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Comparison of GGE biplot and AMMI analysis of multi-environment trial (MET) data to assess adaptability and stability of rice genotypes

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Genotype × Environment (G×E) interaction and stability performance were investigated on paddy yield of eighteen rice genotypes and twelve locations using two well renowned statistical models; genotype main effect and G×E Biplot analysis (GGE) and additive main effects and multiplicative interaction (AMMI) analysis. The aim of this study was to elucidate the performance of some advance rice lines/genotypes at multiple locations in multi environment trials (METs) using GGE biplot and AMMI analyses. The results of GGE biplot and AMMI analyses performed over the data of paddy yield at multiple locations of two years 2014 and 2015 indicated that G×E interaction plays a crucial role in determining the performance of genetic material in METs. The results declare that GGE and AMMI not only provide easy and affective evaluation of genotypes into environment interactions in a number of locations but also a comprehensive understanding of the variability of the target locations. AMMI analyses for data of both years indicated that RRI 7 was the highest priority selected genotype for six locations, NIAB 1175 for four and RRI 3 for three locations. Dhokri and Kala Shah Kaku were the highest yielding, while Faisalabad and Dhokri were the most stable environments in 2014. Likewise, Faisalabad and PARC Islamabad were the highest yielding as well as most stable environments in 2015. Basmati 515 and PS 2 were the most favorable genotypes in 2014 and 2015, respectively for their high paddy yield and stability at all locations. The results further suggested that both models were useful and presented similar interpretations about MET data.

Key words: Genotype main effect and G × E biplot analysis (GGE), additive main effects and multiplicative interaction (AMMI) analysis, rice, fine type, multiple locations.

INTRODUCTION

Rice is being used as staple food by more than three billion of world population which represents 50 to 80% of their daily calorie intake (Khush, 2005; Amirjani, 2011). This population will increase to over 4.6 billion by 2050 (Honarnejad et al., 2000) which will demand more than 50% of rice needs to be produced to cope with the growing population (Ashikari et al., 2005; Srividya et al., 2010). Rice is the second most important staple food

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crop in Pakistan not only in local consumption but also in view of large exports (Anonymous, 2006). In Pakistan, rice was grown on approximately 2.89 million hectares with a total production of 7.01 million tonnes and earned a foreign exchange of worth US$ 1.53 billion. It accounts for 3.2% in value added in agriculture and 0.7% of Gross Domestic Product (Pakistan Economic Survey, 2015).

Rice production in Pakistan is confined in four, more or less distinct agro-ecological zones. Each zone represents diverse edaphic, hydrological and climatic conditions. Genotypes with wide adaptability, which can perform consistently well over a range of environments is required. Crop stability, is the ability of a crop to exhibit minimum interaction with both predictable and unpredictable environments (Qayyum et al., 2000). Rice yield in Pakistan is very low as compared to other rice growing countries of the world. With the passage of time, due to drastic climatic changes, there are developing vast differences in agro-climatic conditions among different locations of Pakistan. These phenomena make new developing rice varieties more unstable when grown under diverse environmental conditions and results in poor yield (Duncan, 1955).

Genotype × Environment (G × E) interaction is important to plant breeder for examining yield stability of genotypes (Davis and Rutgar, 1976). Linnemann et al. (1995) stated that it is important to understand crop development in relation to biophysical conditions and changes in season when selecting well-adapted genotypes and correct planting date. Varieties that show low G × E interaction and have high stable yields are desirable for crop breeders and farmers, because due to their genetic composition their yields are larger that indicates that the environments have less effect on the performance of genotypes. Therefore, evolution of rice varieties that have high yield and stability in performance over a wide range of environments will remain an important criterion in rice breeding (Tai, 1971).

To achieve this goal, innovative statistical techniques like Genotype main effect and G × E biplot analysis (GGE) and additive main effects and multiplicative interaction (AMMI) analysis will be needed to compare the lines and testing environments in order to separate rice genotypes with high adaption capability to diverse environments for accomplishing specific socio-economic and agricultural needs (Prasad and Singh, 1990; McLaren and Chaudhary, 1994; Kueneman, 2006; Khush et al., 1979). The objective of the present study is to present the idea how to interpret results of GGE biplot and AMMI analyses to study G × E interactions and stability in performance of advance fine rice genotypes grown at different locations of Pakistan.

