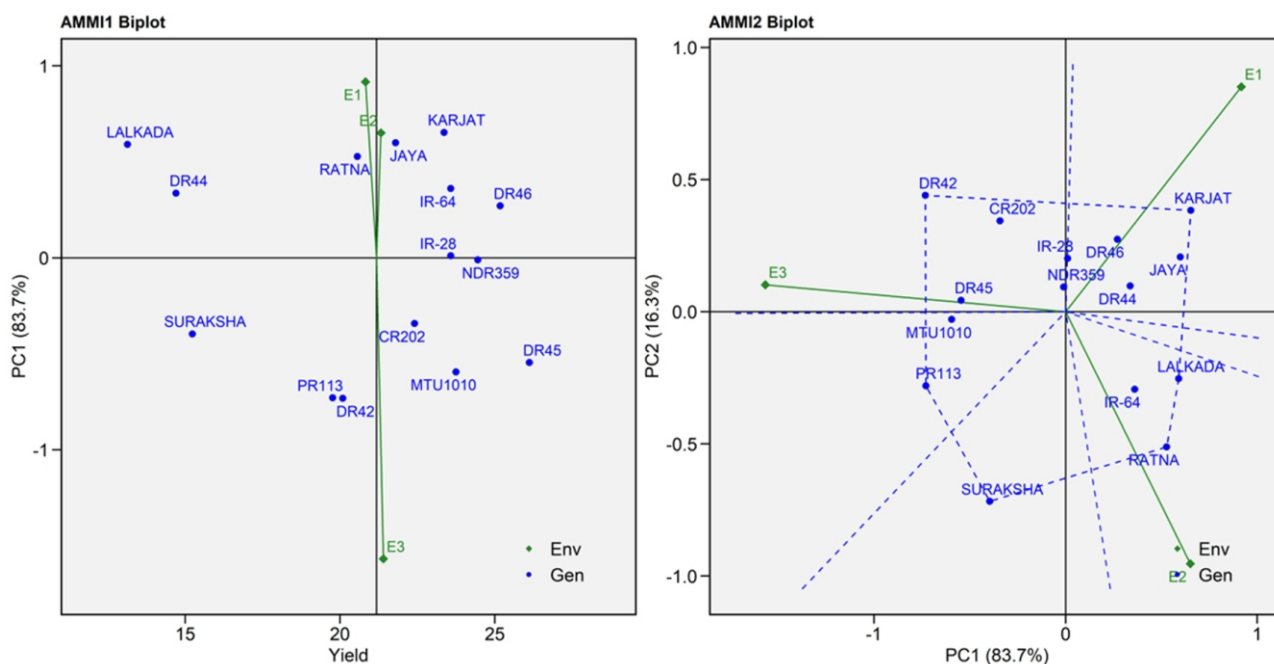
Variety	DF	DM	PH	NET/P	PL	NP m <sup>2</sup>	NG/P	TW	AC	BOC	GY
DR42	95.89	124.11	106.00	11.56	23.46	218.44	140.44	23.89	25.69	10.77	45.20
CR202	94.44	126.67	112.11	11.78	25.74	275.00	174.44	24.61	25.21	14.07	46.10
PR113	104.44	138.67	103.76	10.67	23.09	261.89	154.89	23.94	25.76	12.94	44.70
DR46	96.89	127.44	103.16	11.33	23.64	260.00	167.33	24.62	25.44	10.73	50.80
MTU1010	97.00	124.22	111.12	11.11	26.01	239.44	170.60	23.20	25.71	11.41	56.80
NDR359	103.67	139.11	118.08	13.11	26.47	266.67	170.89	25.23	25.28	10.97	53.10
DR44	96.00	128.67	101.58	9.56	24.04	231.78	137.33	22.52	25.47	10.96	40.20
JAYA	99.44	132.89	94.93	9.89	23.74	250.11	164.76	26.46	25.19	14.43	43.60
DR45	99.33	130.22	105.83	12.44	25.67	266.89	156.44	25.31	23.31	13.47	47.80
IR-64	97.00	129.11	103.96	12.22	24.31	262.56	172.47	25.07	25.33	13.57	47.30
RATNA	103.44	136.22	110.78	12.00	26.46	258.22	161.22	24.03	23.16	14.43	46.20
SURAKSHA	104.22	138.56	112.40	8.44	27.76	249.44	130.44	22.76	25.22	11.82	41.40
LALKADA	101.44	131.44	109.09	9.33	21.21	243.22	135.56	22.92	25.46	16.46	42.10
KARJAT	96.78	131.11	107.64	10.89	24.44	261.22	155.64	25.28	25.74	12.67	45.00
IR-28	101.44	133.00	104.32	12.33	22.19	265.33	173.89	22.13	23.89	13.98	48.30

