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Grain Yield Stability of Rice Genotypes

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Abstract. Stability analysis identifies the adaptation of a crop genotype in different environments. The objective of this study was to evaluate promising rice genotypes for yield stability at different mid-hill environments of Nepal. The multilocation trials were conducted in 2017 and 2018 at three locations *viz* Lumle, Kaski; Pakhribas, Dhankuta; and Kabre, Dolakha. Seven rice genotypes namely NR11115-B-B-31-3, NR11139-B-B-B-13-3, NR10676-B-5-3, NR11011-B-B-B-B-29, NR11105-B-B-27, 08FAN10, and Khumal-4 were evaluated in each location. The experiment was laid out in a randomized complete block design with three replications. The rice genotype NR10676-B-5-3 produced the highest grain yield (6.72 t/ha) among all genotypes. The growing environmental factors (climate and soil conditions) affect the grain yield performance of rice genotypes. The variation in climatic factors greatly contributed to the variation in grain yield. Polygon view of genotypic main effect plus genotype-by-environment interaction (GGE) biplot showed that the genotypes NR10676-B-53 and NR11105-B-B-27 were suitable for Lumle; NR11115-B-B-31-3 and NR11139-B-B-B-13-3 for Pakhribas; and 08FAN10 and NR11011-B-B-B-B-29 for Kabre. The GGE biplot showed that genotype NR10676-B-5-3 was stable hence it was near to the point of ideal genotype. This study suggests that NR10676-B-5-3 can be grown for higher grain yield production in mid-hills of Nepal.

Keywords: environment, grain yield, Nepal, rice, stability

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1. Introduction

Rice (*Oryza sativa* L.) is the first staple food crop that supported the bulk of the population livelihood, as well as Nepal's national economy. The total area, production and productivity of rice is 1469545 ha, 5151925 t and 3.5 t/ha, respectively in Nepal [1]. Nepal Agricultural Research Council (NARC) has been playing a significant role to improve the rice productivity in the country by developing stable and high yielding rice varieties. In 1972 at Parwanipur the National Rice Improvement Program established to coordinate the research and development

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activities on rice as a key commodity crop which contributes significantly to the national food security and economy [2] [3].To provide the suitable cultivars to farmers living in mid-hills of Nepal, Rice Breeding Unit, Agriculture Botany Division, started the varietal development program since 1975 at Khumaltar. Generating the different genotypes and their evaluation and testing are the common methods in rice breeding programs in Nepal [4]. The evaluation of rice genotypes under different environments is one of the important tasks of rice breeding programs. Multi-location evaluation of genotypes helps the plant breeders to identify the adaptability of a genotype to a particular environment and also the stability of that genotype over various environments [5]. Genotypes evaluated in various locations and over various years have provided significant variations in grain yield due to the response of genotypes to environmental factors [6]. The variability in the grain yield is characterized primarily by the impacts of environment and genotype under the similar conditions of management [7]. The degree to which that character performs is the product of the genotype (G) of the crop, environment (E), and interaction of the genotype G and E (G x E). The evaluation of genotypes for the stability of performance in various environmental conditions for yield has been an integral aspect of any breeding program. Stability is the ability of plants to maintain their yield on changes in environmental conditions. Yield stability is a character inherited through the competitiveness of genetically heterogeneous populations [8]. G × E interactions significantly influence the varieties' phenotype; therefore, the stability study is important to evaluate the performance of varieties in various conditions and to enable plant breeders to choose suitable varieties. The decision regarding release of a variety is generally focused on whether the performance of variety was satisfactory as compared to performance of one or more standard cultivars grown over crop seasons. To increase commercial cultivation over a wide range of agro-climatic conditions in mid and high hills of Nepal, stable crop varieties are needed. Stability analysis has been used by many researchers [9] [10] to decide whether the performance of the genotype is satisfactory. Stability and adaptation studies are useful for releasing a genotype to cultivate in wide environments. Therefore, the objective of the present study was to identify high yielding and stable rice genotypes for mid hills of Nepal. The results of this study enable us to identify suitable rice varieties for farmers' cultivation in mid hills of Nepal.

