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# GENOTYPE X ENVIRONMENT INTERACTION ANALYSIS FOR GRAIN YIELD IN NEW PLANT TYPE (NPT) WHEAT DERIVATIVES

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## SUMMARY

Twenty three new plant type (NPT) wheat derivatives with three checks were evaluated for grain yield and stability under timely (TSI) and late-sown irrigated environments (LSI).The experiment was conducted in six environments at two locations in 2006-07 and 2007-08. Analysis of variance of stability for grain yield through Eberhart and Russell's model and AMMI analysis revealed highly significant differences among genotypes and environments and significant genotype x environment (G x E) interaction (GEI). Highly significant mean squares due to environment + genotype x environment interactions (E + G x E) in the Eberhart and Russell model revealed that genotype interacted considerably with environmental conditions that existed under TSI and LSI condition. Further partitioning of E + G x E effects indicated that E (linear), G x E (linear) component, and pooled deviation were highly significant for grain yield. Some genotypes showed linear effects over environments, while others showed significant deviation from a linear relationship. Partitioning of G x E interaction into principal components in AMMI analysis revealed that the two interaction principal component axes accounted for 90.4% of the total GEI variation. Genotypes DL 893, DL 901, DL 966 and PBW 343 exhibited high *per se* performance under TSI, whereas DL 880, DL 882, DL 886, DL 892, DL 893, DL 901 and DL 927 recorded high *per se* performance under LSI at both locations. Based on *per se* performance, regression coefficient, and deviations from regression as well as AMMI analysis, genotypes DL 886, DL 901, DL 924, DL 927, DL 966 and DL 960 were found to be stable and are adaptable to both TSI and LSI. Both Eberhart and Russell and AMMI results are comparable in identifying stable genotypes for the test environments.

**Keywords:** wheat, *Triticum aestivum*, stability, grain yield

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## INTRODUCTION

Wheat (*Triticum aestivum* L.) is a major crop that contributes to the nutrient supply of the world's population. In India, it is the second most important food crop planted to an area of 29 million hectares and with production amounting to 92.3 million tons (FAO 2012). Grain yield is a function of genotype, environment and genotype x environment interaction (GEI) (Trethowan and Crossa, 2007; Sial *et al.,* 2007; Hamam *et al.,* 2009). An understanding of environmental and genotypic causes of GEI is important at all stages of crop improvement as they have a bearing on parent selection, selection based on yield as well as cultivar adaptation. GEI studies thus provide a basis for selection of genotypes that are suitable for general or specific cultivation; they also provide information about the effect of environment on cultivar performance (Khan *et al.,* 2007). Further, the yield plateau in wheat productivity is now of great concern. It necessitates the development of high-yielding genotypes with wide or specific (local) adaptation to the environments within a target area (Rane *et al.,* 2007). The rice-wheat cropping system is predominant in the wheat-growing regions of India wherein delay in rice harvest also delays the sowing of wheat. There is a need to develop and identify wheat genotypes for different sowing conditions. In addition, the wheat crop is being increasingly grown in areas where ambient temperatures exceed the optimum temperature (Samrat *et al*., 2010). Sowing time has significant impact on the performance of genotypes in terms of yield and yield components (Hamam *et al*., 2009; Samrat *et al*., 2010). The present study was undertaken to analyze GEI and evaluate the stability of new plant type (NPT) wheat derivatives for grain yield. NPT wheat was developed using a local germplasm called "Sirsa farm wheat" (SFW) and released wheat and genetic stocks at Indian Agricultural Research Institute (IARI), New Delhi (Singh *et al.,* 2001).Timely sown irrigated (TSI) and late sown-irrigated (LSI) conditions were the environments chosen to evaluate the performance (yield and yield component) of genotypes at two locations. The aim was to identity stable and responsive genotypes across environments sown at different dates.

