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GENETICS AND PLANT BREEDING

G × E interaction and Stability Analysis of Maize Hybrids Using Eberhart and Russell Model

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ABSTRACT

The present study was carried out to identify stable Maize hybrids across various environments as the performance of each hybrid tends to vary when grown in different seasons or locations. Twenty one Maize hybrids and two commercial checks were tested over three locations in India *viz.,* Viluppuram, Trivandrum and Nagercoil. Eberhart and Russell model of stability analysis was carried out which revealed a significant effect of each environment on the hybrids taken, for all the ten morphological traits except the number of leaves. The hybrid AU-101 was identified as a stable hybrid with high mean under less favourable conditions and the hybrid AU-114 was recognized as a stable hybrid under favourable conditions. None of the check hybrids *viz.,* CP-818 and Bioseed-TX369 showed stability in any of the environment. Thus, it emphasized the need for the development of location specific hybrids or a hybrid that is, stable across environments.

Highlights

- Eberhart and Russell model of stability analysis is used in this research and assessed the performance of hybrids across the environments.

Keywords: Stability, maize hybrids, environments

In India, Maize is the third most important cereal crop after Rice and Wheat. It contributes a lion share to the total food production globally. The Maize production is estimated at 26.2 million tonnes (FAOSTAT, 2017) in India and the projected demand for Maize is expected to be 42 million tonnes by the year 2025 (Sain Dass *et al.* 2009). Corn which literarily means "that which sustains life" (Akinyele and Adigun, 2006) has been cultivated throughout India. The significance of the crop has grown due to its multipurpose nature and the high yielding maize hybrids met the quest for higher yield by farmers. Even with these highly productive hybrids, farmers experience the distress of inconsistent yield across different environments.

There is a growing need to identify maize hybrids that perform uniformly and consistently for yield regardless of environments. Eberhart and Russell (1966) stated that a desirable cultivar should have an average yield performance that is higher under favourable conditions and less fluctuating under unfavourable conditions than that of the group of cultivars when tested in many environments. There is an ever growing demand for environment specific hybrids, hence the present study was carried out to identify stable and environment specific hybrids and to test the hybrid performance in environment other than conventional maize growing areas.

MATERIALS AND METHODS

The materials for stability analysis consisted of twenty one maize hybrids of single cross origin were received from Department of Genetics and Plant Breeding, Annamalai University and two private commercial hybrids (CP-818, BIO-TX369) were used as checks. The study was conducted over three environments during June, 2017 in a one row trial. The particulars of three environments are given in Table 1. Experiments were laid out in randomized block design with three replications. Fifteen plants per replication were maintained for each hybrid.

Ten morphological traits *viz.*, days to 50% tasseling, number of leaves, days to maturity, plant height (cm), cob placement height (cm), ear length (cm), number of kernels per row, number of kernels per ear, hundred seed weight (g) and yield per plant (g) were recorded from five randomly selected plants for each hybrid per replication. Linear regression model of stability suggested by Eberhart and Russell (1966) was employed and the data was analyzed using TNAUSTAT software.

RESULTS AND DISCUSSION

The combined analysis of variance revealed significant differences among the hybrids for all the traits thus indicated the existence of inherent genetic variability and suggest the possibility of selecting a stable hybrid from the lot. Similar results were reported by Usharani (2012) and Lata *et al.* (2010). Highly significant genotype x environment interaction was observed for almost all the characters except number of leaves indicating that all the hybrids interacted considerably well with the environmental conditions (Table 2). Similar interaction for various traits was also reported by Admassu *et al.* (2008).

Analysis of variance for Eberhart and Russell model revealed highly significant E+ (G×E) for all the characters against pooled error and indicated distinct nature of seasons and GxE interactions in the phenotypic expression. Highly significant values for environment (linear) variance indicated considerable additive environmental variance for all the traits. Pooled deviations were also highly significant for most of the characters except for number of leaves (Bharathiveeramani *et al.* 2016) and cob placement height which indicated that unpredictable portion formed the major part of the GxE interactions. The contribution of linear portion to GxE interactions was revealed by highly significant GxE (Linear) variance for nine traits except number of leaves (Table 3). Similar works were done by Gami *et al.* (2017) and Matin *et al.* (2017).

