# Genotype-Environment Interaction Studies Over Seasons for Kernel Yield in Maize (*Zea mays L.*)

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***Abstract*—** *Forty five single cross hybrids derived from 10 inbred lines of maize were tested for kernel yield across three seasons viz., rabi, summer and kharif adopting AMMI model to assess the G × E interaction and to identify the stable hybrids for kernel yield. Seasons were found to contribute to the variations in performance of hybrids indicating that unpredictable seasonal conditions are one of the constraints in selecting superior and adaptable hybrids. The hybrids viz., BML 6 × PDM 1474, BML 7 × DFTY, BML 15 × PDM 1474, DFTY × Heypool, DFTY × PDM 1452 and Heypool × PDM 1474 across seasons recoded significantly higher kernel yield over general mean. The first two interaction principal components viz., PC 1 (74.00 %) and PC 2 (16.00 %) of GGE-biplot analysis explained 90.00 % of total variation caused by genotype × environment interaction. Hybrids viz., DFTY × Heypool, BML 15 × PDM 1452 and Heypool × PDM 1474 were the vertex hybrids or winners indicating that they are the best performing or responsive hybrids. Summer season was found to be the most discriminating season in culling the unproductive ones and also to save time and expenditure. Kharif and rabi seasons were the most representative testing seasons for kernel yield. Hybrids viz., BML 2 × DFTY, BML 2 × Heypool, BML 6 × PDM 1474, BML 7 × DFTY, BML 15 × PDM 1474, DFTY × PDM 1452, Heypool × PDM 1474 and PDM 1452 × PDM 1474 were more stable as well as high yielding, whereas DFTY × Heypool, BML 15 × PDM 1452, BML 15 × Heypool and DFTY × PDM 1474 were more variable but high yielding. The hybrids BML 6 × PDM 1474, BML 7 × DFTY, BML 15 × PDM 1474, DFTY × Heypool and Heypool × PDM 1474 were located near to ideal genotype with high mean and stability and could be ranked as desirable hybrids for kernel yield.*

***Keywords*— *Maize, AMMI GGE biplot analysis, Kernel yield, Genotype × environment interaction*.**

## I. INTRODUCTION

Maize is an important cereal crop worldwide and is ranked third after wheat and rice for its nutritional quality and uses Cassamon,; Ali *et al*, 2014. It is mostly used as a food, feed, forage, green fuel, vegetable oil and starch and is the backbone of the poultry feed industry. Kernel yield is a quantitative character, which depends on several yield contributing factors. Genotype × environment interaction reduces the association between the phenotype and genotype which in-turn reduces the selection response (Yan and Kang, 2003). Genotype–environment interactions may cause inconsistencies in genotype ranking across environments. Therefore, testing of identification and interpretation of G × E interaction is essential to make genetic progress (Kang, 2002 and Crossa, 2012). In the process of breeding, newly developed hybrids should be tested in multiple environments to determine the performance and stability before their commercial release. Multi environment trials aids in identification and recommendation of superior stable genotypes in mega environments. Seasons were found to contribute to the variations in performance of hybrids indicating that unpredictable seasonal conditions are one of the constraints in selecting superior and adaptable hybrids. AMMI model combines analysis of variance for the genotype and environment main effects with principal components analysis of the G × E interactions (Gauch and Zobel, 1996). It is useful in statistical analysis of comparative experimental yield clarify the effect of genotype in the environment, patterns and relationship of genotypes and the environment and also for improving the precision of yield estimation (Zobel *et al*, 1988; Crossa *et al*., 1990 and Annicchiarico, 2002). The present study was carried out to identify superior experimental hybrids as well as to select the best environment (Season) for testing hybrids developed in the maize breeding through AMMI biplot method.