2. Materials and Methods

2.1. Plant Materials and Experimental Sites

The rice genotypes *viz* NR 11115-B-B-31-3, NR 11139-B-B-B-13-3, NR 10676-B-5-3, NR 11011-B-B-B-B-29, NR 11105-B-B-27, 08FAN10 and Khumal-4 were obtained from Agriculture Botany Division, Khumaltar, Lalitpur, Nepal. The experiments were conducted at Kabre (Dolakha), Lumle (Kaski) and Pakhribas (Dhankuta) of Nepal. The description of experimental locations was given in Table 1. The climatic data during the experimental periods was given in Table 2.

Table 1. Details of Experimental Locations

Experimental location	Geographical details	Soil	References
Kabre (Dolakha)	$86^0$9’ E longitude, $27^0$38’N latitude and 1740 m altitude	Sandy loam soil with pH from 4.5 to 6.2. i.e. slightly acidic	[11]
Lumle, (Kaski)	84°26'01.3"E longitude, 28°03'33.7"N latitude and 1740 m altitude	Loam soil with pH 5.6, i.e. moderately acidic	[12]
Pakhribas (Dhankuta)	87.29°E longitude, 27.04°N latitude and 1334 masl altitude	Sandy loam soil with pH slightly acidic	[13]

Table 2. Climate Data of the Experimental Locations

Months	Kabre			Lumle			Pakhribas		
	Max. Temp. (°C)	Min. Temp. (°C)	Rainfall (mm)	Max. Temp. (°C)	Min. Temp. (°C)	Rainfall (mm)	Max. Temp. (°C)	Min. Temp. (°C)	Rainfall (mm)
July, 2017	25	19	497	24.76	17.47	1702.7	28.20	18.00	50.7
August	27	18	478.1	24.1	17.9	1100.4	27.40	15.30	40.2
September	27.5	17.5	243.2	24.27	19.1	578.6	24.00	15.00	40.2
October	27	12.3	58	22.94	17.37	343.7	26.50	12.00	35.5
November	24.5	9	0	18.86	9.18	2.5	23.81	8.00	0
December	21.5	7.8	0	17.09	7.03	30.9	20.10	5.30	0
Jan-2018	19.3	5.5	6.2	14.21	4.4	4.5	17.50	1.50	2.8
February	24.3	7	3	17.35	7.28	30	21.00	5.00	0
March	24.5	8.3	32	20.68	10.13	82.3	24.60	8.60	17.4
April	26.5	12.5	73.6	21.11	11.75	155.6	26.50	10.60	13.5
May	28.5	13.3	180.3	22.35	14.29	243.5	25.20	10.80	69.5
June	28.8	17	181.2	24.49	17.05	616.6	29.50	16.00	96.8

Source: NARC [14], [15], [16]

2.2. Experimental Design and Agronomic Management Practices

The experimental studies in randomized complete block designs (RCBD) with three replications were performed in two successive years 2017 and 2018 in rainy or summer seasons. The size of the plot was held at 6 m^2. The planting geometry of 20 cm × 15 cm was maintained. Fertilizer and farmyard manure (FYM) were used at the rate of 140:70:40 NPK kg/ha and 10 t/ha respectively as per the recommendation. The full dose of P_2O_5 and K_2O and half dose of N was used as basal dose and the remaining 50% nitrogenous fertilizer was further split into two parts. The first part was applied at the tillering stage and the second part was applied at the booting stage. The grain yield was estimated using the formula adopted by Marahatta [17].

$$\text{Grain yield} \left(\frac{kg}{ha}\right) \text{at } 14\% \text{ moisture} = \frac{(100 - M) \times \text{Plot yield (kg)} \times 10000\ m^2}{(100 - 14) \times \text{Net plot area}, m^2} \quad (1)$$

where: M is the grain moisture content in percentage; Net plot area = 6 m^2

2.3. Statistical Analysis

Every location data was individually accustomed to Analysis of Variance (ANOVA) to examine variances among genotypes for grain yield and pooled across locations to determine G x E interaction. For Eberhart and Russell's model, the significant G × E was used for stability analyses [18]. A genotype with unit regression coefficient (bi=1) and deviation not significantly different from zero ($S^2di=0$) was taken to be a stable genotype with the unit response. The mean comparisons among genotypes means were estimated by the least significant difference (LSD) test at 5% level of significance [19]. The ANOVA was performed using RCBD to derive variance components using GenStat statistical package (12^{th} edition) [20]. The stability analysis was done using GEAR software Version 4.1 [21].