## MATERIALS AND METHODS

Twenty-six NPT wheat derivatives, along with three national checks (PBW 343, HD 2329 and Raj 3765), were evaluated for stability of grain yield across two sowing times/locations/seasons (Table 1). The experiment was conducted at two locations: New Delhi (IARI Research Farm) and IARI Regional Research Station, Pusa at Bihar. At New Delhi, the experiment was carried out for two successive years (2006-07 and 2007-08) in two environments, TSI and LSI. The Pusa experiment was carried out for a year (2007-08) in two environments. The six environments in the present study are designated thus: Env1: TSI-New Delhi 2006/2007; Env2: LSI-New Delhi 2006/2007; Env3: TSI-New Delhi 2007/2008; Env4: LSI-New Delhi 2007/2008; Env5: TSI-Bihar 2007/2008; and Env6: LSI-Bihar 2007/2008 (Table 1). At both locations, the experiment was laid out in randomized block design with three replications. Each entry was plotted in four 5-m-long rows. The rows were spaced 23 cm apart and plant-to-plant distance within a row was 10 cm. Standard cultivation practices prescribed for wheat under irrigated conditions were followed precisely. The plot yields were converted into quintals per hectare (q/ha). The data were subjected to a separate analysis of variance (ANOVA) for grain yield for each test location. Bartlett's test of homogeneity was used for difference estimation between test locations and was found to be non significant, indicating homogeneity of the test environments. A combined ANOVA was performed for grain yield. The mean squares of GEI for yield and yield components were used to test the effect of genotypes. The statistical analysis was carried out using software SAS 9.2 version. Multivariate analysis, namely AMMI analysis, was carried out as previously described (Gauch, 1992; Gauch *et al*., 2008). AMMI, which stands for additive main effect and multiplicative interaction, is widely used for G x E investigation of multi-environment cultivar traits (Crossa *et al.,* 1990). The model was additive and the results of AMMI analysis are shown in common graphs called biplots (Gauch and Zobel, 1997). The data were also subjected to regression analysis using a model proposed by Eberhart and Russell (1966). The regression of each genotype in each environment on an environmental index and a function of the squared deviations from its regression would provide estimates of stability parameters: the regression coefficient ($b_i$) and mean square deviations ($S^2d_i$) from linear regression. The mean sum of squares due to varieties and locations was tested against the mean sum of squares due to varieties x location. The mean sum of squares due to varieties x location was tested against pooled error. Pooled deviations were tested against pooled error. The results from both analyses were compared and are presented.

**Table 1.** Details of environments (ENV) under study and sowing dates of timely sown (TSI) and late sown irrigated (LSI) wheat crops.

| Location | Latitude/ longitude | Year | Date of sowing TSI | LSI |
|---|---|---|---|---|
| New Delhi, India | 28.63°/ | 2006-07 | 28 Nov 2006 (Env1) | 23 Dec 2006 (Env2) |
| | 77.15° | 2007-08 | 23 Nov 2007 (Env3) | 26 Dec 2007 (Env4) |
| Pusa (Bihar),India | 25.98°/ | 2007-08 | 11 Nov 2007 (Env5) | 14 Dec 2007 (Env6) |
| | 35.65° | | | |

## RESULTS AND DISCUSSION

The pooled analysis of variance for grain yield revealed that genotypes, environments, and GEI were highly significant ($P < 0.0001$). Analysis of variance of stability for grain yield through Eberhart and Russell's model and AMMI analysis also revealed highly significant differences among genotypes, environments and significant GEI (Table 2). The variance due to environment was significant, which indicates a distinct and differential effect of sowing condition. The variance for genotypic effect was also highly significant implying differential responses of the genotypes selected for the study. The variance due to G x E had shown significant interaction for grain yield reflecting differential responses of genotypes to different environments — some genotypes showed wider adaptability while others exhibited specific adaptation. The two environments, TSI and LSI were studied and the variation in the present study indicates that sowing time has significant influence on yield performance of genotypes. These results confirm the findings of Shantha *et al.* (2007) and Samrat *et al.* (2010). Highly significant mean squares due to E + GEI revealed that genotype interacted considerably with environmental conditions that existed under TSI and LSI conditions (Samrat *et al.*, 2010). Further partitioning of E + G x E effects in Eberhart and Russell's model revealed that E (linear), G x E (linear) component, and pooled deviation were highly significant for grain yield, indicating that some genotypes showed linear effects over environments, while others showed significant deviation from the linear relationship. Menon *et al.* (1997) reported that the environmental linear component was significant for grain yield, while Madariya *et al.* (2001) reported both linear and nonlinear components of GEI for grain yield. In the AMMI analysis, the GEI effect is further partitioned into principal component axis effects and the model separates the additive main effects from the interaction using principal component analysis by which interaction patterns can be analyzed (Table 2). Environments accounted for the largest proportion of the sum of squares (60.83%) for grain yield, followed by G x E (22.18%) and genotypes (16.97%). It can be inferred from the large sum of squares for environment that the environments were diverse, with large differences among environmental means causing most of the variation in grain yield (Inamullah *et al.,* 2006).