The mean performance, regression (b_i) and squared deviation (s^2d_i) for ten morphological traits are presented in Table 4a and 4b. It is interesting to note that no one hybrid was stable for all the

Table 1: Particulars of three environments

Particulars	E_1	E_2	E_3
Location	Melkaranai, Villupuram Dt, Tamil Nadu	Vithura, Trivandrum Dt, Kerala	Nagercoil, Kanyakumari Dt, Tamil Nadu
Latitude	13.0939°N	8.6741°N	8.2383°N
Longitude	80.2924°E	77.0794°E	77.2727°E
Season	June 2017	June 2017	July 2017
Soil Type	Sandy clay loam	Sandy clay loam	Sandy clay loam
Soil pH	7.4	6.3	6.6
EC	0.34	0.14	0.14
Soil Status			
N	Low	Low	Low
P	Medium	High	High
K	High	Low	Medium
Fe	Sufficient	Sufficient	Sufficient
Mn	Low	Low	Sufficient
Zn	Low	Low	Sufficient
Cu	Sufficient	Sufficient	Sufficient
Climate			
Avg. Temp (°C)	30.7	26.7	27.9
Avg. Rainfall (mm)	100	191.7	98.3

Table 2: Combined analysis of variance for ten morphological characters

Sources	df	MSS									
		Days to 50% tasseling	Number of leaves	Days to maturity	Plant height (cm)	Cob placement height (cm)	Ear length (cm)	Number of kernel rows	Number of kernels per ear	100 seed weight (g)	Yield per plant
Replication	2	1.30	2.81	2.03	334.25	37.25	1.94	5.58	3040.91	13.49	968.42
Genotype	22	2.44**	1.11**	6.93**	615.78**	106.51**	4.81**	22.77**	11995.67**	29.13**	1648.08**
Environment	2	203.32**	26.11**	223.95**	3165.35**	543.49**	90.12**	13.04**	16791.65**	293.26**	19411.49**
G × E	44	1.59**	0.26	5.80**	114.64**	39.84**	1.52**	5.91**	2360.62**	6.85**	632.97**
Pooled error	132	0.80	0.61	2.18	133.56	50.35	0.98	5.16	2040.12	5.79	386.23

**: Significant at 5% level; **: Significant at 1% level.*

Table 3: Analysis of variance for Eberhart and Russell model

Sources	df	MSS									
		Days to 50% tasseling	Number of leaves	Days to maturity	Plant height (cm)	Cob placement height (cm)	Ear length (cm)	Number of kernel rows	Number of kernels per ear	100 seed weight (g)	Yield per plant (g)
Genotypes	22	2.44**	1.11**	6.85**	615.88**	106.51**	4.82**	22.78**	11995.88**	29.15**	1648.09**
Environments	2	203.32**	26.11**	223.95**	3165.35**	543.49**	90.12**	13.04**	16791.65**	293.26**	19411.49**
G × E	44	1.59**	0.26	5.80**	114.64**	39.84**	1.52**	5.91**	2360.62**	6.85**	632.97**
E + (G × E)	46	10.37**	1.38**	15.29**	247.28**	61.74**	5.37**	6.22**	2988.06**	19.30**	1449.43**
Environment (Linear)	1	406.63**	52.23**	447.89**	6330.70**	1086.97**	180.24**	26.09**	33583.30**	586.51**	38822.99**
Genotype ´ Environment (Linear)	22	1.03**	0.22	2.08**	151.32**	51.62**	0.92**	4.63**	1684.94**	3.26*	514.36**
Pooled deviation	23	2.07**	0.28	9.12**	74.57*	26.83	2.03**	6.87**	2904.35**	9.99*	718.89**
Pooled error	132	0.80	0.61	2.18	133.56	50.35	0.98	5.16	2040.12	5.79	386.23

**: Significant at 5% level; **: Significant at 1% level.*

characters. Twenty one hybrids and two checks with higher/lower mean values than grand mean were grouped into four based on stability parameters *viz.*, regression coefficient and squared deviation, according to the methodology followed by Mehra and Ramanujam (1979) and Singh and Singh (1980) (Table 5). The hybrids falling in group I have desirable mean, regression coefficient value around one with non significant squared deviation. Under group II, hybrids with less than unity regression value and non significant squared deviation are taken, indicating suitability towards unfavourable environments. Again, the hybrids with more than unity regression is also classified under group II indicating the hybrid's suitability towards favourable environments. Behaviour of hybrids falling in group III and group IV cannot be predicted as they exhibit significant squared deviation, irrespective of the regression coefficient values.