3. Results and Discussion

3.1. Grain Yield at Various Environments

In our study grain yield was influenced by environmental conditions. The rice genotypes significantly varied for their grain yields at Lumle, Kabre and Pakhribas (Table 4). The location differs greatly in altitude, temperature and rainfall variation that affects performance. Rice is cultivated in diverse agroecosystems and its production is greatly affected by its growing environments. The experimental location were diverse in their climatic parameters (temperature and rainfall) (Table 2). Such variation in climate factors over years affected the grain yield performance of rice genotypes. At Lumle, rice genotypes *viz* NR10676-B-5-3 (5.38 t/ha), NR11105-B-B-27 (5.30 t/ha) and NR11115-B-B-31-3 (4.38 t/ha) produced higher grain yield. At Kabre condition genotype namely 08FAN10 produced higher grain yield of 8.23 t/ha followed by NR10676-B-5-3 (7.80 t/ha) and NR11011-B-B-B-B-29 (7.40 t/ha). Similarly the genotypes NR11115-B-B-31-3 (7.34 t/ha) and NR11139-B-B-B-13-3 (7.25 t/ha) produced higher grain yield at Pakhribas condition (Table 3). The pooled data over locations (environments) and years showed that the genotype NR10676-B-5-3 produced the highest grain yield (6.72 t/ha) followed by NR11105-B-B-27 (6.34 t/ha) and NR11115-B-B-31-3 (6.19 t/ha) (Table 5).

Table 3. Combined Analysis of Variance of Grain Yield for Rice Genotypes Evaluated at Three Environments

Source of variation	df	SS	MS	Explained SS%
Genotype (G)	6	12.21	2.04*	6.58
Environment (E)	2	70.02	35.01**	37.74
G × E interaction (GEI)	12	23.59	1.97*	12.72
Error	40	79.70	1.99	
Total	62	185.53		

**Indicates significance at P<0.01 probability level, *Indicates significance at P<0.01 probability level, df=degree of freedom; SS=Sum of square; MS=Mean of square

The interactive effects of the genotype × environment illustrated that genotypes responded differently to environmental variations at locations suggesting that the necessity of testing rice varieties at multiple locations [22]. The factors explained (%) demonstrated that genotype (6.58%), environment (37.74%), and interaction (12.72%) influenced the grain yield of rice (Table 3).

Table 4. Combined Grain Yield Performance of Rice Genotypes in 2017 and 2018

SN	Genotypes	Grain Yield (t/ha)		
		Lumle	Kabre	Pakhribas
1	NR 11115-B-B-31-3	4.83	6.41	7.34
2	NR 11139-B-B-B-13-3	4.52	5.87	7.25
3	NR 10676-B-5-3	5.38	7.8	7.01
4	NR 11011-B-B-B-B-29	4.38	7.4	5.97
5	NR 11105-B-B-27	5.3	7.36	6.36
6	08FAN10	4.36	8.23	4.97
7	Khumal-4	3.26	6.34	6.01
	Grand mean	4.58	7.07	6.42
	F test	*	*	*
	LSD (0.05)	1.447	1.901	1.986
	CV (%)	17.8	15.1	17.4

*Significant at 5% level

3.2. Genotype × Environment Interaction

The pooled analysis of variance for grain yield showed that genotypic variation, genotypes and environment interaction were found significant (Table 4). The environmental/location factor contributed differences in mean grain yield across three locations and two years that may be due to variation in soil types, sowing date, sunshine hours and amount of rainfall, humidity, altitude during the crop life cycle. In pooled analysis genotypes NR10676-B-5-3 (6.72 t/ha), NR11105-B-B-27 (6.34 t/ha) and NR11115-B-B-31-3 (6.19 t/ha) produced the higher grain yield across three locations and two years 2017 and 2018. This result revealed that there was a differential yield performance among genotypes across test environments due to the presence of

GE interaction. The relative contributions of GE interaction effects for grain yield in this study were similar to the findings in other previous studies [23] and [24].

