Evaluating tropical single cross maize hybrids for adaptability and commercial value

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Abstract

Stability analysis was carried out to study stability in performance and genotype x environment interactions for sixty single cross hybrids along with three checks viz., 900M Gold, CP 818 and NK 6240 in three research farms of Foliage Crop Solutions Private Limited viz., Attur (Tamilnadu), Hosur (Tamilnadu), and Renebennur (Karnataka) under irrigated conditions during 2011-13. Data were recorded on different morphological and yield parameters viz., days to 50% silking, days to maturity, plant height, number of leaves, ear length, number of kernels row^{-1}, number of kernels ear^{-1}, hundred seed weight, and grain yield and the mean was used for statistical analysis. Analysis of variance carried out for all the characters revealed that the variance due to genotypes was highly significant for all the characters studied in all the three environments. Pooled analysis of variance for stability done using Eberhart and Russel model of stability revealed that the variance due to genotypes, environments and environment components were highly significant for all the characters studied. However, it was found that the variance due to genotype x environment (linear) component was non-significant only for ear length and number of kernel rows and significant for the remaining characters.

Keywords: maize, base populations, stability analysis

Introduction

Maize (*Zea mays* L) is a versatile crop that adapts easily to a wide range of production environments (Gerpacio and Pingali, 2007). Maize is the third most important crop in the world, after wheat and rice, in terms of growing area, production and grain yield (Shiri et al, 2010). Maize contributes more than 800 million tonnes annually to the global food basket which is the highest among the cereal food crops. Among the maize growing countries, USA stands first followed by China accounting for 35% of the total maize produced in the world. In India, maize is the third most important food crop next to rice and wheat. It is grown in an area of 8.67 million ha with a production of 22.26 million tonnes and productivity of 2.56 tonnes ha^{-1} (Directorate of Maize Research, 2013). The projected demand for maize in India is expected to be 42 million tonnes by the year 2025, out of which 21% will be used for food (Sain Dass et al, 2009).

Since maize is a highly cross pollinated crop it offers great scope for exploitation of heterosis by development of hybrids. But the performance of these hybrids are not the same at all the places. Hence the plant breeder has to select hybrids which perform consistently across all the environments. Since the phenotype of the hybrid is the result of Genotype (G) x Environment (E), such G x E interaction effect causes problem to the breeder in selecting a genotype with consistent performance across environments. Genotype x Environment interactions pose major problem in developing new cultivars and phenotypically stable genotypes, because the environmental condition varies from year to year/region to region. Wide adaption to the particular environment and consistent performance of recommended genotypes is one of the main objectives in breeding programme. A genotype is considered to be stable if it possess an unchanged or least changed performance regardless of any variation in the environmental conditions. Such stabilty analysis in maize has been reported by many authors like Showemimo, (2007), Rahman et al (2010) and Shri (2013). Hence the assessment of stability or desirability among genotypes assumes importance. Of the various models available for assessment of stability such as Eberhart and Russel (1966), Perkins and Jinks (1968) and Freeman and Perkins (1971) models, the model proposed by Eberhart and Russell is widely employed by plant breeders.

Tollenaar and Lee (2002) reported that high-yielding maize hybrids can differ in yield stability and that yield stability and high grain yield are not mutually exclusive. Thirteen maize hybrids and two checks were evaluated for their yield stability using Eberhart and Russell's stability parameters at three diverse locations of North Western Himalayan region by Lata et al

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Table 1 - Analysis of variance for individual environments for biometric characters.

Characters	Location	Source of Variation	Replication	Genotypes	Error	SE d±	CV
		df	2	64	124	-	-
Days to 50% silking	Attur	2.05	5.50**	0.69	0.68	1.56	2.05
	Hosur	7.35**	4.06**	0.44	0.54	1.14	7.35**
	Ranebennur	2.73	8.62**	2.23	1.22	2.48	2.73
Days to maturity	Attur	1.93	54.84**	2.02	1.16	1.5	1.93
	Hosur	3.35**	37.16**	0.57	0.62	0.74	3.35**
	Ranebennur	1.5	45.98**	2.49	1.29	1.6	1.5
Plant height	Attur	332.51**	870.14**	59.3	6.29	3.35	332.51**
	Hosur	14773.70**	1061.04**	165.09	10.49	5.57	14773.70**
	Ranebennur	316.47	911.41**	132.06	9.38	6.99	316.47
Number of leaves	Attur	3.64**	0.86**	0.2	0.37	3.09	3.64**
	Hosur	2.99**	1.28**	0.47	0.56	4.78	2.99**
	Ranebennur	5.04**	1.69**	0.33	0.47	4.4	5.04**