## II. MATERIAL AND METHODS

Forty five single cross hybrids developed from 10 inbred lines (BML 2, BML 6, BML 7, BML 15, DFTY, Heypool, PDM 1416, PDM 1428, PDM 1452 and PDM 1474) of maize through diallel mating design were evaluated for their performance over three seasons *viz.*, *rabi*, *summer* and *kharif* from 2016-17 to 2017-18 at Agricultural Research Station, Perumallapalli, A.P. The experiment was laid out in a randomized block design with three replications with five meters row length. A spacing of 75 × 20 cm in *kharif* and 60 × 20 cm in *summer* and *rabi* between rows and plant to plant, respectively was followed. The two seeds per hill were dibbled and thinning operation was carried out one week after germination to maintain single plant per hill. All the recommended package of practices were adopted in raising a healthy crop. Data were recorded for 15 morpho-physiological and yield contributing characters on five randomly selected plants and whole plot basis in each replication. The mean values for different characters were analysed according to Panse and Sukhatme (1978). The AMMI model (The Additive Main Effects and Multiplicative Interaction) was used to assess the G × E interaction (Hybrids × Seasons) according to Gauch and Zobel (1996). Statistical data analysis was performed using Genstat 12$^{th}$ computer statistical program (Genstat, 2009). AMMI analysis was performed in Excel biplot Macros (Johnson and Bhattacharya, 2020).

## III. RESULTS AND DISCUSSION

Pooled mean data analysis of variance over seasons was carried out after testing for homogeneity of error variances using Bartlett,s test. Pooled analysis of the variance for kernel yield was presented in Table 1. Partitioning of total sum of squares to the additive (genetic) and non-additive (ecological) component through analysis of variance indicated the significant differences among hybrids, seasons and hybrids × seasons interactions. The expression of the character not only depends on genetic factors but also on the external environment (Borojevic, 1965). The results of analysis of variance reveal that the proportion of the total variance of kernel yield attributable to seasons (41.66 %) was higher than the hybrids (34.28 %) and hybrids × seasons interaction (12.29 %) (Table 1). Significant hybrids × seasons interaction indicated that rank of genotypes varry at all the three seasons.

**TABLE 1**
**POOLED DATA ANALYSIS OF VARIANCE FOR KERNEL YIELD (g plant$^{-1}$) OF MAIZE OVER SEASONS**

| S.No | Source of variation | DF | Mean sum of squares | Per cent contribution (%) |
|---|---|---|---|---|
| 1 | Hybrids | 44 | 909.32** | 34.28 |
| 2 | Seasons | 2 | 24310.68** | 41.66 |
| 3 | Hybrids × Seasons | 88 | 163.01** | 12.29 |
| 4 | Pooled Error | 264 | 51.11 | 1.19 |
| 5 | Total | 404 | 116713.89 | |

***Note: per cent contribution were worked out based on sum of squares; *Significant at 5% level, **Significant at 1% level***

Kernel yield among hybrids ranged from 103.93 (BML 15 × PDM 14298) to 146.70 (BML 7 × DFTY) with a mean of 129.90 g in *rabi*; from 96.27 (BML 7 × BML 15) to 142 57 (Heypool × PDM 1474) with a mean of 126 26 g in *kharif* and from 86.94 (PDM 1428 × PDM 1452) to 129.03 (DFTY × Heypool) with a mean of 105.18 g per plant in *summer*. Pooled mean across seasons varied from 98.77 (BML 15 × PDM 1428) to139.19 (Heypool × PDM 1474) with a general mean of 120.56 g per plant. The hybrids *viz.*, BML 6 × PDM 1474, BML 7 × DFTY, BML 15 × PDM 1474, DFTY × Heypool, DFTY × PDM 1452 and Heypool × PDM 1474 across seasons recoded significantly higher kernel yield over general mean (Table 2).