**Table 2.** Analysis of variance of the Eberhart and Russell model and AMMI for grain yield stability among NPT wheat derivatives under timely and late sowing conditions.

| Eberhart and Russell (1966) model | | | | AMMI analysis | | | |
|---|---|---|---|---|---|---|---|
| Source | df | SS | MSS | Source | df | SS | MSS |
| Rep within Env | 12 | 39.43 | 3.29 | Model | 155 | 1587.42 | 102.31** |
| Genotypes | 25 | 2692.21 | 107.69 | Genotype | 25 | 2692.22 (16.97) | 107.69** |
| E+ (G x E) | 130 | 13165.2 | 101.27 | Environment | 5 | 9646.72 (60.83) | 1929.34** |
| E | 5 | 9646.71 | 1929.34 | G x E | 125 | 3518.48 (22.18) | 28.15** |
| G x E | 125 | 3518.48 | 28.15 | PCA I | 29 | 1661.45 (47.22) | 57.29** |
| E (lin) | 1 | 9646.71 | 9646.71 | PCA II | 27 | 1167.48 (33.18) | 43.24** |
| G x E(lin) | 25 | 1188.04 | 47.52 | PCA III | 25 | 366.53 (10.42) | 14.66* |
| Pooled deviation | 104 | 2330.44 | 22.41 | Residual | 44 | 323.02 | 7.34 |

**= significant at probability level of less than 0.01; *= significant at probability level of less than 0.05; figures in parentheses are percentage contribution to the sum of squares; G= genotypes; E= environments.

The mean grain yield across locations was 33.58 q/ha (range was between 26.74 q/ha [DL935] and 40.85 q/ha [DL882]) (Table 3). At New Delhi during the 2006-07 crop season, the mean grain yield of 44.81 q/ha and a yield range between 37.88 q/ha (DL974) and 52.85 q/ha (DL892) were recorded under TSI. With LSI, mean grain yield was 24.85 q/ha (range: from 13.42 q/ha [DL974] to 33.94 q/ha [DL892]). However, in 2007-08 at the same location (New Delhi), mean grain yields of 32.53 q/ha and 24.67 q/ha were recorded under TSI and LSI, respectively. The corresponding ranges were 22.61 (DL954) - 42.42 q/ha (DL899) and 14.78 (DL973) - 33.33 q/ha (DL882). At Pusa, during 2007-08, mean grain yields of 42.81 q/ha and 31.79 q/ha and yield ranges from 28.86 (DL898) to 57.36 q/ha (PBW 343) and from 26.74 (DL935) to 40.85 q/ha (DL882) were recorded under TSI and LSI, respectively. Some genotypes had superior performance over the high-yielding check PBW 343 under both conditions. DL893, DL901, DL966, and PBW 343 showed high *per se* performance under TSI conditions, whereas DL880, DL882, DL886, DL892, DL893, DL901, and DL927 recorded high *per se* performance under LSI conditions at both locations.

**Table 3.** Mean performance and stability parameters for grain yield among NPT wheat derivatives (as per the Eberhart and Russell model).

