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Assessment of Genotype × Environment Interactions for Flowering and Grain Yield in Maize Hybrids using AMMI and GGE Bi-Plot Analysis

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ABSTRACT

The performance of genotypes often diverges in response to production environments represented by temporal and spatial variation resulting in significant crossover interactions. Crop cultivars should perform consistently across years and locations from the commercial crop production point of view. However, cultivars show inconsistent performance across the environments due to cross over genotype environment interaction. Hence, a investigation was carried to assess the genotype ×environment interactions for flowering and grain yield in maize hybrids using AMMI and GGE bi-plot analysis. Based on the polygon view of the GGE bi-plot, the hybrids MAI 349×MAI 283 for days to anthesis, MAI 283×KDMI 16 for ASI and KDMI 16×BGUDI 118 for grain yield were found to have wider adaptation across the locations. ASV and SI revealed that hybrids MAI 349×MAI 283 and BGUDI 120×VL 109252 for flowering and MAI 349×MAI 283 and KDMI 16 × MAI 283 for grain yield were widely adapted across locations. Among the three production environments, E-III (ARS, Bheemarayanagudi) was found to be favorable for the expression of grain yield and its component traits.

Keywords Maize (*Zea mays* L.), AMMI, Genotype environment interaction, AMMI stability value, GGE bi-plot.

INTRODUCTION

Maize (*Zea mays* L.), known as queen of cereals because of its highest genetic yield potential among the cereals is emerging as third most important crop after rice and wheat (Anonymous 1 2014). It is one of the most versatile emerging crops having wider adaptability under varied agro-climatic conditions (Parihar *et al*. 2011). It is a multi-faceted crop used as food, feed and industrial crop globally (Anonymous 2 2018). India rank 4th and 7th in area and production, respectively, among the maize growing countries, representing around 4% of world maize area and 2% of total production (DACNET 2020). India produced 30 million tonnes from 9.9 million

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hectare area during 2020-21 (Anonymous 3 2021). The demand for maize is increasing year over year. During 2016, it reached 24 MT, which is 2% more than the previous year. In order to meet the domestic demand India would require 45 MT of Maize by the year 2022 (Anonymous 2 2018). To meet the increasing demand, all the breeding program should be aimed at development and deployment of stable and adaptable variety/hybrid which could perform more or less uniformly under different environmental conditions (Arunkumar *et al.* 2020).

The advent of changes in climatic conditions coupled with unpredictable rainfall pattern and incidence of pest and disease pose threats to crop production especially grains (FAO 2007). These demand the development of a widely adapted, stable, early maturing and high yielding crop cultvars. Once, the crop cultivar is developed and then stability needs to be tested. The adaptability /stability of a variety over diverse environments are tested by the degree of its interaction with different environments under which it is tested (Finlay and Wilkinson 1963). The performance of genotypes differ very often in response to production environments represented by temporal (year-to-year) and spatial (location-to location) variation resulting in significant crossover genotype × year and genotype × location interactions. Crop cultivars should perform consistently across years, referred to as stability and across locations referred to as adaptability from the commercial crop production point of view. However, cultivars show inconsistent performance across the environments due to cross over genotype × environment interaction (GEI). Hence, it is important to identify stable cultivars with consistent performance across environments. Genotype environment interaction provides an opportunity to the plant breeder for developing, identifying and selecting improved stable and adaptable cultivars.

MATERIALS AND METHODS

The investigation was carried out at three locations viz., K-Block, GKVK, UAS, Bengaluru (E I), Agricultural Research Station, Bheemarayanagudi (E II) and Kudapali-Village (Hirekerur-Taluk, Haveri-District) (E III) representing diverse agro-climatic zone 5, 3 and 8, respectively of Karnataka state.

The experimental material comprised of eight newly developed single cross maize hybrids (SCHs), selected among the 380 hybrids based on their average yielding performance over two locations (E-I and E-II) during 2016-17 rainy season and seven check hybrids (3 public and 4 private institute bred). Each hybrid was sown in a single row of 3.0 m length with inter and intra row spacing of 0.60 m and 0.30 m, respectively, following Randomized Completely Block Design with three replications during 2016-17 post rainy season. Recommended package of practices were followed to raise a healthy crop under protective irrigation. Data on the 11 quantitative traits were recorded on five randomly selected competitive plants from each hybrid and replication.