**TABLE 2**
**MEAN PERFORMANCE OF MAIZE HYBRIDS ACROSS SEASONS FOR KERNEL YIELD (g plant$^{-1}$) IN MAIZE**

| S.No | Hybrid(s) No. | Parentage | *Rabi* | *Summer* | *Kharif* | Mean over season |
|---|---|---|---|---|---|---|
| 1 | H1 | BML2×BML6 | 135.50 | 102.27 | 138.63 | 125.47 |
| 2 | H2 | BML2×BML7 | 142.73 | 108.23 | 131.60 | 127.52 |
| 3 | H3 | BML2×BML15 | 124.77 | 95.73 | 119.73 | 113.41 |
| 4 | H4 | BML2×DFTY | 129.17 | 107.40 | 133.17 | 123.24 |
| 5 | H5 | BML2×Heypool | 143.88 | 116.33 | 128.23 | 129.48 |
| 6 | H6 | BML2×PDM1416 | 127.50 | 96.93 | 136.67 | 120.37 |
| 7 | H7 | BML2×PDM1428 | 116.13 | 110.90 | 117.27 | 114.77 |
| 8 | H8 | BML2×PDM1452 | 128.57 | 97.27 | 131.60 | 119.14 |
| 9 | H9 | BML2×PDM1474 | 131.33 | 118.00 | 132.37 | 127.23 |
| 10 | H10 | BML6×BML7 | 120.43 | 94.87 | 118.47 | 111.25 |
| 11 | H11 | BML6×BML15 | 114.87 | 94.67 | 118.52 | 109.35 |
| 12 | H12 | BML6×DFTY | 138.90 | 117.10 | 120.10 | 125.37 |
| 13 | H13 | BML6×Heypool | 126.03 | 107.83 | 130.83 | 121.57 |
| 14 | H14 | BML6×PDM1416 | 137.57 | 105.47 | 130.50 | 124.51 |
| 15 | H15 | BML6×PDM1428 | 122.30 | 98.57 | 120.53 | 113.80 |
| 16 | H16 | BML6×PDM1452 | 137.53 | 106.33 | 124.03 | 122.63 |
| 17 | H17 | BML6×PDM1474 | 145.83 | 122.93 | 132.13 | 133.63 |
| 18 | H18 | BML7×BML15 | 135.10 | 91.13 | 96.27 | 107.50 |
| 19 | H19 | BML7×DFTY | 146.70 | 126.47 | 138.40 | 137.19 |
| 20 | H20 | BML7×Heypool | 134.43 | 90.49 | 135.53 | 120.15 |
| 21 | H21 | BML7×PDM1416 | 107.80 | 90.00 | 117.48 | 105.09 |
| 22 | H22 | BML7×PDM1428 | 120.62 | 108.40 | 118.13 | 115.72 |
| 23 | H23 | BML7×PDM1452 | 136.07 | 91.80 | 120.57 | 116.14 |
| 24 | H24 | BML7×PDM1474 | 122.07 | 113.33 | 131.67 | 122.36 |
| 25 | H25 | BML15×DFTY | 129.40 | 92.47 | 135.93 | 119.27 |
| 26 | H26 | BML15×Heypool | 143.90 | 100.33 | 131.27 | 125.17 |
| 27 | H27 | BML15×PDM1416 | 110.47 | 99.03 | 108.73 | 106.08 |
| 28 | H28 | BML15×PDM1428 | 103.93 | 90.07 | 102.30 | 98.77 |
| 29 | H29 | BML15×PDM1452 | 144.73 | 108.93 | 139.80 | 131.16 |
| 30 | H30 | BML15×PDM1474 | 143.77 | 125.73 | 141.53 | 137.01 |
| 31 | H31 | DFTY×Heypool | 143.20 | 129.03 | 138.93 | 137.06 |
| 32 | H32 | DFTY×PDM1416 | 111.03 | 111.93 | 120.80 | 114.59 |
| 33 | H33 | DFTY×PDM1428 | 128.83 | 114.43 | 136.37 | 126.54 |
| 34 | H34 | DFTY×PDM1452 | 143.40 | 120.27 | 135.37 | 133.01 |
| 35 | H35 | DFTY×PDM1474 | 138.17 | 97.53 | 139.73 | 125.14 |
| 36 | H36 | Heypool×PDM1416 | 120.73 | 96.75 | 126.90 | 114.79 |
| 37 | H37 | Heypool×PDM1428 | 124.13 | 107.83 | 121.40 | 117.79 |
| 38 | H38 | Heypool×PDM1452 | 138.80 | 104.97 | 138.63 | 127.47 |
| 39 | H39 | Heypool×PDM1474 | 145.77 | 129.23 | 142.57 | 139.19 |
| 40 | H40 | PDM 1416 × PDM 1428 | 105.97 | 97.67 | 104.00 | 102.54 |
| 41 | H41 | PDM 1416 × PDM 1452 | 114.53 | 93.63 | 113.43 | 107.20 |
| 42 | H42 | PDM 1416 × PDM 1474 | 138.73 | 99.53 | 131.10 | 123.12 |
| 43 | H43 | PDM 1428 × PDM 1452 | 114.07 | 86.94 | 105.87 | 102.29 |
| 44 | H44 | PDM 1428 × PDM 1474 | 133.67 | 102.67 | 129.33 | 121.89 |
| 45 | H45 | PDM 1452 × PDM 1474 | 142.40 | 111.73 | 130.70 | 128.28 |
| | | **Grand Mean** | **129.90** | **105.18** | **126.60** | **120.56** |