| Genotype | Grain yield (q/ha) | | | | | | | Stability parameters | |
|---|---|---|---|---|---|---|---|---|---|
| | New Delhi (2006-07) | | New Delhi (2007-08) | | Pusa Bihar (2007-08) | | Overall mean | | |
| | TSI | LSI | TSI | LSI | TSI | LSI | | bi | S²Di |
| DL880 | 38.96 | 32.36 | 40.69 | 29.99 | 32.39 | 35.94 | 35.06 | 0.22* | 12.88** |
| DL882 | 41.59 | 33.03 | 38.98 | 33.33 | 45.14 | 53.04 | 40.85 | 0.44 | 49.52** |
| DL886 | 46.47 | 33.25 | 33.68 | 32.89 | 50.59 | 38.55 | 39.24 | 0.81 | 6.07 |
| DL892 | 52.85 | 33.94 | 38.75 | 29.41 | 38.2 | 36.23 | 38.23 | 0.76 | 19.89** |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| DL893 | 49.97 | 29.27 | 32.55 | 28.70 | 51.32 | 40.58 | 38.73 | 1.13 | 6.99* |
| DL898 | 40.96 | 29.28 | 32.03 | 28.55 | 26.86 | 36.81 | 32.41 | 0.27 | 25.71** |
| DL899 | 45.36 | 28.84 | 42.42 | 29.19 | 42.36 | 30.44 | 36.43 | 0.78 | 12.72** |
| DL901 | 46.26 | 31.22 | 42.04 | 30.58 | 46.17 | 35.36 | 38.61 | 0.79 | 1.36 |
| DL902 | 43.38 | 22.32 | 29.08 | 25.94 | 37.94 | 24.35 | 30.50 | 0.91 | 5.59 |
| DL903 | 38.55 | 20.94 | 36.73 | 27.25 | 34.26 | 23.48 | 30.20 | 0.66 | 22.42** |
| DL908 | 49.32 | 18.72 | 31.71 | 17.97 | 29.35 | 22.90 | 28.33 | 1.15 | 42.70** |
| DL910 | 45.17 | 27.97 | 29.48 | 21.16 | 49.87 | 32.17 | 34.30 | 1.20 | 10.98* |
| DL919 | 47.58 | 25.27 | 29.75 | 23.62 | 30.87 | 23.19 | 30.05 | 0.85 | 32.82** |
| DL924 | 49.12 | 27.82 | 29.33 | 23.29 | 44.3 | 35.36 | 34.87 | 1.12 | 4.98 |
| DL927 | 41.87 | 25.23 | 32.10 | 26.42 | 46.11 | 36.23 | 34.66 | 0.92 | 3.62 |
| DL935 | 47.80 | 18.81 | 22.84 | 17.10 | 35.15 | 18.73 | 26.74 | 1.31 | 22.40** |
| DL940 | 49.55 | 19.77 | 24.35 | 19.71 | 35.81 | 21.16 | 28.39 | 1.28 | 22.98** |
| DL954 | 41.72 | 21.61 | 22.61 | 19.57 | 40.09 | 20.58 | 27.70 | 1.12 | 11.45** |
| DL966 | 46.06 | 24.23 | 33.90 | 24.06 | 51.88 | 32.17 | 35.38 | 1.29 | 4.40 |
| DL960 | 44.03 | 29.10 | 37.71 | 28.75 | 44.29 | 30.44 | 35.72 | 0.81 | 1.47 |
| DL974 | 37.88 | 13.42 | 28.43 | 19.42 | 45.04 | 26.09 | 28.38 | 1.28 | 12.65** |
| DL976 | 38.54 | 23.98 | 32.78 | 28.12 | 56.49 | 46.38 | 37.72 | 1.02 | 82.61** |
| DL973 | 40.49 | 15.62 | 28.29 | 14.78 | 43.62 | 27.54 | 28.39 | 1.38* | 1.39 |
| PBW343 (c) | 47.45 | 21.80 | 36.35 | 19.71 | 57.36 | 40.44 | 37.19 | 1.58 | 30.04** |
| HD2329 (c) | 48.55 | 15.16 | 28.61 | 17.97 | 43.26 | 26.67 | 30.04 | 1.55* | -2.83 |
| RAJ3765 (c) | 45.55 | 23.19 | 30.51 | 24.06 | 54.20 | 31.59 | 34.85 | 1.37 | 14.80** |
| Environmental index | 11.23 | -8.72 | -1.05 | -8.90 | 9.23 | -1.79 | | | |
| Grand mean | 44.81 | 24.85 | 32.53 | 24.67 | 42.81 | 31.79 | 33.58 | | |
| CV (%) | 10.36 | 16.66 | 7.79 | 12.68 | 10.53 | 10.43 | 17.61 | | |
| CD at 5% | 7.62 | 6.79 | 4.16 | 5.13 | 7.39 | 5.44 | 3.87 | | |