DF=Days to 50% flowering, DM= Days to maturity, PH= Plant height (cm), NET/P= Number of effective tillers per plant, PL=Panicle length (cm), NP= Number of panicle/m<sup>2</sup>, NG/P= Number of grains per panicle, TW=Test weight (g), AC= Amylose content (%), BOC= Bran oil content (%), GY= Grain yield (q ha<sup>-1</sup>)

The results showed that 87.26% of the total sum of squares was attributed to genotypic effects, 2.17% to environmental effects, and 7.87% to genotype × environment interaction (GEI) effects (Table 2). The AMMI model effectively captured the presence of GEI, with two significant principal components (PCs) explaining 83.17% and 16.3% of the interaction variance, respectively. Together, these components provided a comprehensive explanation of the interaction patterns among the 15 rice varieties across different production years and seasons. Kumar *et al.* (2022) also found that three principal components exhibited more than one Eigen values and accounted 83.91 percent of total variation present in rice genotype. PC1 accounted 49.18 % of the total variability contributed by the traits like number of grains per panicle, 1000-grain weight, grain yield per plant and amylose content. Furthermore, the analysis highlighted the substantial role of environmental factors in influencing yield variability. Devi *et al.* (2020) also find that a genotype has an IPCA score of nearly zero it has small interaction effect with environment and considered as stable. The specific environment was suitable for the rice genotypes, G14 (MTU-1010) and G 15 (WGL-14). Mohammadi *et al.* (2017), Ngailo *et al.* (2019) findings also align closely with the present studies, reinforcing the robustness of this approach. Biplots, as described by Anowara *et al.* (2014), visually represent the relationships between varieties and environments, offering a comprehensive view of their interconnections. The mean grain yield value of variety averaged over environments indicated that the genotypes, MTU1010 had the highest grain yield (56.80 q ha<sup>-1</sup>) followed by NDR359 (53.10 q ha<sup>-1</sup>) and DR46 (50.80 q ha<sup>-1</sup>) while genotypes DR44 had lowest grain yield (40.20 q ha<sup>-1</sup>). Different varieties showed inconsistent performance across all the environments. The environmental mean grain yield ranged from 40.20 to 56.80 q ha<sup>-1</sup> over season and variety (Table 3).

The AMMI 1 biplot interpretation involves displacements along axes indicating differences in mean effects, while displacements along the ordinate denote differences in interaction effects. Varieties clustering together suggest similar adaptability, while environments grouped together exert a similar influence on varieties (Kempton, 1984). A variety with a near-zero IPCA score indicates minimal interaction effects, implying stability. Mean grain yields of rice varieties are presented in Table 3. Varieties and environments aligned on parallel lines share similar yields, with those positioned to the right of the axis midpoint indicating higher yields compared to those on the left. In this study, variety like MTU1010, NDR359, DR46 and KARJAT exhibited high mean grain yields with notable additive effects. Specifically, variety MTU 1010 exhibited the best for yield performance (Fig.1). The variety DR46 and NDR359 recorded better performance in environments E1 and E3, while KARJAT performed well in E1 and E2 environments. This aligns with the findings of Das *et al.* (2009). Additionally, DR 45, CR 202 and DR 42 exhibited better performance in environments E1 and E3 is consistent with the results reported by Lingaiah *et al.* (2020).

The Which-Won-Where GGE biplot is noteworthy for revealing varieties by environmental patterns. It begins by enclosing the farthest varieties from the biplot origin within a polygon, segmenting the biplot into sectors using perpendicular lines drawn from the origin (Yan and Tinker, 2006). Fig. 2 (a), representing this experiment in a polygon view, showed that the 15 rice varieties were grouped into 7 sectors, while the 3 test environments fell into 3 sectors within the polygon. Each sector contains specific groups of environments and varieties, defining the mega environment (Yan and Rajkan, 2002). For instance, the sector cover the E1 environment included NDR 359, PR 113 and IR28, varieties signifying their responsiveness in this