MATERIALS AND METHODS

Studies were conducted under the agro climatic conditions of experimental farm of research area at nine different locations, viz., Dhokri, Dera Ismael Khan, Faisalabad, Gujranwala, for assessing the performance of twelve Basmati rice lines, that is, BR-1, BR-18, BR-23, DR-65, NIAB-1114, NIAB-1175, PK 8431-1-2-1-2-4, PK 8660-13-3-1, PK 8685-5-1-1-1-1, PK BB-4, Rachna-1080, and RRI-7 including two check varieties, that is, Basmati 515 and Super Basmati in 2014. While in the second year 2015, NIAB-1114, NIAB-1175, PK BB-1, PK BB-4, PK 9408-8-1-2-2, RRI-3, and RRI-7 were used including one check variety, that is, PS 2, to be evaluated in Regional Adaptability Yield Trials.

One month old seedlings were transplanted at plant to plant and row to row distance of 20 cm. The experiments were sown in randomized complete block design (RCBD) in a triplicate fashion at each site. To avoid the chance of mortality, two to three seedlings per hill were placed. The fertilizer was applied at the rate of 120 N + 60 P_2O_5 + 0 K_2O kg/ha, whereas in aromatic group at the rate of 80 N + 40 P_2O_5 + 0 K_2O kg/ha. During crop growth stages, standard agronomic practices were followed. The quality characters such as size (length, length/width, length/width × thickness) were carried out according (Kush et al., 1979; Sagar et al., 1988; Kawai and Amano, 1991; Singh, 1997). Paddy yield was recorded after the harvest of the crop. At maturity, yield was recorded and subjected to analysis of variance (ANOVA) as suggested by Steel and Torrie (1980) to determine the significance of genotypes, environments and genotype environment interactions.

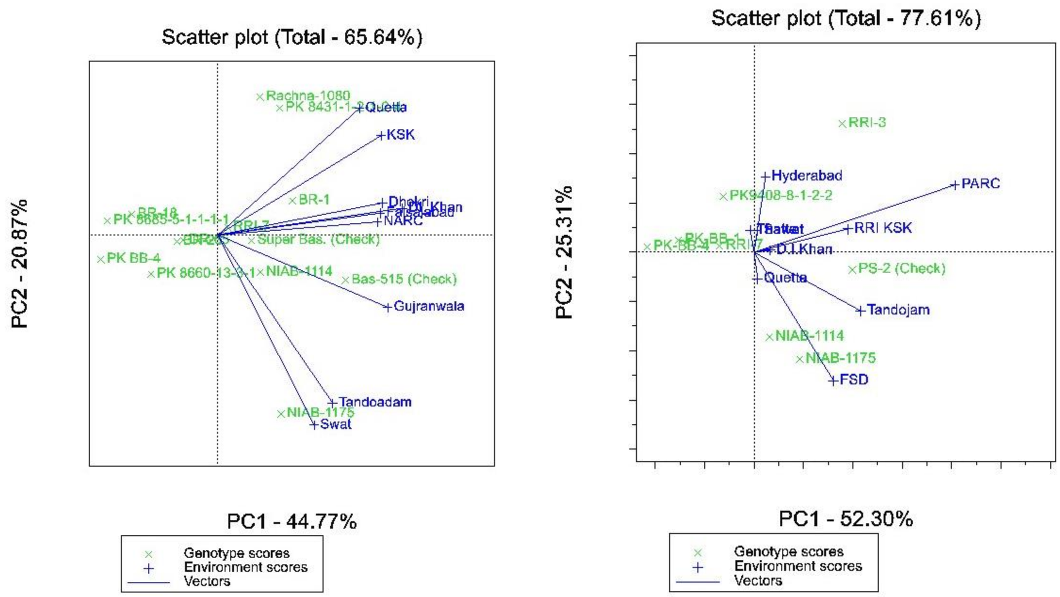
GGE biplot is being rigorously used for analyzing multi-environment trail (MET) data, which provides a working guide for breeders on biplot analysis and interpretation of results (Domitruk et al., 2001). Earlier, many studies have been interpreted using simple statistical techniques. Therefore, advance statistical techniques were used for this MET data in order to interpret three important results necessarily required in multi-location trials such as identifying high yielding and most stable genotype, best test environment and best performing genotype in specific environment. These questions become very hard in such METs that involve a large number of genotypes.

RESULTS AND DISCUSSION

GGE biplot analysis

Biplots graphs (Figure 1a and b) are plotted where aspects of all the Basmati rice genotypes and environments are on the same axes so that the interrelationship can be easily depicted. Therefore, biplot 1a explains 65.64% of the total variations while Figure 1b explains 77.61% of the total variations. In both biplots, all the genotype and environment vectors are drawn showing the specific interactions between genotypes and environments.