**Stability analysis by Eberhart and Russell (1966)**

According to Eberhart and Russell (1966), a stable genotype is one with a high mean, a regression coefficient of unity ($\beta_i = 1$), and a minimum deviation from the regression coefficient ($S^2d_i$) = 0 or close to these values of non-significant deviation. Where $\beta_i > 1$*, the genotype is responsive to favorable environment. If $\beta_i < 1$*, the genotype performs well despite an unfavorable environment. Thus, this analysis allows the identification of stable genotype for a trait across environments and of genotypes that are most responsive to favorable or unfavorable environment. A higher value of environmental index indicating a relatively more favorable environment is required for final manifestation of yield. In the present study, the environmental index was positive for timely sown irrigated condition except for one under TSI at New Delhi (2007-08). Under late sown irrigated environment, it was negative. The effect of environment (timely and late sowing) in the final manifestation of grain yield and adaptability of genotypes was also indicated. Based on performance *per se*, the regression coefficient, and deviations from regression, genotypes DL886, DL901, DL924, DL927, DL966 and DL960 were found to be stable and adaptable to both timely and late-sown environments, suggesting that these genotypes may be better exploited in terms of grain yield.

**AMMI analysis**

AMMI analysis permits the estimation of interaction effects of genotype in each location and it helps identify the genotypes best suited for specific environments. Selection of genotypes can be obtained with the aid of biplot analysis. The results of AMMI analysis are shown in common graphs called biplots and are useful in supporting breeding program decisions such as specific adaptation and selection of environments (Gauch and Zobel, 1997; Ebdon and Gauch, 2002). Admassu *et al*. (2008), in accordance with Zobel *et al*. (1988), proposed that two interaction principal component axes for the AMMI model was sufficient for a predictive model and, therefore, the interaction of 26 wheat genotypes with six test environments was predicted by the first two interaction principal components. The first interaction principal component axis (PCA I) covered 47.22% of GEI sum of squares, whereas, the second and third interaction principal component axes (PCA II and PCA III) explained further 33.18% and 10.42% of sum of squares of this interaction. The first two interaction principal component axes accounted for 90.4% of the total GEI (Table 2). Biplot mean yield vs. PCAI (Figure 1) and PCAI vs. PCAII (Figure 2) were used to identify stable genotypes for yield and yield components. Genotypes DL882, DL886, DL893, and DL901 produced higher yields and DL882 recorded the highest (Fig. 1). In contrast, genotypes DL935, DL940, DL908, DL919 and DL903 are poor yielders. DL882 showed superior performance at Pusa with an average yield of 53.05 q/ha under late-sown conditions and 45.14 q/ha under TSI. The average yield was 40.85 q/ha across locations. In addition, this genotype also showed superior performance (better than checks) in Delhi in both environments.

The IPCA scores of a genotype in AMMI analysis indicate the stability or adaptation over environments. The greater the IPCA scores, either negative or positive (as it is a relative value), the more specifically adapted is the genotype to certain environments. The more the IPCA scores approximate zero, the more stable or adapted the genotypes are over the entire environments sampled (Crossa *et al.,* 1990). Kaya *et al.* (2006) stated that genotypes having PC1 scores > 0 were recognized as high-yielding and those having PC1 scores < 0 were regarded as low-yielding. In the present study, genotypes DL882, DL893, DL910, DL924, DL927, DL954, DL966, DL974, DL976, DL973 and check varieties PBW 343, HD 2329, and Raj 3765 showed PCA1 values greater than zero. Environments 1 and 5 were found to be favorable for yield expression, while environments 4 and 2 were highly unstable. Hence, TSI condition is highly suitable for realizing potential yield, although some genotypes performed better under late-sown condition as well. Akdamar *et al*. (2002), Ozturk *et al.* (2006) and Subedi *et al.* (2007) also reported that planting date has significant influence on yield. The four groupings were evident in the biplot, depending on the signs of the genotypic and environmental scores (Fig. 1): Group 1 = DL973, HD 2329, and DL954 with average yield and positive PCA1 scores; Group 2 = DL886, DL893, DL976, and PBW 343 with high mean and positive PCA 1 scores; Group 3 = DL882, DL901, and DL892 with high mean and negative PCA1 scores and Group 4 = DL935, DL940, and DL902 with average to low yield and negative PCA1 scores. A genotype showing high positive interaction in an environment is therefore better adapted to that environment.