The hybrids × seasons interaction was further partitioned in to two principal components (PCA 1 and PCA 2) through AMMI analysis. The first two interaction principal components *viz*., PC 1 (74.00 %) and PC 2 (16.00 %) of GGE-biplot analysis explained 90.00 % of total variation caused by genotype + genotype × environment interaction and hence is considered satisfactory. The use of GGE biplot analysis helps in determining stable performing hybrids for kernel yield. Hybrids in different ecological conditions possessing the higher value of the first component close to zero were noted as stable (Sabaghniaa *et al*. 2006) .The high value of PCA 2 indicates that the best expression of the character in a specific environmental conditions (Bozovic *et al*., 2018). In this regard, AMMI is more suitable in the initial statistical analysis of yield trials which provides estimate of G × E interactions and summarizes the various pattern and relationships among genotypes and environments (Crossa *et al*., 1990). PCA scores of hybrids showed both positive and negative values in the present study.

The GGE biplot analysis which provides graphical display is considered as an innovative methodology or applied plant breeding (Yan *et al*. 2000). The which-won-where pattern, relationships among test seasons and hybrids were visualized using their respective GGE biplots. GGE analysis was performed to study the relationship between and among seasons. The principal components of GGE biplots for kernel yield of hybrids evaluated in three seasons *viz*., first principal component (PCA 1) and the second principal component (PCA 2) sores were plotted against X axis Y axis, respectively. The polygon view of tested hybrids during three seasons was presented in Fig 1. All three seasons fell into one sector, whereas hybrids were grouped in all the sectors indicating that a single cultivar had the highest yield in all the environments. Hybrids *viz*., 31 (DFTY × Heypool), 29 (BML 15 × PDM 1452) and 39 (Heypool × PDM 1474) were the vertex hybrids or winners indicating that they are the best performing or responsive hybrids (Fig. 1).

Lengths of season vectors are proportional to standard deviation of genotype yield in a corresponding treatment. Seasons having long vectors classify hybrids more when compared to seasons with short vector. *Summer* season was the most discriminative season for kernel yield. The test seasons presenting shorter angles were the most representative ones. Accordingly, in the present study *rabi* and *kharif* seasons were found most representative seasons for kernel yield (Fig. 2).