According to the grouping, the hybrid G14 is stable for two traits *viz.*, days to 50% tasseling and plant height, as it was placed under group I. Under group II (b<1), the hybrid G12 is stable for six traits *viz.*, days to 50% tasseling, days to maturity, cob placement height, number of kernels per row, number of kernels per ear and yield per plant in unfavourable conditions. The hybrid G20 is placed under group II (b>1) and is stable in favourable conditions for three traits *viz.*, number of kernels per ear, hundred seed weight and yield per plant. These results are in line with the reports of Kaundal

Table 4a: Stability parameters for morphological traits across environments

Geno-types	Days to 50% Tasseling			Number of leaves			Days to maturity			Plant height			Cob placement height		
	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean (cm)	b_i	S^2d_i	Mean (cm)	b_i	S^2d_i
G_{1}	**50.80****	1.25	-0.21	13.56	1.11	**0.62***	**103.00****	1.09	1.96	215.85	0.88	0.36	67.76	1.76	32.24
G_{2}	51.95	1.21	0.56	12.75	1.40	-0.17	104.64	1.20	**3.08***	**194.29****	0.25	-8.45	66.35	2.82	23.03
G_{3}	51.94	0.96	0.31	13.57	1.25	-0.1	103.85	0.83	2.08	209.77	0.93	-25.44	69.41	0.82	-13.38
G_{4}	**51.05***	1.39	-0.14	13.45	1.26	-0.16	**103.19***	1.41	**2.37***	208.23	0.90	39.57	70.19	0.62	**66.26***
G_{5}	53.26	1.01	**0.95***	13.52	1.41	-0.2	106.46	1.01	**8.95****	**198.71****	0.67	-11.42	67.99	1.57	6.70
G_{6}	52.06	0.76	-0.14	14.39	1.41	-0.08	104.76	0.65	**7.68****	213.68	0.35	93.83	77.77	1.61	**76.07***
G_{7}	52.78	0.98	1.07*	13.83	0.93	-0.11	104.80	0.82	**3.06***	220.86	0.48	-40.88	84.85	1.66	-12.65
G_{8}	52.20	1.26	0.02	13.51	0.93	0.14	104.31	1.21	0.57	**197.87****	0.32	113.08	67.85	2.06	1.06
G_{9}	53.15	1.11	**5.13****	13.51	1.10	-0.2	105.93	1.07	**8.24****	**195.53****	1.49	114.57	66.65	0.35	31.30
G_{10}	52.50	1.03	-0.18	14.32	1.24	0.15	106.13	0.93	**15.44****	206.81	1.50	-27.6	66.77	0.02	-13.61
G_{11}	52.02	1.09	-0.02	13.89	0.63	-0.14	104.06	0.83	2.08	**202.49***	1.11	-16.02	67.17	0.50	-13.24
G_{12}	51.96	0.68	-0.24	14.11	0.94	-0.15	**102.96****	0.47	0.01	214.31	1.32	102.34	68.21	0.27	-14.06
G_{13}	**49.91****	1.13	**5.31****	13.70	0.78	-0.18	**101.76****	0.84	**11.23****	223.19	1.61	-17.57	72.81	0.09	-12.37
G_{14}	51.89	0.97	-0.2	13.82	0.78	-0.18	103.52	0.98	**3.86***	210.07	0.92	-39.15	78.61	1.02	-8.49
G_{15}	52.06	0.87	0.72	**14.94***	0.64	0.06	105.07	1.13	**6.08****	229.84	1.62	53.82	78.28	0.66	42.99
G_{16}	52.57	0.76	**1.11***	14.30	0.31	-0.12	105.28	0.75	**5.98****	248.34	2.82	-33.57	75.21	-1.35	**61.54***
G_{17}	51.77	1.13	-0.26	13.86	1.25	-0.2	103.94	1.11	-0.04	229.48	0.88	37.05	**61.73****	1.51	7.46
G_{18}	51.41	0.98	-0.26	**14.97***	0.46	-0.02	106.22	0.90	**24.17****	219.09	1.86	6.45	68.90	0.08	8.07
G_{19}	53.30	0.26	0.67	**15.50****	0.63	-0.14	106.83	0.25	**21.24****	220.88	1.98	-32.2	75.47	-0.06	-1.41
G_{20}	54.16	1.27	**10.85****	13.92	1.08	**0.79***	108.41	1.81	**22.20****	219.08	0.16	-2.48	72.78	**2.59***	-16.28
G_{21}	52.82	0.90	**14.00****	14.07	1.08	0.32	106.45	1.35	**37.55****	247.68	1.39	**220.80***	84.71	0.02	4.17
C_{1}	51.67	1.11	**2.51****	14.74	1.28	**1.51****	104.33	1.34	-0.69	210.84	0.39	19.76	75.24	1.70	-7.75
C_{2}	52.00	0.89	-0.19	14.16	1.11	0.2	104.67	1.02	**5.87****	209.63	0.14	**144.28***	70.65	**2.69***	-16.47
	52.14			14.02			104.81			215.06			71.97		