The cumulative mean grain yield analysis showed significant differences among the rice genotypes across the three locations (Table 5). Therefore, the significant value for location showed that the genotypic genetic potentials were predisposed by the surroundings owing to the consequence of diversity in the surroundings.

Table 5. Combined Grain Yield Data Across Three Locations (Kabre, Lumle And Pakhribas) and Two Years (2017 And 2018)

SN	Genotypes	Grain yield (t/ha)
1	NR 11115-B-B-31-3	6.19
2	NR 11139-B-B-B-13-3	5.88
3	NR 10676-B-5-3	6.72
4	NR 11011-B-B-B-B-29	5.93
5	NR 11105-B-B-27	6.34
6	08FAN10	5.85
7	Khumal-4	5.20
	Grand mean	6.02
	LSD (0.05)	0.974
	F test, G	*
	L	**
	G × L	*
	G × Y	*
	L × Y	*
	G × L × Y	*
	CV (%)	16.4

*Significant at 5% level, **Significant at 1% level, G: Genotypes, L: Location, Y: Year

3.3. Stability Analysis

An ideal genotype provides the highest yield in tested environments. For broad selection, the ideal genotypes are those genotypes which have both high mean yield and high stability. An "ideal" view was drawn (Figure 1 and Figure 2) that showed LPNBR1615 was the nearest to the ideal genotype. A genotype closer to the "ideal" genotype is more desirable. The genotypes would be more suitable when they are close to the performance line.

Mean yield performance along with the rank of genotypes across environments indicated that the genotypes had high variation around the mean yield. This result was similar to the result obtained by Sharifi et al. [25].

In order to identify specific or relatively broader adaptation of a rice genotype, studies on the magnitude and patterns of GE interaction effect are very important. The biplot (Figure 3) represented a polygon indicating that the vertex genotypes were NR10676-B-5-3, 08FAN10, Khumal-4, NR11139-B-B-B-13-3 and NR11115-B-B-31-3. The genotypes on the vertexes were the longest distance from the biplot origin and were expected to be the greatest or the worst in one or more environmental conditions. The allocation of potential mega-environments was shown by "which won where" graph. The lines perpendicular to the polygon separated the mega-environments. The NR10676-B-53 and NR11105-B-B-27 were suitable for Lumle; NR11115-B-B-31-3 and NR11139-B-B-B-13-3 for Pakhribbas; and 08FAN10 and NR11011-B-B-B-B-29 for Kabre.

Previously, various stability measurements have been used by Finlay and Wilkinson [26] that have considered linear regression slopes as a measure of stability. Eberhart and Russel [18] stressed the need to consider both linear and nonlinear components in Genotype x Environment Interaction in evaluating the stability of the genotypes. According to this model, the term stable variety has been used for a variety that performs uniformly in all environments. Hence, the stable variety has a high mean (Xi), unit regression (bi=1.0) and the deviations from regression as small as possible ($S^2di=0$). The coefficient of regression (bi) describes the adaptiveness of the evaluated genotypes over the evaluated environments. The varieties having b-value near to unity and higher mean grain yield demonstrate the more average stability.