Based on Figure 1a and b, it is possible to assess both mean yields and stability performance through biplot environments with shorter/acute angle between their vectors are more correlated while those with larger/obtuse angle are negatively correlated. Shorter the angle, higher the value of positive correlation between two locations. Presence of close associations among the environments suggests that the same information about the behavior of studied genotypes was obtained from other locations and performance of all the genotypes was same at these locations. The location vectors are lines that connect the biplot origin and the markers of test locations and the angle between them is related to the



(a) 2014 **(b) 2015**

Figure 1. Vector view of GGE biplot for relationships among locations/environments during 2014 and 2015.

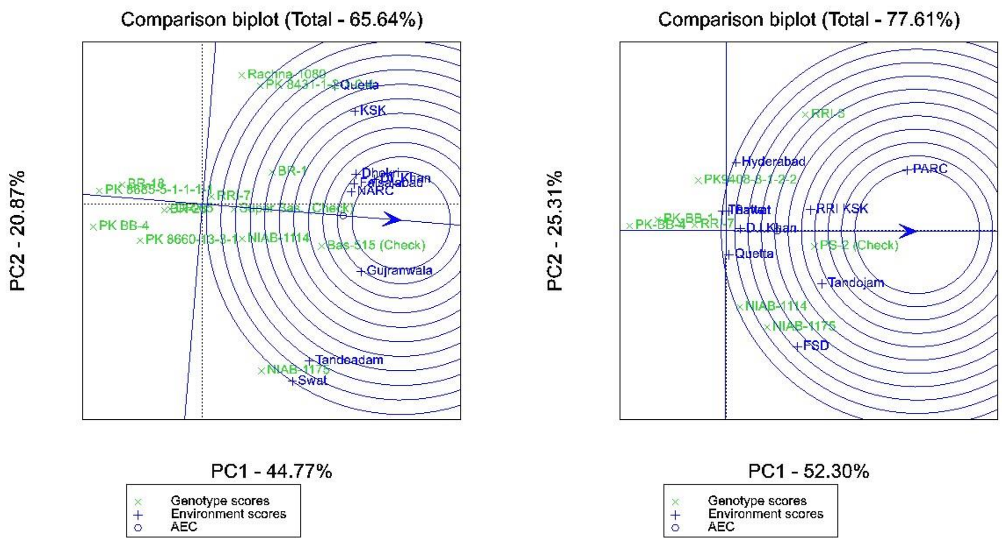
correlation coefficient. Therefore, the results suggest to drop one of these locations in order to secure resources and any other location may be added having different environmental conditions. For example, in the year 2014, locations Dhokri, Faisalabad, D.I. Khan and NARC Islamabad have shorter angles and thus show higher correlation among themselves. Therefore, it will be wiser to consider any one of these locations next year that will be representative of all these locations in order to secure inputs.

GGE biplot can also be used to interpret genotypes with similar response to the target environments. Two genotypes can be easily compared by joining them with straight lines passing through them and biplot origin. Based on Figure 1a and b, it can be visualized that genotypes that have shorter angle or are in close proximities on biplots indicate their similar response to the environments. For example, Rachna-1080 and PK 8431-1-2-1-2-4 showed similar response to environments tested in 2014, while response of NIAB-1175 was very different in comparison with these two. NIAB-1175 and NIAB-1114 have shorter or acute angle between them indicating that these two responded similarly and the differences between them was proportional in all target locations. Genotypes located at more distance from center of biplot are less stable and near to origin genotypes are more stable (Jones, 1926). RRI-7 are more stable than NIAB-1114 in 2015.

An average tester coordinate (ATC) horizontal and vertical axes is drawn such that it passes through the biplot origin and the average location and show the stability and mean yield of each genotype (Yan and Nicholas, 2006). Genotypes and environments on the same parallel line or ordinate have similar yield and a genotype or environment on the right side of the mid-point of ATC vertical axis has higher yield than those of left hand side. Figure 2a and b shows that PK BB-4 was the least yielding genotype among all the studied locations as the angle of its vector is obtuse with respect to all the environment vectors, in both years. While the check variety Basmati 515 was above average in 2014 and PS 2 check variety in 2015, in all the locations as indicated by the longest vector and acute angle with respect to all the other location vectors.