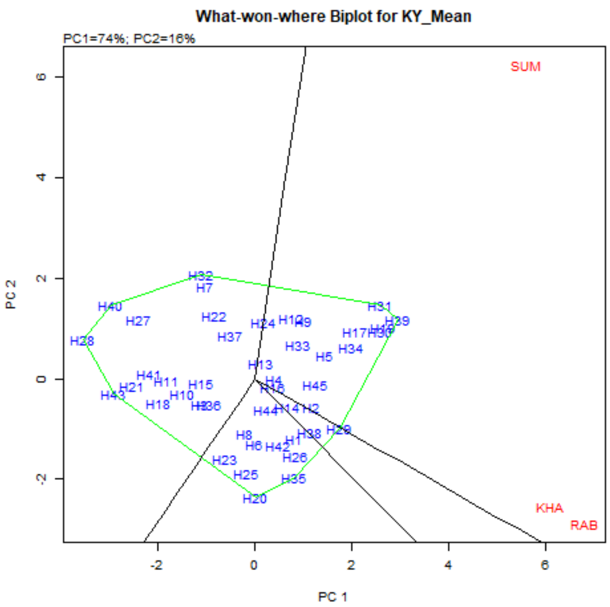


**FIGURE 1: Which won where pattern of GGE biplot for kernel yield in maize**

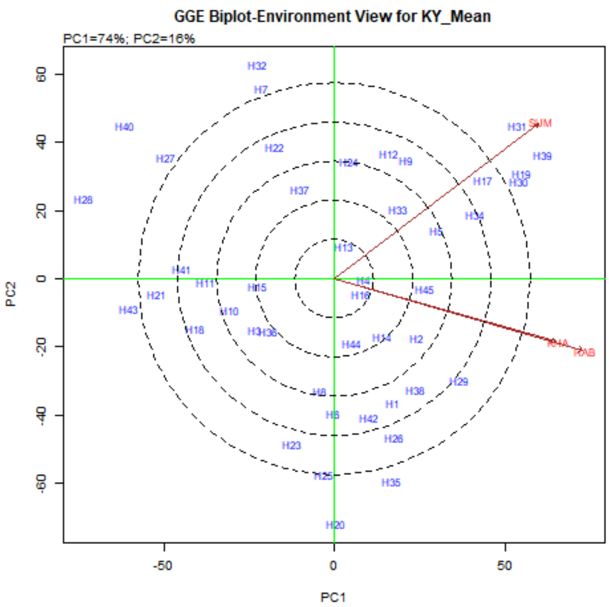


**FIGURE 2: Discriminativeness *vs* representativeness of seasons for kernel yield in maize**

Yield performance and stability of hybrids was evaluated by an average environment coordination (AEC) method. Hybrids *viz*., 4 (BML 2 × DFTY), 5 (BML 2 × Heypool), 17 (BML 6 × PDM 1474), 9 (BML 7 × DFTY), 30 (BML 15 × PDM 1474), 34 (DFTY × PDM 1452) and 45 (PDM 1452 × PDM 1474) were more stable as well as high yielding, whereas 31 (DFTY × Heypool), 29 (BML 15 × PDM 1452), 26 (BML 15 × Heypool) and 35 (DFTY × PDM 1474) were more variable but high yielding (Fig. 3). Kaplan *et al*. (2017), Mebratu *et al*., (2019), Garoma *et al*., (2020) and Ramesh Kumar *et al*., (2020) have also reported that GGE Biplot method can be used to reliably in the evaluation of different maize genotypes grown in different environments.

Genotypes with high average yield with relatively stable in performance across environments is referred as ideal genotypes and such genotypes are present at the center of concentric circle in GGE-biplot. Hybrids ranking on the basis of mean yield and stability in comparison to ideal genotype were depicted in Fig 4. Hybrids *viz*., 17 (BML 6 × PDM 1474), 19 (BML 7 × DFTY), 30 (BML 15 × PDM 1474), 31 (DFTY × Heypool), 34 (DFTY × PDM 1452) and 39 (Heypool × PDM 1474) were located near to ideal genotype and could be ranked as desirable hybrids stable with high mean yield and stable in performance for kernel yield.