Table 4b: Stability parameters for morphological traits across environments

Geno-types	Ear length			Number of kernel rows			Number of kernels per ear			100 seed weight			Yield per plant		
	Mean (cm)	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean	b_i	S^2d_i	Mean (g)	b_i	S^2d_i	Mean (g)	b_i	S^2d_i
G_{1}	18.60	0.73	**2.72****	44.24	0.16	1.34	**640.50****	2.73	**3456.09***	28.30	1.14	0.18	189.72	1.93	-94.93
G_{2}	18.11	1.11	**3.27****	43.67	0.33	**8.31***	**665.70**	2.13	**3608.22***	28.01	1.53	-1.86	**191.98***	2.04	353.72
G_{3}	**21.57****	1.24	0.64	45.18	2.88	**6.87***	538.70	1.64	**4135.36****	**31.68***	1.71	**16.44****	171.93	1.63	**1160.24****
G_{4}	19.57	1.14	-0.18	38.26	1.21	0.01	472.64	0.60	46.04	**35.69****	1.11	4.44	172.08	0.79	-4.62
G_{5}	19.22	0.89	0.43	44.21	**2.24***	-1.72	535.83	1.25	**2240.51***	26.53	0.83	**10.83***	147.33	0.54	**658.42***
G_{6}	18.12	1.13	**2.74****	44.64	-0.90	-1.19	**617.66***	-0.32	336.71	22.50	0.94	-1.7	140.72	0.62	-79.41
G_{7}	**21.40****	0.39	-0.28	42.71	2.87	**13.90****	**623.45***	0.25	**6173.52****	28.75	**0.34***	-1.92	182.42	0.26	**473.29***
G_{8}	18.06	1.47	**1.42***	41.35	1.88	-1.67	565.63	1.43	-382.58	26.39	0.72	**7.02***	153.21	0.65	46.27
G_{9}	19.43	0.96	**1.08***	43.24	3.51	**6.33***	534.58	0.88	1600.64	28.08	0.30	3.35	149.11	0.61	-124.34
G_{10}	19.12	1.07	**2.13****	41.07	-2.55	-1.04	489.56	0.51	-42.09	29.98	0.81	0.22	156.55	0.45	172.76
G_{11}	17.69	0.91	**1.11***	43.03	-0.74	-1.39	441.20	1.03	159.31	28.77	0.80	-1.9	136.19	0.54	355.88
G_{12}	**21.23****	0.95	**3.58****	**47.34****	**-0.78***	-1.68	**701.89****	-1.81	561.8	30.19	1.08	12.31**	215.81**	0.59	126.09
G_{13}	19.84	1.22	**2.26****	**48.03****	1.61	2.61	568.45	0.71	**2044.14***	28.75	1.04	-1.84	164.24	0.94	239.95