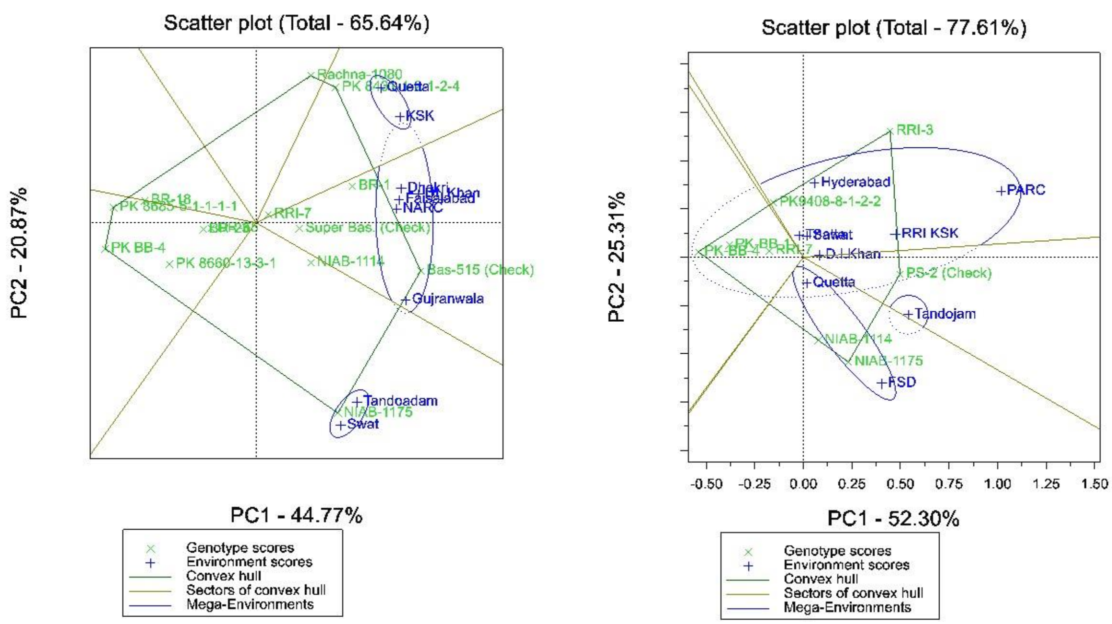
The smaller the absolute length of projection of a genotype, the more stable it is (Fehr, 1987). The biplots in Figure 2a and b further showed that NIAB 1147, Rachna 1080 and PK 8431-1-2-1-2-4 were the least stable genotypes and showed unstable yield performance at all the locations in 2014 as indicated by longer vectors/distance from ATC horizontal. During 2015, NIAB 1175, NIAB 1114 and RRI 3 were the least stable genotypes, as indicated by the longer distances from ATC horizontal. Super Basmati and RRI 7 were the most stable genotypes in 2014, while RRI 7, PK BB-4 and then PS 2 were the most stable in year 2015 as indicated by shorter distances from ATC horizontal axis (Figure 2a and b).

According to the biplot shown in Figure 3a and b, the corner genotypes that are the most responsive ones, can be visually determined. These corner genotypes were PK 8685-5-1-1-1-1, Rachna 1080, Basmati 515, NIAB 1175 and PK BB 4 in 2014 whereas PK BB 4, RRI 3, PS 2 and NIAB 1175 during the next year, 2015. Further, locations



(a) 2014 **(b) 2015**

Figure 2. GGE biplot of ideal genotype and comparison of the genotypes with the ideal genotype (center of the concentric circles) for year 2014 and 2015.



(a) 2014 **(b) 2015**

Figure 3. GGE biplot identification of winning genotypes and their related mega-environments for year 2014 and 2015.

are divided into three sectors or mega-environments in both years. During the first year, 2014, the first sector represents Quetta and Kala Shah Kaku (KSK) with genotype Rachna and PK 8431-1-2-1-2-4 as the most favorable genotypes. The second sector represents Dhokri, D.I.Khan, NARC Islamabad, Faisalabad, Dhokri and Gujranwala, with genotype Basmati 515 as the most favorable. The third sector represents Tondojam and

Table 1. AMMI analysis showing genotype means and scores for years 2014 and 2015.