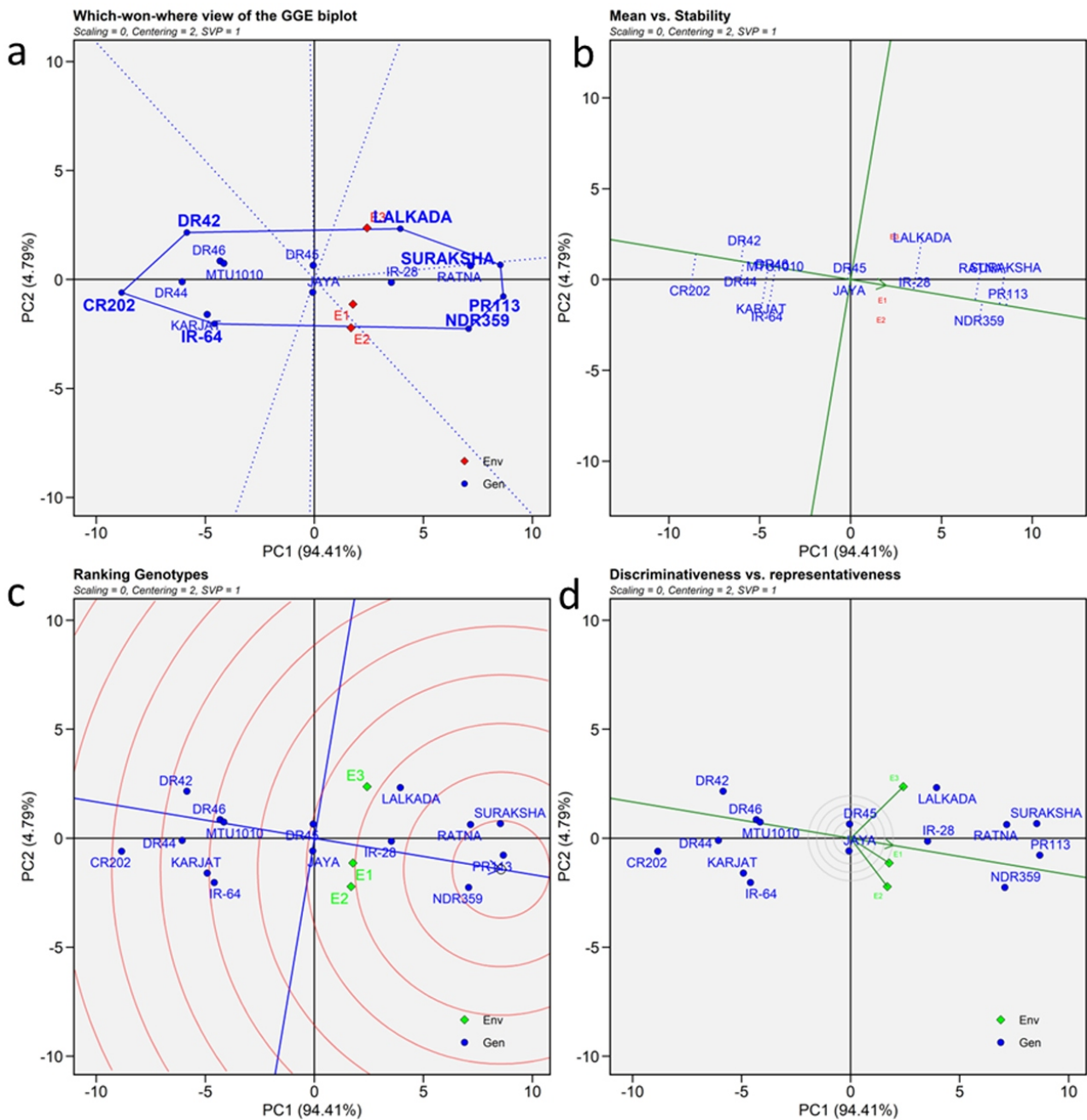


**Fig. 1:** Biplot of (a) the first interaction principal component axis (IPCA1) versus mean yields, (b) the first interaction principal component axis (IPCA1) versus the second interaction principal component axis (IPCA2).

environment. Notably, variety NDR 359 and PR 113 exhibit the longest vectors from the origin, indicating specific adaptation to this environment but potentially lower stability across all environments. Similarly, the sector corresponding to the E3 environment consisted variety of RATNA, SURASHA, and LALKADA, which show responsiveness in this specific environment. Moreover, varieties SURASHA and LALKADA possessed the longest vectors, highlighting their pronounced responsiveness in this particular environment. Consequently, NDR359 and PR 113 emerged as the winning varieties in the E1 environment, while SURASHA and LALKADA at the top in the E3 environment. Interestingly, none of the varieties emerged as winners in the E2 environment. This methodology resonates with the studies of Thungo *et al.* (2020) and Poudel *et al.* (2020b), who identified highly responsive genotypes in heat-stressed environments using the What-Won-Where GGE biplot, highlighting the vertex genotype as the winner in the corresponding environment. Additionally, Neisse *et al.* (2018) and Kumar *et al.* (2022) successfully identified high-yielding varieties specifically adapted to particular environments using a similar methodology.