G_{14}	19.24	0.57	-0.24	**47.28****	1.90	-1.03	576.10	0.45	78.35	26.12	1.15	**42.83****	149.28	1.17	**378.93***
G_{15}	19.83	1.19	0.16	45.51	2.01	2.08	603.35	1.12	**4222.23****	25.39	1.05	**21.48****	154.70	1.04	**1469.61****
G_{16}	**20.47***	0.44	**4.61****	43.50	4.55	2.65	601.43	1.84	**5908.86****	**31.84***	1.18	**8.20***	**196.73****	1.41	**1936.71****
G_{17}	**20.53****	1.91	0.02	43.17	-2.82	4.15	597.48	0.24	**3751.46***	**33.06****	1.19	4.29	**203.94****	1.24	**1926.48****
G_{18}	19.82	0.63	1.27	43.17	0.75	2.75	549.99	0.00	-487.07	**31.89***	1.08	**18.82****	176.22	0.75	**435.85***
G_{19}	18.36	**0.64**	-0.32	40.07	0.00	-0.01	480.47	-0.03	-242.32	30.22	**0.40***	-1.88	143.95	**0.09**	-125.14
G_{20}	18.24	1.00	**4.27****	44.96	0.22	-0.78	607.06	**2.73***	-675.35	31.06	1.35	-1.07	**194.60***	1.70	-52.91
G_{21}	19.91	0.95	0.05	**48.55****	4.77	-1.17	587.26	2.60	502.5	28.44	0.91	1.3	170.28	1.43	121.09
C_1	18.52	1.31	**6.27****	42.22	0.66	**25.74****	541.47	1.32	56.62	**35.18****	1.52	**44.49****	**205.59****	1.79	**1759.74****
C_2	16.52	1.14	**2.09****	38.17	0.22	**53.32****	529.58	1.71	14106.26**	26.72	0.84	1.39	150.27	0.79	**1595.66****
	19.28			43.63			568.26			29.28			170.30		

Table 5: Grouping of hybrids based on stability parameters

Characters	Group I	Group II		Group III	Group IV
		b<1	b>1		
Days to 50% tasseling	G_3, G_{11}, G_{14}, G_{18}	G_6, G_{12}, G_{15}, C_2	G_1, G_2, G_4, G_{17}	G_{13}, C_1	Nil
Number of leaves	G_{12}, G_{21}	G_{15}, G_{16}, G_{18}, G_{19}	G_6, G_{10}, C_2	C_1	Nil
Days to maturity	G_1	G_3, G_{11}, G_{12}	G_8, G_{17}, C_1	G_2, G_4, G_6, G_7, G_{13}	G_{14}, C_2
Plant height	G_3, G_4, G_{14}	G_2, G_5, G_6, G_8, C_1	G_9, G_{10}, G_{11}, G_{12}	C_2	Nil
Cob placement height	Nil	G_3, G_9, G_{10}, G_{11}, G_{12}, G_{18}	G_1, G_2, G_5, G_8, G_{17}, C_2	G_4	Nil
Ear length	G_{21}	G_7	G_3, G_4, G_{15}, G_{17}	G_{13}, G_{16}, G_{18}	G_9, G_{12}
Number of kernels per row	Nil	G_1, G_6, G_{12}, G_{20}	G_5, G_{13}, G_{14}, G_{15}, G_{21}	G_2, G_3	Nil
Number of kernels per ear	Nil	G_6, G_{12}, G_{14}	G_{20}, G_{21}	G_1, G_2, G_7, G_{13}, G_{15}, G_{16}, G_{17}	Nil
Hundred seed weight	Nil	G_{10}, G_{19}	G_4, G_{17}, G_{20}	G_3, G_{16}	G_{12}, G_{18}
Yield per plant	Nil	G_4, G_{12}	G_1, G_2, G_{20}	G_3, G_7, G_{16}, G_{17}, G_{18}, C_1	Nil

and Sharma (2006), Jha *et al.* (1986) and Arun and Singh (2004).

Considering the overall performance, G12 (AU-101) was found promising with stable performance (group II) and may be used for general cultivation in unfavourable environments. G20 (AU-114) was found to be stable in favourable environment. None of the hybrids were stable across environments, hence emphasises the need for environment specific hybrids.

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