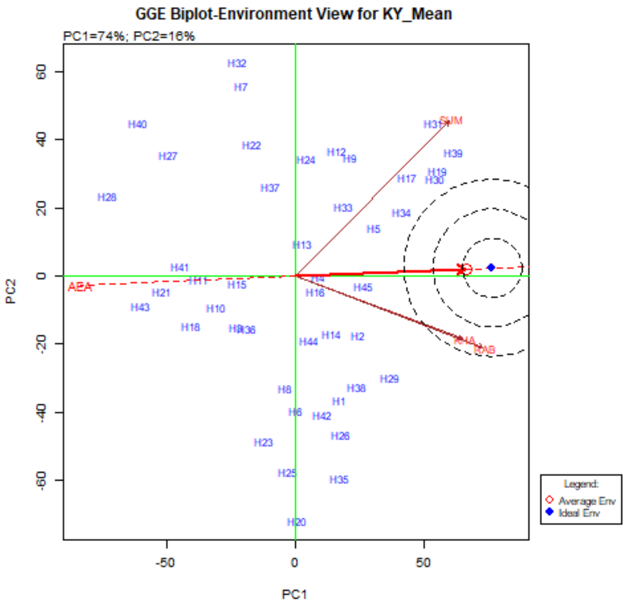


**FIGURE 3: Mean vs Stability for kernel yield in maize**

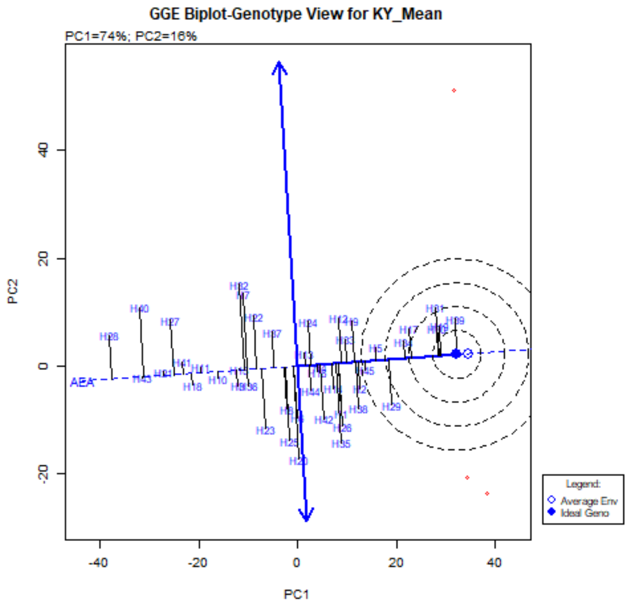


**FIGURE 4: Ranking pattern of hybrids in relation to ideal genotype for kernel yield in maize**

## IV. CONCLUSIONS

Seasons were found to contribute to the variations in performance of hybrids indicating that unpredictable seasonal conditions are one of the constraints in selecting superior and adaptable hybrids. The hybrids *viz*., BML 6 × PDM 1474, BML 7 × DFTY, BML 15 × PDM 1474, DFTY × Heypool, DFTY × PDM 1452 and Heypool × PDM 1474 across seasons recoded significantly higher kernel yield over general mean. Hybrids *viz*., DFTY × Heypool, BML 15 × PDM 1452) and Heypool × PDM 1474 were the vertex hybrids or winners indicating that they are the best performing or responsive hybrids. *Summer* season was found to be the most discriminating season in culling the unproductive ones and to save time and expenditure. *Kharif* and *rabi* seasons were the most representative testing seasons for kernel yield. Hybrids *viz*., BML 2 × DFTY, BML 2 × Heypool, BML6 × PDM 1474, BML 7 × DFTY, BML 15 × PDM 1474, DFTY × PDM 1452, Heypool × PDM1474 and PDM 1452 × PDM 1474 were more stable as well as high yielding. Hybrids close to the ideal genotype were ranked as the ones with high mean and phenotypic stability. The hybrids *viz*., BML 6 × PDM 1474, BML 7 × DFTY, BML 15 × PDM 1474, DFTY × Heypool and Heypool × PDM 1474 were located near to ideal genotype with high mean and stability and could be ranked as desirable hybrids for kernel yield.

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