Genotype	Mean yield (t/ha)	IPCAg[1]	IPCAg[2]
(a) 2014			
Bas-515 (Check)	3.593	16.09175	-4.67193
BR-1	3.526	13.36208	3.71975
BR-18	3.184	6.75859	14.33930
BR-23	3.498	6.88055	13.67038
DR-65	2.929	17.26309	19.30991
NIAB-1114	4.036	-41.06903	-6.34334
NIAB-1175	4.229	-12.91891	-27.36193
PK 8431-1-2-1-2-4	3.712	-41.00750	2.57288
PK 8660-13-3-1	3.618	23.90716	-13.43998
PK 8685-5-1-1-1-1	3.850	4.18955	-35.37994
PK BB-4	3.570	0.78376	6.59637
Rachna-1080	3.712	16.28548	-6.37743
RRI-7	3.758	-23.35728	23.96435
Super Bas. (Check)	3.542	12.83071	9.40160
(b) 2015			
NIAB-1114	3.312	-2.86682	-20.35945
NIAB-1175	3.377	-13.31683	-25.82723
PK-BB-1	2.988	17.94437	3.20326
PK-BB-4	2.845	23.66649	1.55312
PK9408-8-1-2-2	3.089	4.92062	13.44066
PS-2 (Check)	3.632	-23.93160	-4.42479
RRI-3	3.556	-22.82621	30.59649
RRI-7	3.257	16.40997	1.81793

Swat, with genotype NIAB 1175 as the most favorable. Likewise, during second year 2015, first sector represents Hyderabad, PARC Islamabad, Swat, RRI Kala Shah Kaku, D.I. Khan, with genotype RRI 3 as the most favorable genotypes. The second sector represents Quetta and Faisalabad, with genotype NIAB 1175 as the most favorable. The third sector represents Tondojam, with genotype PS 2 as the most favorable. Also, those genotypes within the polygon were less responsive to location than the corner genotypes. For example, in the second sector of locations in 2014, NIAB 1114 and Super Basmati were less responsive to corner winning genotype, that is, Basmati 515 at this specific location.

AMMI analysis

The mean paddy yield (t/ha) value (Table 1a and b) of genotypes averaged over environments indicated that the genotype NIAB 1175 has the highest (4.2 t/ha) paddy yield followed by NIAB 1114 (4.03 t/ha), PK 8685-5-1-1-1-1 (3.85 t/ha) and RRI-7 (3.75 t/ha) during the first year while during the second year PS 2 showed the highest (3.63 t/ha) paddy yield followed by RRI-3 (3.55 t/ha) and NIAB 1175 (3.37 t/ha). The environments mean paddy yield ranged from Dhokri (4.88 t/ha) to Quetta (2.41 t/ha) in 2014, whereas Faisalabad (4.64 t/ha) to DI Khan (0.33 t/ha) during the second year 2015. Table 2a and b shows IPCA[1] and IPCA[2] scores, which represent the adaptability of a genotype over environments and association between genotypes and environment (Albert, 2004). Regardless of the positive of negative signs, genotypes with large scores have high interactions and unstable, whereas genotypes with small scores or close to zero have low interaction and stable (Zobel et al., 1988). Therefore, RRI Kala Shah Kaku and Hyderabad were the most stable and rich environments while Swat and PARC Islamabad are the most unstable and poor environments among all in 2014 and 2015, respectively. The same results are shown in GGE biplot indicated by the length of the vectors.

Based on IPCA[1] scores and multiplicative interaction between IPCAs of genotypes and environment, ranking of the genotypes in each environment can be visualized. Table 3a and b shows the ranking of the genotypes according to their performances in respective environments for the year 2014 and 2015, respectively. The candidate variety RRI-7 performed best in two locations (Dhokri and Faisalabad) in terms of yield and four locations (Thatta, Swat, Quetta and DI Khan) in 2014

Table 2. AMMI analysis showing environment (Location) means and scores for years 2014 and 2015.

District	Mean (t/ha)	Variance (margin = 1236)	IPCAe[1]	IPCAe[2]
(a) 2014				
Dhokri	4.886	119	5.47188	22.63350
DI_Khan	3.079	489	27.12555	12.51417
Faisalabad	3.176	255	4.75110	10.22964
Gujranwala	3.908	139	8.71778	6.49590
KSK	4.659	1148	-3.76996	-45.14122
NARC	2.824	785	-17.25875	-21.22751
Quetta	2.412	125	11.77937	10.90798
Swat	3.920	2388	-62.77031	14.95285
Tandoadam	3.764	555	25.95335	-11.36531
(b) 2015		**Variance (margin =2489)**		
D.I.Khan	0.325	16	9.24895	0.70044
FSD	4.637	541	-5.84538	-33.79006
Hyderabad	4.454	262	9.09141	19.96271
PARC	4.592	1006	-36.86304	17.24029
Quetta	3.668	36	13.70134	-6.71723
RRI KSK	3.369	424	-7.48116	6.08910
Swat	0.934	97	14.83913	5.95706
Tandojam	3.608	365	-12.91098	-15.52964
Thatta	3.725	66	16.21973	6.08733

Table 3. First four AMMI selections per environment for years 2014 and 2015.