* - Significant at 5% level; ** - significant at 1% level

(2010). They found that the hybrids PMZ 4, Vivek 21, 110-08-01, and BISCO 1141 showed high mean performance for grain yield coupled with average regression coefficient and least deviation from regression coefficient and hence were identified as stable over different locations. Rahman et al (2010b) conducted stability analysis to study the performance and genotype x environment interactions for 18 maize hybrids across three locations of Pakistan namely Peshawar, Baffa and Pirsabak. Based on yield performance, the Hybrid «DK-1 x EV-9806» was found the highest yielder across the three locations followed by hybrid AGB-108, while the lowest yield was observed for hybrid CSCY. Hybrid AGB-108 was comparatively stable for grain yield across the locations.

Mosa et al (2011) studied the grain yield stability of five promising white single cross maize hybrids and four yellow three way cross hybrids together with three commercial checks. Based on the Eberhart and Russell's stability parameters, the single cross hybrids SC Sk101, SC Sk105, and SC Sk106 were identified for release in Egypt since they showed stable grain yield over three way cross hybrids and checks under varying environments. An experiment was conducted by Karadavut and Akilli (2012) to determine the genotype-environment interaction and also the stable corn cultivar for grain yield in Turkey. The study for two years at three different locations revealed that the cultivar three was the most stable one with high mean yield of 9.4 t ha^{-1} across the environments together with preferred regression coefficient near to unity and deviation from regression value around zero. Nadagoud et al (2012) assessed the stability of 20 promising inbred maize lines along with two established inbred lines as checks at three locations and they found a number of inbreds as stable for different characters. Among them, the inbreds 2089, 2090, 2070, 2036, 2119, 2033, and 2024 were identified as stable ones for grain yield per plant based on Eberhart and Russel's stability parameters.

The first single cross hybrid «Paras» developed at the Punjab Agricultural University, Ludhiana paved the way for intensive single cross hybrid development in the country and during the last 15 years the focus has been on this (Sai kumar et al, 2012). The large scale growing of single cross hybrids has improved the average productivity by 73 kg ha^{-1} $year^{-1}$ which is two-three times higher than the productivity improvement recorded during 1950-2000 (Yadav, 2013). The present investigation was carried out in order to understand the changes in the relative performance of different maize inbred lines across different environments i.e., genotype x environment interactions and to find out the stable inbred lines which could be further used in hybrid development programme.

Materials and Methods

Sixty single cross hybrids obtained by crossing fifteen lines and four testers in isolated crossing blocks formed the base materials for this study. Three standard checks viz. 900M Gold, CP 818 and NK 6240 were included to compare the stability of trial hybrids. The trials were conducted at the research farms of Foliage Crop Solutions Private Limited situated in three different locations namely Attur (Tamilnadu), Hosur (Tamilnadu) and Renebennur (Karnataka) under irrigated conditions. Attur is located in Salem district, Tamilnadu, India. The mean maximum temperature was 25°C - 42°C, minimum temperature was 19°C - 25°C and average annual rainfall was 939 mm. The location Hosur is in Krishnagiri district, Tamilnadu, India where average annual rainfall was 830 mm and mean temperature range was 17.1°C - 36.0°C. Ranebennur is located in Haveri district, Karnataka, India where the temperature in the area was ranging from 17°C - 42.2°C. The average annual rainfall of the location was 592 mm.

The sixty hybrids with three standard checks were raised in a randomized block design with three replications with a spacing of 60 x 25 cm. All the cultural practices with need based plant protection measures were followed. Farm yard manure was applied @12.5 t ha^{-1} to the experimental field before last ploughing. Inorganic fertilizers were applied at the rate of 250 kg N:75 kg P_2O_5:75 kg K_2O ha^{-1}. Full dose of P_2O_5 and K_2O were applied as basal dose just before sowing while N was applied in three splits. Around 25% N was applied as basal, 50% on 25^{th} day after sowing and the remaining 25% on 45^{th} day after sowing.

Observations were recorded on nine morphological characters viz., days to 50% silking, days to ma-

Table 2 - Analysis of variance for individual environments for yield characters.