Stability of the hybrids was estimated using Additive Main Effects Multiplicative Interaction (AMMI) model. AMMI stability values (ASV) were used to quantify and rank the genotypes according their yield stability following the equation given by Purchase (1997). The GGE-bi-plot, which is a combination of AMMI bi-plot and GGE concepts (Yan *et. al.* 2000) was used for visual interpretation of patterns of GEI

RESULTS AND DISCUSSION

AMMI analysis of variance

Pooled AMMI analysis of variance revealed that all the traits were significantly affected by hybrid and location (except ear circumference and kernel rows ear^{-1} for hybrid: Anthesis silking interval (ASI) and kernel rows ear^{-1} for location). Hybrid, location and GLI, respectively, contributed 42.0 %, 06.0 % and 17.0 % to the variation in days to silking. Days to anthesis was significantly affected by hybrid, location and GLI with contribution of 32.0 %, 13.0% and 15.0 %, respectively. Hybrid, location and GLI contributed 38.0 %, 05.0 % and 15 % of variation, respectively, for ASI. The character grain yield plant^{-1} was significantly affected by hybrid, location and GLI with 29.0 %, 20.0% and 20.0% contribution, respectively. The contribution of hybrid, location and GLI towards variation in ear length, ear circumference, kernel rows ear^{-1}, kernels row^{-1}, plant height, shelling % and test weight is presented in Table 1.

Table 1. Pooled AMMI analysis of variance for flowering, grain yield and its component traits in maize across three locations. *Significant at p @ 0.05 ** Significant at p @ 0.01.

Source of variation	df	Days to anthesis				Days to silking				ASI				Ear length(cm)			
		MSS	F cal	P≥F	% variation	MSS	F cal	P≥F	% variation	MSS	F cal	P≥F	% ariation	MSS	F cal	P≥F	% variations
Genotypes	14	18.27	5.15	<0.001	0.32	24.16	7.280	<0.001	0.42	4.31	6.10	<0.001	0.38	10.01	4.49	<0.001	0.14
Location	2	51.67	14.55	<0.001	0.13	24.18	7.286	<0.001	0.06	4.09	5.78	0.0281	0.05	290.97	130.48	<0.001	0.58
Genotype × Location	28	4.33	1.22	0.243	0.15	5.02	1.512	0.0769	0.17	0.87	1.22	0.2371	0.15	3.01	1.35	0.1505	0.08
IPCA1	15	5.24	1.48	0.1335	0.65	5.81	1.749	0.0566	0.62	1.08	1.53	0.1127	0.67	4.04	1.81	0.0467	0.72
IPCA2	13	3.27	0.92	0.5355	0.35	4.11	1.237	0.2684	0.38	0.62	0.87	0.5853	0.33	1.82	0.82	0.6432	0.28
Error	84	3.55				3.32				0.71				2.23			

Table 1. Continued.

Source of variation	df	Ear circumference (cm)				Kernal rows ear^{-1}				Kernals row^{-1}				Plant height (cm)			
		MSS	F cal	P≥F	% variation	MSS	F cal	P≥F	% variation	MSS	F cal	P≥F	% ariation	MSS	F cal	P≥F	% variations
Genotypes	14	2.022	2.51	0.0049	0.13	1.42	1.75	0.0606	0.14	59.79	5.32	<0.001	0.28	1290	4.42	<0.001	0.27
Location	2	42.90	53.29	<0.001	0.38	6.46	7.95	0.0082	0.09	309.49	27.56	<0.001	0.21	6552	22.44	<0.001	0.20
Genotype × Location	28	1.27	1.58	0.0585	0.16	1.18	1.45	0.1005		19.95	1.78	0.0235	0.19	372	1.27	0.1985	0.16
IPCA1	15	2.01	2.49	0.0044	0.85	1.35	1.67	0.0738	0.23	19.8	1.76	0.0539	0.53	593	2.03	0.0224	0.85
IPCA2	13	0.42	0.52	0.9078	0.15	0.97	1.19	0.298	0.62	20.12	1.79	0.0576	0.47	118	0.40	0.9644	0.15
Error	84	0.80				0.81				11.23				292			

Table 1. Continued.

Source of variation	df	Shelling %				Test weight (g)				Grain yield plant^{-1} (g)			
		MSS	F cal	P ≥ F	% variation	MSS	F cal	P ≥ F	% variation	MSS	F cal	P ≥ F	% variation
Genotypes	14	25.32	6.96	<0.001	0.36	67.59	8.73	<0.001	0.35	2916	5.55	<0.001	0.29
Location	2	66.93	18.39	<0.001	0.14	255.05	32.95	<0.001	0.19	13928	26.53	<0.001	0.20
Genotype × Location	28	5.81	1.60	0.0533	0.17	17.56	2.27	0.0022	0.18	992	1.89	0.0139	0.20
IPCA1	15	7.44	2.04	0.0213	0.68	20.5	2.65	0.0025	0.63	1314	2.50	0.0042	0.71
IPCA2	13	3.94	1.08	0.3855	0.31	14.16	1.83	0.0514	0.37	620	1.18	0.3081	0.29
Error	84	3.64				7.74				525			