The nature of interaction of genotypes with environments can be known from AMMI II biplot (Figure 2), which is generated by using genotypic and environmental scores of the first PCA (IPCA I) and second PCA (IPCA II). It is evident from the biplot that differential response of genotypes to environments existed — i.e., some genotypes were stable across test environments, while others were more adaptable to specific environment(s). Genotypes placed near the plot origin were less sensitive than those located far from it. The genotypes Raj 3765, DL976, and PBW 343 showed a favorable response to the environment 5 (TSI at Pusa); the genotypes DL882, DL898, and DL880 are suitable for environment 1 (TSI-Delhi); HD 2329, DL935, and DL940 were for environment 6 (LSI-Pusa), while DL919, DL898, and DL880 were suitable for environments 2, 3, and 4. Details of the environments are presented in Table 1. The genotypes DL960, DL924, DL901, DL886, and DL927 were found to be less sensitive to environmental interactive forces as they are plotted close to the origin, indicating that these genotypes are stable across environments.

The 26 wheat genotypes used in this study differed in response to the environments with respect to the grain yield and the influence of environment was predominant in the manifestation of yield. Both Eberhart and Russell (1966) as well as AMMI analysis results are comparable in the identification of stable genotypes for the test environments. AMMI clearly differentiated genotypes with narrow specific adaptability and other genotypes with superior stable performance across environments. We identified NPT genotypes with stable performance and yields comparable to that of the high-yielding cultivars used as checks, thus providing useful material to wheat breeders.