Characters	Location	Source of Variation	Replication	Genotypes	Error	SE d±	CV
		df	2	64	124	-	-
Ear length	Attur	5.78	8.55**	2.51	1.3	9.02	5.78
	Hosur	4.15**	8.18**	0.27	0.42	3.14	4.15**
	Ranebennur	1.96**	10.12**	0.29	0.44	3.49	1.96**
Number of kernel rows	Attur	3.75	5.42**	1.44	0.98	7.92	3.75
	Hosur	0.06	7.95**	0.44	0.54	4.3	0.06
	Ranebennur	2.26	4.62**	1.91	1.13	9.21	2.26
Number of kernels/ear	Attur	1386.93	8755.35**	2723.8	42.61	11.1	1386.93
	Hosur	6588.83**	15073.30**	618.67	20.31	5.32	6588.83**
	Ranebennur	4878.99**	18550.40**	715.69	21.84	6.23	4878.99**
Hundred seed weight	Attur	7.09	75.13**	5.02	1.83	6.51	7.09
	Hosur	1.20**	99.28**	0.32	0.47	1.71	1.20**
	Ranebennur	1.57	100.17**	1.06	0.84	3.52	1.57
Grain yield	Attur	1.43*	8.53**	0.3	0.45	5.69	1.43*
	Hosur	3.9**	6.80**	0.23	0.39	5.02	3.9**
	Ranebennur	0.99	10.42**	0.38	0.5	8.88	0.99

* - Significant at 5% level; ** - significant at 1% level

turity, plant height (cm), number of leaves, ear length (cm), number of kernels row^{-1}, number of kernels ear^{-1}, hundred seed weight (g), and grain yield (tones ha^{-1}) and the average was used for statistical analysis. The stability of yield performance for each genotype was calculated by regressing the mean yields of individual genotypes on environmental index and calculating the deviations from regression as suggested by Eberhart and Russell (1966). However, regression coefficient (βi) was considered as an indication of the response of the genotype to varying environments while mean square for deviations from regression (S^2_d) was used as the criterion of stability as suggested by Becker and Leon (1988).The statistical analysis was carried out using WINDOSTAT software developed by Indostat services, Hyderabad.

Results and Discussion

Variation for quantitative characters is under the control of many genes and the contribution of genes can differ among environments. This conditional contribution of genes is the basis of genotype-by-environment (G x E) interactions (Worku et al, 2008). Tollenaar and Lee (2002) reported that high yielding maize hybrids can differ in their yield stability and that yield stability and high grain yield are not mutually exclusive. Although there are number of models available to study stability of genotypes, the model proposed by Eberhart and Russell (1966) is widely used for its simplicity and reliability. The present study was therefore aimed at evaluating the 60 single cross hybrids for their adaptability and stability in performance utilizing the stability model suggested by Eberhart and Russell (1966).

Analysis of variance for RBD was carried out for all the characters individually in each environment (Tables 1 and 2) and the results revealed that the variance due to genotypes was highly significant for all the nine characters studied in all the three environments. Pooled analysis of variance for stability of nine characters was done using Eberhart and Russel model of stability (1966) and the results are furnished in Table 3. The results of pooled analysis showed that the variance due to genotypes, environments and environment (linear) components were highly significant for all the nine characters studied. However, the variance due to genotype x environment interaction was significant only for plant height, number of leaves, hundred seed weight and grain yield. The variance due to the genotype x environment (linear) component was non-significant for ear length and number of kernel rows, but significant for the remaining seven characters. Similar reports on variance due to different components were given by Abera et al (2006), Worku and Zelleke (2008), Arunkumar and Singh (2004) and Kaundal and Sharma (2006).

Days to 50% silking

Lowest environmental index for days to 50% silking was recorded at Attur location indicating that the tested hybrids showed earliness in flowering when compared to other two locations. The hybrid FI-139 x FI-140 was found to be stable for earliness over all the three environments for days to 50% silking since it showed a regression coefficient of unity and a non-significant deviation from linear regression. (Supplementary table 1) Observations on mean performance of inbreds also revealed the availability of early to late maturing inbreds among the inbreds derived from hybrid mixture base population (5.1.1). Hence, hybrid mixture base population shall be effectively utilized as a base population to develop stable hybrids for earliness in flowering which may be of great use for rainfed environments in particular. Rahman et al (2010) identified the hybrid 9815 as stable one for earliness with respect to days to silking based on Eberhart and Russel stability parameters. Gargi and Saikia (2001) and Kaundal and Sharma (2006) also identified stable hybrids for days to 50% silking using stability analysis.

Days to maturity

As observed for days to 50% silking, Attur location showed earliness for days to maturity also which was evident from lowest environmental index. In contrast, Hosur location recorded highest environmental index revealing that the hybrids took more time to mature when compared to other two locations. This

Table 3 - Pooled ANOVA for stability and environmental indices of nine characters over environments.