The GGE biplot method employs visual representations through Average Environment Coordinates (AEC) to graphically assess performance and stability. The AEC is calculated as the mean of the first and second principal component scores of the test environments, represented by an arrowhead in Fig. 2 (b). The line extending from the arrowhead to the origin is the AEC abscissa, while the line perpendicular to it at the origin represents

the ordinate. The length of the abscissa denotes whether genotypes yield above or below average-right of the origin signifies above-average yield, while left indicates below-average yield. On the other hand, the length of the ordinate approximates the genotype's, genotype-environment interaction (GEI) associated with stability. A longer ordinate suggests lower stability, while a shorter ordinate implies higher stability in performance across environments. Fig. 2 (b), mean vs stability, illustrates that rice varieties NDR 359, PR 113, and IR-28 exhibited above-average yields with higher stability. Conversely, LALKADA and SURAKSHA also showed above-average yields but with lower stability. Likewise, DR 44, DR 46 and MTU1010 demonstrate stability but yielded below the average. Meanwhile, CR 202, KARJAT and IR-64 not only exhibited below-average yields but also lacked stability. The ideal lines on the plot represent the highest yield with absolute stability, pinpointed by the arrowhead. Comparatively, the distances of other lines from this ideal point indicate their desirability. In this context, PR 113 appeared most desirable as it lied closest to the AEC, signifying a high level of desirability based on its performance and stability. Similar evaluations using the Mean vs Stability GGE biplot have been conducted by Neisse *et al.* (2018), identifying high-yielding and stable genotypes using the Average Environment Coordinate (AEC). Additionally, observations of stable genotypes through Average Environment (tester) Coordinate methods have been noted by Yan (2001), Yan and Hunt (2001), Singh *et al.* (2019) and Poudel *et al.* (2020b). These methods consistently provide insights into high-performing and stable genotypes, aiding in the selection process.



**Fig. 2:** GGE biplot showing 15 rice varieties under different environments (a) which-won-where view, (b) Mean vs stability, (c) Ranking of genotypes and (d) Discriminativeness vs. representativeness view.

The ideal variety, although practically unattainable, is represented by the arrowhead. Two coordinate axes were drawn to rank the variety effectively: the first axis connecting the arrowhead and the origin, and the second axis perpendicular to the first at the origin (Fig. 2c). By observing concentric circles around the arrowhead, variety could be ranked based on their inclusion within these circles and their distance from the arrowhead along the ordinate. According to this analysis, the

rice variety PR 113 stood very close to the ideal line, making it an excellent reference for evaluating other rice varieties, followed by NDR 359, SURAKSHA, RATNA, LALKADA and IR 20 in the rank of desirable variety suggesting their suitability for further testing across various environments. This method of identifying ideal genotypes, characterized by high yield and stability across multiple environments, aligns with the approaches described by Yan and Kang (2002) and Yan and

Tinker (2006). The assessment of genotype desirability based on proximity to an ideal genotype, as seen with PR113, resonates with the methodology of Yan (2001). Similar findings and methods have been observed and documented by Akther *et al.* (2015), further validating this approach for genotype evaluation and selection.

The GGE biplot uses the length of the environment vector as a measure of discriminativeness. A longer vector indicates higher standard deviation within the environment, signifying greater discriminative ability. In this study, the E3 environment vector appeared notably longer, indicating its higher discriminative ability compared to the other environments (Fig. 2d). Additionally, the cosine of the angle between the environment vectors revealed the interrelationships among the environments. For instance, when the angle was less than 90° between E1 and E3, it signified a positive but low correlation coefficient between these environments. On the other hand, a positive and high correlation coefficient was observed between E2 and E3, depicted by the 90° angle between E2 and E3. These larger angles indicate that the environments are not redundant and have distinct characteristics. The discriminativeness vs representativeness view provided by the GGE biplot allows for the evaluation of advantageous environments, considering both their discriminative abilities and representativeness. This approach proves advantageous over the AMMI biplot (Aktas, 2016) and aids in identifying environments capable of efficiently selecting superior genotypes. Discriminative vs. Representative GGE biplot has already been used by Philipo *et al.* (2021) to compare the discriminating ability and desirability of the environments, showing its effectiveness in assessing and selecting environments for genotype evaluation.

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