Significant mean squares attributable to locations indicated differences in the influence of locations on the productivity of hybrids. Substantial contribution of GLI towards traits variation suggested differential responses of hybrids to locations (Flores *et al.* 1998). Hence, it is appropriate to assess yield stability under different environments and identify hybrids with specific/wide adaptation (Kang 1993). Further, GLI was partitioned into two IPC axes by Gollob's F-test (Gollob 1968) which together explained ≥ 60.0 % of the total GLI variance for all the traits indicating a good fit of AMMI model to the data. This suggested a good approximation of bi-plot for inferring patterns of GLI and predictability of genotype performance across locations. Earlier, Faria Sirlene Viana *et al.*(2017) reported that the first two principal components explained 76.8% of the variation due to the hybrid × environment interaction from their studies on maize. Similarly, Sserumaga *et al.* (2016) and Lalisa *et al.* (2016) reported contribution of two principal components to the extent of 73.00 % and 65.50 %, respectively, towards G × E interaction.

GGL bi-plot

Differences in genotype stability and adaptability

Table 2. Estimates of IPC scores and stability parameters to assess adaptability of maize hybrids for flowering, grain yield and its component traits across three locations.

Sl.		Days to anthesis								Days to silking							
No.	Hybrids	Mean	Rank	IPC1	IPC2	ASV	Rank	SI	Rank	Mean	Rank	IPC1	IPC2	ASV	Rank	SI	Rank
1	KDMI 16×MAI 283	56.46	2	-0.65	-0.26	1.23	9	11	4	57.79	1	-1.07	-0.06	1.75	15	16	9
2	KDMI 16×BGUDI 118	55.97	1	-1.03	0.05	1.91	15	16	9	57.84	2	-0.88	0.59	1.55	13	15	8
3	BGUDI 88×MAI 349	56.50	3	0.45	0.23	0.86	6	9	2	58.8	3	0.72	-0.21	1.19	9	12	3
4	BGUDI 120×VL109252	58.37	9	-0.78	0.03	1.44	11	20	12	59.27	5	-0.44	0.04	0.71	6	11	2
5	MAI 394×BGUDI 88	57.35	5	0.41	0.64	1.00	8	13	6	59.49	6	0.83	0.73	1.54	12	18	10
6	MAI 283×KDMI 16	56.81	4	-0.92	-0.39	1.74	14	18	10	58.88	4	-0.99	0.10	1.61	14	18	11
7	MAI 349×MAI 283	58.01	6	0.02	0.20	0.21	1	7	1	60.22	8	0.31	0.37	0.62	5	13	6
8	MAI 283×BGUDI 120	58.93	11	0.01	0.99	0.99	7	18	11	62.61	14	0.28	0.66	0.80	7	21	13
9	Arjun	58.32	8	0.11	-0.10	0.22	2	10	3	60.07	7	-0.08	-0.16	0.21	2	9	1
10	CP 818	60.14	14	0.84	0.39	1.59	13	27	14	62.91	15	0.68	0.65	1.28	10	25	15
11	NK 6240	61.04	15	0.76	-0.62	1.53	12	27	15	62.6	13	0.65	-0.86	1.36	11	24	14
12	Nityashree	58.01	7	0.06	-0.75	0.75	5	12	5	61.44	12	0.01	-1.06	1.06	8	20	12
13	Hema	59.35	13	0.58	-0.82	1.36	10	23	13	60.61	10	0.14	-0.58	0.62	4	14	7
14	DKC 9133	58.88	10	0.37	-0.12	0.69	4	14	7	60.56	9	-0.05	-0.27	0.28	3	12	4
15	DKC 9150	58.97	12	-0.22	0.52	0.66	3	15	8	60.88	11	-0.11	0.07	0.19	1	12	5

Table 2. Continued.

				ASI					
Sl. No.	Hybrids	Mean	Rank	IPC1	IPC2	ASV	Rank	SI	Rank
1	KDMI 16×MAI 283	1.56	2	0.20	-0.75	0.85	10	12	5
2	KDMI 16×BGUDI 118	1.96	8	-0.30	0.29	0.67	8	16	9
3	BGUDI 88×MAI 349	1.96	8	-0.30	0.29	0.67	8	16	9
4	BGUDI 120×VL109252	1.70	5	0.02	-0.12	0.13	1	6	1
5	MAI 394×BGUDI 88	2.25	10	-0.34	0.43	0.81	9	19	10
6	MAI 283×KDMI 16	2.08	9	-0.11	0.04	0.23	3	12	6
7	MAI 349×MAI 283	2.36	11	-0.19	0.26	0.46	4	15	8
8	MAI 283×BGUDI 120	3.68	15	0.29	0.01	0.60	7	22	12
9	Arjun	1.74	6	0.03	-0.20	0.21	2	8	2
10	CP 818	2.77	13	-0.85	-0.12	1.73	15	28	15
11	NK 6240	1.61	3	0.15	0.39	0.49	5	8	3
12	Nityashree	3.46	14	0.58	0.33	1.23	13	27	14
13	Hema	1.26	1	-0.52	-0.11	1.06	12	13	7
14	DKC 9133	1.68	4	-0.03	-0.56	0.56	6	10	4
15	DKC 9150	1.91	7	0.64	-0.15	1.31	14	21	11

Table 2. Continued.