Source of Variation	df	Days to 50% silking	Days to maturity	Plant height	Number of leaves	Ear length	Number of kernel rows	Number of kernels/ear	100 seed weight	Grain yield
Genotypes	62	4.50**	39.80**	841.48**	0.86**	6.22**	4.70**	9829.61**	81.18**	5.22**
Environments	2	741.73**	788.17**	91207.35**	40.39**	80.59**	3.30**	33107.23**	449.82**	150.95**
Genotype x environment	124	0.78	3.10	58.35*	0.21*	1.36	0.65	2199.85	5.17**	1.68*
Total	188	9.89	23.55	1286.29	0.85	3.81	2.01	5044.85	34.97	4.44
Env.+ (gen. x env.)	126	12.54**	15.56**	1505.16**	0.85**	2.62**	0.69	2690.45**	12.23**	4.05**
Environments (Linear)	1	1483.45**	1576.35**	182414.70**	80.77**	161.18**	6.59**	66214.46**	899.63**	301.89**
Gen. x Env.(Lin.)	62	1.01**	3.76*	79.14**	0.28**	1.56	0.56	2801.60*	7.29**	2.33**
Pooled Deviation	63	0.54*	2.39**	36.97	0.13	1.14**	0.73**	1572.74**	3.01**	1.02**
Pooled Error	372	0.37	0.56	39.24	0.11	0.34	0.42	448.23	0.71	0.10
Environmental index										
Attur		-3.71	-3.53	21.45	0.62	1.14	-0.04	14.63	2.09	0.96
Hosur		0.66	3.55	22.48	0.29	-0.02	0.24	11.79	0.92	0.83
Ranebennur		3.06	-0.02	-43.93	-0.91	-1.12	-0.21	-26.42	-3.01	-1.79

may be due to cooler climatic conditions prevailing at Hosur. Wide variability was observed among the hybrids for days to maturity as indicated by the recorded range of 92.67 to 107.89 days.

The hybrids «FI-127 x FI-143» and «FI-139 x FI-142» recorded lowest days to maturity. These two hybrids showed non-significant regression value greater than one and non-significant deviation from regression line (Supplementary table 1). This explains the suitability of these hybrids for favourable environments with respect to maturity. None of the late maturing hybrids revealed desirable b_i and S^2_d values. There are similar reports of identifying stable hybrids for days to maturity using stability analysis (Loffler et al, 1986; Singh et al, 2009; Lata et al, 2010).

Plant height

Hosur location was identified as the best environment for plant growth which recorded highest environmental index while Ranebennur location showed reduced plant height as evidenced from low environmental index. The mean over three environments showed the presence of wide variability within the tested hybrids ranging from 155.1 cm to 234.99 cm. Among the hybrids, «FI-104 x FI-142» exhibited better stability for tallness with regression value very close to unity and non-significant deviation from regression. However, hybrids with moderate plant height are preferred in maize to get high yields combined with lodging resistance. In this view, the hybrids «FI-130 x FI-140» and «FI-144 x FI-142» were found to have moderate plant height along with b_i value closer to one and non-significant S^2_d values indicating their suitability to all environments with respect to plant height (Supplementary table 1). All the inbreds involved in these crosses were derived from composite base population which indicates the suitability of composites for developing stable single cross hybrids with optimum plant height. Saindass et al (1987), Arunkumar and Singh (2004), Rahman et al (2010) and Nadagoud et al (2012) identified stable maize genotypes for plant height using the values of mean, regression coefficient and deviation from linear regression.

Number of leaves

Environmental index revealed that the number of leaves recorded by the hybrids was high at Attur location and was lowest at Ranebennur location. Among the trial hybrids, «FI-59 x FI-142» and «FI-141 x FI-142» registered higher number of leaves together with a regression coefficient of one and a non-significant deviation from regression. This indicated that these two hybrids are stable in their expression showing better adaptability to varying environmental conditions (Supplementary table 1). Another two hybrids viz. «FI-5 x FI-142» and «FI-54 x FI-142» also recorded high mean for number of leaves and showed slightly higher regression coefficient coupled with non-significant deviation from regression. This indicated that these hybrids require favourable environments for better character expression. It was also noticed that the male FI-142 was very effective in producing stable hybrids for number of leaves. Nadagoud et al (2012) identified stable inbreds for leaf characters like leaf area and leaf area index by employing Eberhart and Russel stability parameters.

Ear length

It was evident from the environmental index that Attur location had the best cob expression recording high environmental index for ear length whereas Ranebennur location showed reduction in ear length when compared to other two environments. Among the hybrids, «FI-114 x FI-142» recorded high mean value with regression coefficient less than unity and non-significant deviation from regression (Supplementary table 1). The hybrid «FI-104 x FI-142» exhibited high mean for ear length with regression coefficient higher than unity and non-significant deviation from regression revealing that it is specifically suited to favourable environments. Similar finding on identifying stable genotype for cob length using Eberhart and Russel's stability analysis was reported by Nadagoudet al (2012) and Kaundal and Sharma (2006).