Environment	Mean (t/ha)	Score	1	2	3	4
(a) 2014						
DI Khan	3.079	27.13	PK 8660-13-3-1	Rachna-1080	Super Bas. (Check)	Bas-515 (Check)
Tandojam	3.764	25.95	PK 8660-13-3-1	PK 8685-5-1-1-1-1	Rachna-1080	NIAB-1175
Quetta	2.412	11.78	Rachna-1080	Super Bas. (Check)	NIAB-1175	PK 8660-13-3-1
Gujranwala	3.908	8.72	NIAB-1175	Rachna-1080	PK 8660-13-3-1	Super Bas. (Check)
Dhokri	4.886	5.47	RRI-7	BR-23	Super Bas. (Check)	PK BB-4
Faisalabad	3.176	4.75	RRI-7	NIAB-1175	NIAB-1114	Rachna-1080
KSK	4.659	-3.77	NIAB-1175	PK 8685-5-1-1-1-1	NIAB-1114	PK 8660-13-3-1
NARC	2.824	-17.26	NIAB-1175	NIAB-1114	PK 8685-5-1-1-1-1	PK 8431-1-2-1-2-4
Swat	3.920	-62.77	NIAB-1114	PK 8431-1-2-1-2-4	RRI-7	NIAB-1175
(b) 2015						
Thatta	3.725	16.22	RRI-7	RRI-3	PK-BB-1	PK9408-8-1-2-2
Swat	0.934	14.84	RRI-7	RRI-3	PK-BB-1	PS-2 (Check)
Quetta	3.668	13.70	RRI-7	NIAB-1114	NIAB-1175	PS-2 (Check)
D.I.Khan	0.325	9.25	RRI-7	PS-2 (Check)	RRI-3	NIAB-1114
Hyderabad	4.454	9.09	RRI-3	RRI-7	PK9408-8-1-2-2	PS-2 (Check)
Faisalabad	4.637	-5.85	NIAB-1175	NIAB-1114	PS-2 (Check)	RRI-7
RRI KSK	3.369	-7.48	RRI-3	PS-2 (Check)	NIAB-1175	NIAB-1114
Tandojam	3.608	-12.91	PS-2 (Check)	NIAB-1175	NIAB-1114	RRI-3
PARC	4.592	-36.86	RRI-3	PS-2 (Check)	NIAB-1175	PK9408-8-1-2-2

and 2015, respectively. Likewise, genotype NIAB-1175 performed best in three locations (Gujranwala, Kala Shah Kaku and NARC) and one location (Faisalabad) in 2014 and 2015, respectively.

Conclusion

Genotype NIAB 1175 has the highest (4.2 t/ha) paddy yield followed by NIAB 1114 (4.03 t/ha), PK 8685-5-1-1-1-1 (3.85 t/ha) and RRI-7 (3.75 t/ha) in the first year while in the second year, PS 2 showed the highest (3.63 t/ha) paddy yield followed by RRI-3 (3.55 t/ha) and NIAB 1175 (3.37 t/ha). The environments mean paddy yield ranged from Dhokri (4.88 t/ha) to Quetta (2.41 t/ha) in 2014, whereas Faisalabad (4.64 t/ha) to DI Khan (0.33 t/ha) in the second year 2015.

PK BB-4 was the least yielding genotype among all the studied locations in both the years. Super Basmati and RRI 7 were the most stable genotypes in 2014, while RRI 7, PK BB-4 and then PS 2 were the most stable in year 2015. While the check variety Basmati 515 was above average in 2014 and PS 2 check variety in 2015, in all the locations. NIAB 1147, Rachna 1080 and PK 8431-1-2-1-2-4 were the least stable in 2014, while NIAB 1175, NIAB 1114 and RRI 3 were the least stable genotypes in 2015. RRI Kala Shah Kaku and Hyderabad were the most stable and rich environments, while Swat and PARC Islamabad are the most unstable and poor environments among all in 2014 and 2015, respectively.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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