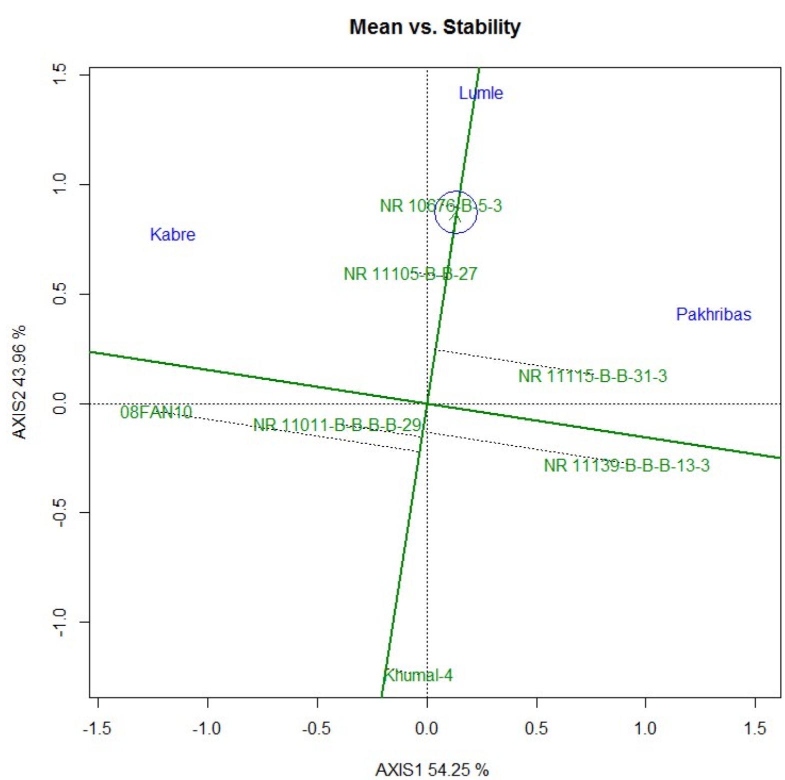

Figure 1. GGE Biplot Showing Ranking of Rice Genotypes for Mean Yield and Stability