Number of kernel rows

High environmental index was recorded at Hosur location while Ranebennur location had the lowest value for number of kernel rows. It was found that none of the hybrids were found to be stable for number of kernels rows. This may be due to high sensitivity of the character to environmental fluctuations (Supplementary table 2).

Number of kernels ear^{-1}

Number of kernels ear^{-1} is an important character contributing to grain yield and large variability for mean ranging from 287.26 to 594.66 kernels ear^{-1} was observed among the hybrids for this character. Attur location recorded high environmental index and Ranebennur location recorded low environmental index for number of kernels/ear (Supplementary table 2) Among 63 hybrids, «FI-5 x FI-143» recorded high mean, regression coefficient below unity and non-significant deviation from regression showing that this hybrid has good adaptability to unfavourable environments.

Hundred seed weight

The overall mean for 100 seed weight exhibited a range of 20.68 to 42.94 g among the hybrids indicating the availability of sufficient variability for this character. The environmental index was highest at Attur location while Ranebennur location recorded the lowest value. High grain weight at Attur location may be attributed to superior soil conditions of the location (Supplementary table 2). The two Hybrids «FI-104 x FI-142» and «FI-139 x FI-109» recorded highest mean value with bi value greater than one and non-significant deviation from regression. This suggests that these two hybrids are more suitable for favourable environments with good crop management. Another hybrid «FI-114 x FI-109» which showed high 100 seed weight than the best check together with regression coefficient near to one and non-significant deviation from regression was identified as stable hybrid suitable for all the three environments under study. Both the parents involved in this hybrid were derived from hybrid mixture which clearly revealed the usefulness of hybrid mixture base population in deriving stable superior parents useful in synthesizing single cross hybrids having higher test weight. Singh et al (2009) identified «L7 x T3» and «L22 x T3» as stable hybrids for 100 grain weight based on Eberhart and Russell stability parameters.

Grain yield

As observed for many of the yield contributing characters, Attur location recorded high environmental index for grain yield also indicating superiority in overall performance when compared with other two environments. Ranebennur location showed poor overall performance as indicated by the lowest environmental index for grain yield. Among the tested hybrids, three hybrid combinations viz. «FI-24 x FI-142», «FI-114 x FI-142», and «FI-54 x FI-142» were identified as best hybrids with a grain yield of over 11 tonnes ha^{-1}. Out of these three hybrids, «FI-54 x FI-142» recorded a regression coefficient very near to unity and non-significant deviation from linear regression indicating the suitability of this hybrid for all environments (Supplementary table 2). On the other hand, the regression coefficient for the hybrids «FI-114 x FI-142» and «FI-24 x FI-142» was greater than unity with significant deviation from regression. This revealed that the stability of these hybrids was below average and are suitable specifically to unfavourable environments. Another two hybrids namely «FI-139 x FI-109» and «FI-130 x FI-142» showed better mean yield compared to the best check of the trials together with regression coefficient near to one and non-significant deviation from regression. Though the grain yield of these two hybrids was at par with the best yielding standard checks, the observations on stability parameters make them ideal hybrids which can be grown over a wide range of environments. All the three single cross hybrids identified as stable over different environments viz. «FI-54 x FI-142»,«FI-139 x FI-109», and «FI-130 x FI-142» shall be further tested in target environments for commercial exploitation. Obeng-Antwi et al (2002) observed that hybrids and improved composites were more stable than local varieties of maize in Ghana. There are reports of identifying stable hybrids in maize based on Eberhart and Russell's stability parameters (Gama and Hallaeur, 1980; Singh et al, 2009; Lata et al, 2010; Rahman et al, 2010; Mosa et al, 2011; Karadavut and Akilli, 2012).

Among the five single cross hybrids showing high mean yield over the standard checks, four hybrids had the tester FI-142 as male. This shows the potential of this inbred line in deriving high yielding single cross hybrids. The inbred FI-142 was derived from composite base population. It was also found that among the three stable hybrids identified, the single cross hybrid «FI-130 x FI-142» was the one having inbred parents derived from composite base population. This confirms the usefulness of composite base populations and in deriving superior stable single cross hybrids for grain yield. The finding is in accordance with the recent results of Delucchi et al (2012) on usefulness of composites as a germplasm source for the development of inbred lines in maize. They also suggested that the composites could be self pollinated and the lines shall be selected based on the test cross performance and their combining ability.

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