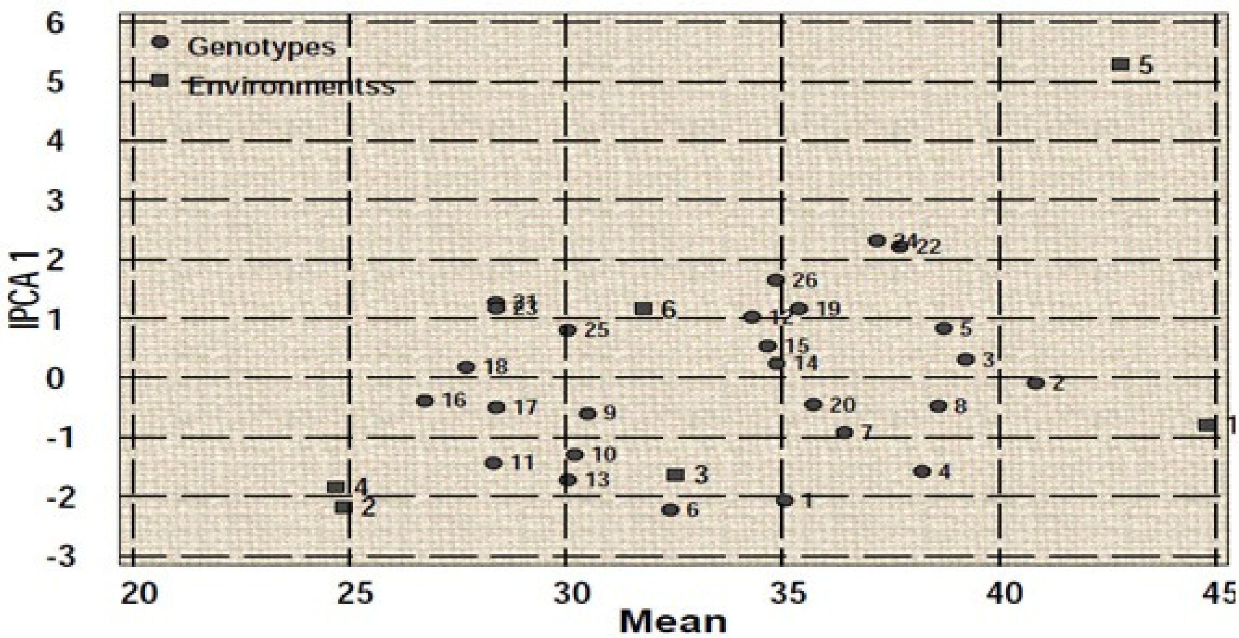


**Figure 1.** Biplot (AMMI) for grain yield obtained by plotting IPCA 1 scores for genotypes and environments against mean grain yield (q/ha). Genotypes or environments with low (positive or negative) or PCA1 scores nearer zero indicate less interaction while large PCA1 scores indicate high interaction. **(**1- DL880, 2 - DL882, 3 - DL886, 4 - DL892, 5 - DL893, 6 - DL898, 7 - DL899, 8 - DL901, 9 - DL902, 10 - DL903, 11 - DL908, 12 - DL910, 13 - DL919, 14 - DL924, 15 - DL927, 16 - DL935, 17 - DL940, 18 - DL954, 19 - DL966, 20 - DL960, 21 - DL974, 22 - DL976, 23 - DL973, 24 - PBW343, 25 - HD2329 and 26 - RAJ3765).

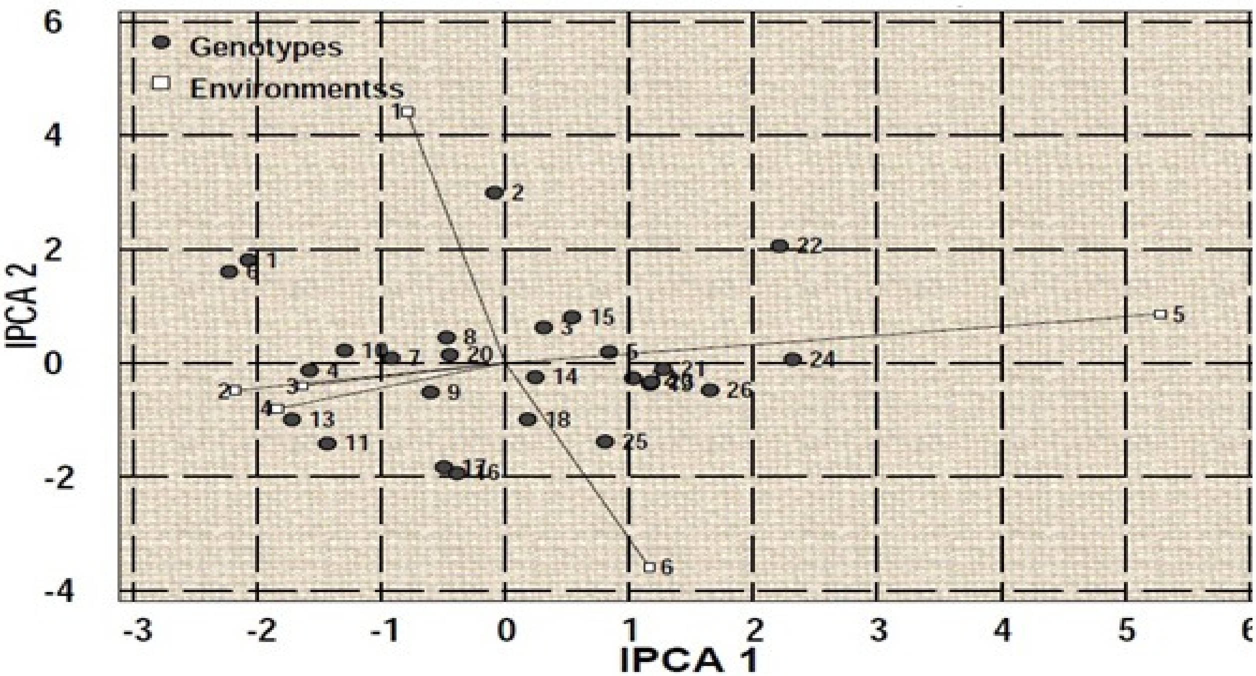


**Figure 2.** Interaction BIPLOT (AMMI II) for grain yield obtained by using genotypic and environmental scores of IPCA1 and IPCA2. Genotypes and environments close to the origin are less sensitive to environmental conditions and are stable (1 - DL880, 2 - DL882, 3 - DL886, 4 - DL892, 5 - DL893, 6 - DL898,7 - DL899, 8 - DL901, 9 - DL902, 10 - DL903, 11 - DL908, 12 - DL910, 13 - DL919, 14 - DL924, 15 - DL927, 16 - DL935, 17 - DL940, 18 - DL954, 19 - DL966, 20 - DL960, 21 - DL974, 22 - DL976, 23 - DL973, 24 - PBW343, 25 - HD2329 and 26 - RAJ3765)

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