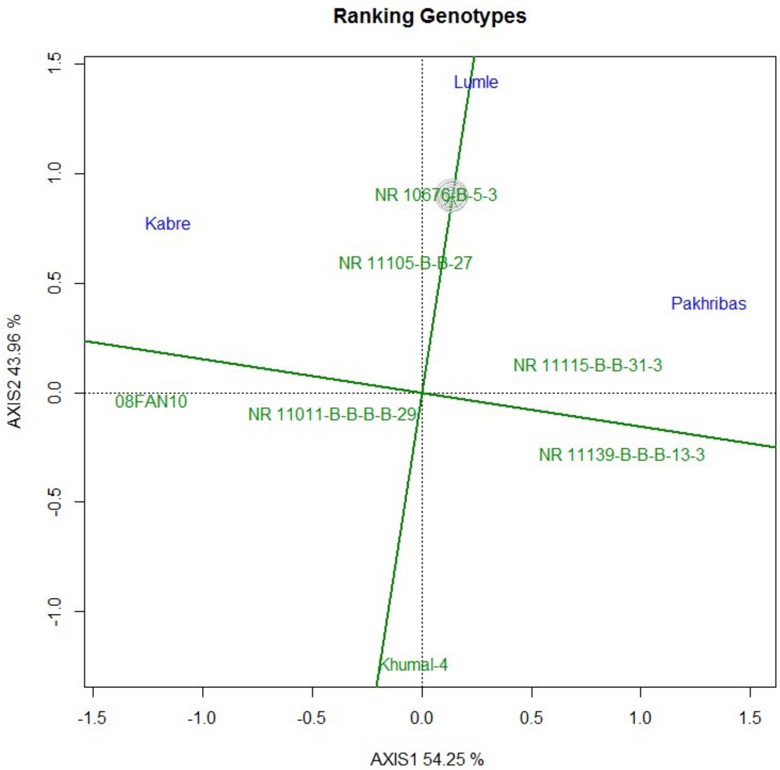

Figure 2: Comparision of Rice Genotypes with Ideal Genotype

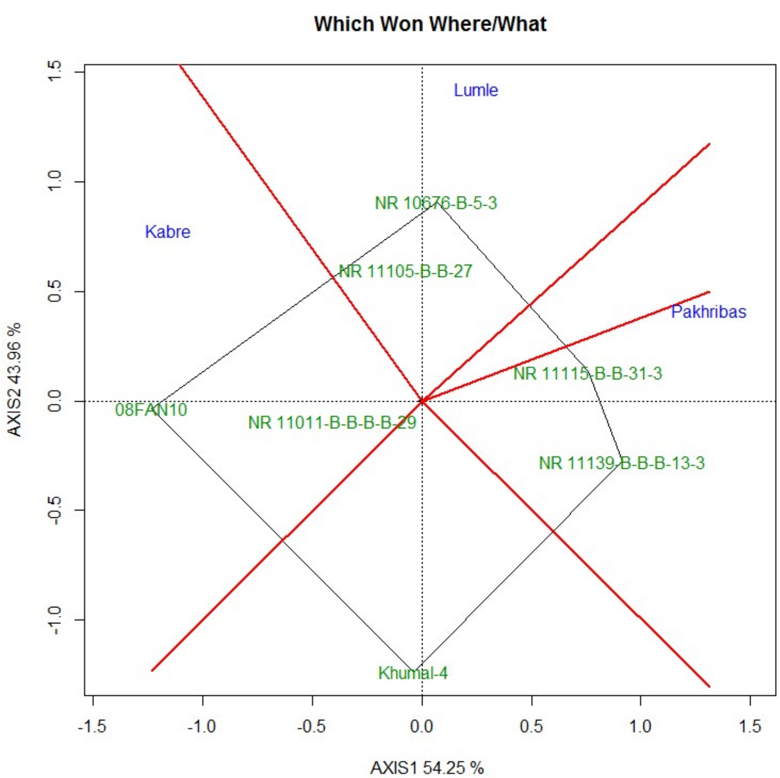

Figure 3. Polygon View of GGE Biplot to the Identification Winning of Rice Genotypes and Their Related Mega Environments

The results (Table 5) showed that genotypes had a higher coefficient of variation which indicated that there was a higher influence of environments in the expression of characters i.e. grain yield for these genotypes. R^2, the coefficient of determination, expresses the proportion of variance in the dependant variable explained by the independent variable. NR 11139-B-B-B-13-3 had the lowest coefficient of determination (R^2=0.5003) which suggested that 50% of the dependent variable was predicted by the independent variable. The R^2 nearly to 1 was desirable. The genotype NR10676-B-5-3 had mean grain yield of 6.72 t/ha and the bi value was 0.95, coefficient of variation (CV) was 11.31% therefore NR 10676-B-5-3 was the most stable genotype (Table 6). Therefore, this genotype was a more desirable genotype.

Table 6. Mean Grain Yield Values (t/ha) and Stability Parameters for Rice Genotypes Across Three Environments/Locations in 2017 and 2018

Genotype	Mean (Xi)	Sd	CV (%)	bi	S^2di	R^2
NR 11115-B-B-31-3	6.1927	1.2655	14.4358	0.7921	0.7719	0.6532
NR 11139-B-B-B-13-3	5.8826	1.3669	15.2361	0.7488	1.5282*	0.5003
NR 10676-B-5-3	6.7288	1.2326	11.318	0.9523	-0.3241	0.9951
NR 11011-B-B-B-B-29	5.934	1.5372	17.9046	1.1538	-0.0517	0.9392
NR 11105-B-B-27	6.3411	1.0283	14.2165	0.7716	-0.2093	0.9387
08FAN10	5.8511	2.0833	19.6023	1.2888*	2.8016*	0.6381
Khumal-4	5.2036	1.6893	18.4643	1.2926*	-0.2025	0.9761

bi = regression coefficient, Sd = Standard deviation, S^2di = the deviations from regression, R^2 = coefficient of determination. (Eberhart and Russell 1966). *Significant at 0.05 probability level

4. Conclusion

Genotype (G) and environment (E) interactions were an important source of rice yield variation. The evaluated rice genotypes were affected by the G × E interaction effects. The climatic factors greatly affected the grain yield of rice genotypes. The highly significant G × E effects suggest that genotypes could be selected for adaptation to specific environments. The NR10676-B-53 and NR11105-B-B-27 were suitable for Lumle; NR11115-B-B-31-3 and NR11139-B-B-B-13-3 for Pakhribas; and 08FAN10 and NR11011-B-B-B-B-29 for Kabre. The stability analysis showed that the genotype NR10676-B-5-3 was the stable and high yielding genotype. This study suggested that farmers could grow NR10676-B-5-3 for higher production in mid-hills of Nepal.

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