Sl.		Ear length (cm)								Ear circumference (cm)							
No.	Hybrids	Mean	Rank	IPC1	IPC2	ASV	Rank	SI	Rank	Mean	Rank	IPC1	IPC2	ASV	Rank	SI	Rank
1	KDMI 16×MAI 283	17.46	2	-0.07	-0.05	0.18	2	4	2	13.96	11	0.27	-0.28	1.50	6	17	8
2	KDMI 16×BGUDI 118	17.25	5	0.36	0.29	0.98	7	12	5	14.45	4	0.42	-0.31	2.34	10	14	6
3	BGUDI 88×MAI 349	16.24	12	-0.76	0.03	1.94	14	26	14	13.46	14	0.26	0.25	1.49	5	19	10
4	BGUDI 120×VL109252	17.18	6	-0.53	0.31	1.39	11	17	9	14.29	7	0.74	0.01	4.14	14	21	12
5	MAI 394×BGUDI 88	15.94	13	0.67	0.18	1.73	12	25	13	13.53	13	-0.39	0.24	2.17	9	22	14
6	MAI 283×KDMI 16	16.45	10	0.24	0.25	0.67	4	14	8	14.43	5	0.03	0.26	0.31	1	6	2
7	MAI 349×MAI 283	19.47	1	0.03	0.15	0.17	1	2	1	14.72	1	0.10	-0.51	0.75	3	4	1
8	MAI 283×BGUDI 120	14.82	15	-1.40	-0.28	3.59	15	30	15	13.03	15	-0.68	0.28	3.79	13	28	15
9	Arjun	17.31	4	-0.07	-0.81	0.83	5	9	3	14.23	8	0.66	-0.07	3.67	12	20	11
10	CP 818	17.36	3	-0.41	0.48	1.14	9	12	6	14.03	9	-0.38	-0.29	2.14	8	17	9
11	NK 6240	16.51	9	0.59	-0.97	1.78	13	22	12	14.57	3	0.37	0.36	2.10	7	10	3
12	Nityashree	16.40	11	0.50	0.30	1.32	10	21	10	14.59	2	-0.51	0.32	2.85	11	13	5
13	Hema	16.90	7	0.27	0.61	0.92	6	13	7	14.32	6	-0.81	-0.46	4.50	15	21	13
14	DKC 9133	15.47	14	0.39	-0.15	1.02	8	22	11	13.89	12	-0.18	-0.12	0.98	4	16	7
15	DKC 9150	16.68	8	0.17	-0.35	0.56	3	11	4	14.00	10	0.09	0.32	0.58	2	12	4

Table 2. Continued.

		Kernal row ear-^{1}							
Sl. No.	Hybrids	Mean	Rank	IPC1	IPC2	ASV	Rank	SI	Rank
1	KDMI 16×MAI 283	13.91	14	0.02	0.32	0.33	2	16	7
2	KDMI 16×BGUDI 118	14.59	4	0.48	0.24	0.80	8	12	4
3	BGUDI 88×MAI 349	14.61	3	0.00	-0.28	0.28	1	4	1
4	BGUDI 120×VL109252	15.38	1	0.13	0.33	0.39	3	4	2
5	MAI 394×BGUDI 88	14.14	9	-0.26	-0.26	0.49	4	13	5
6	MAI 283×KDMI 16	14.65	2	-0.50	0.05	0.80	9	11	3
7	MAI 349×MAI 283	14.47	5	-0.57	0.22	0.95	13	18	11
8	MAI 283×BGUDI 120	13.90	15	-0.40	-0.04	0.64	7	22	12
9	Arjun	14.17	8	0.25	0.29	0.49	5	13	6
10	CP 818	14.11	10	0.30	0.39	0.63	6	16	8
11	NK 6240	14.22	7	0.15	-0.83	0.87	11	18	9
12	Nityashree	14.44	6	-0.47	-0.49	0.91	12	18	10
13	Hema	13.97	12	-0.48	0.35	0.85	10	22	13
14	DKC 9133	13.94	13	0.65	0.19	1.06	14	27	15
15	DKC 9150	14.06	11	0.71	-0.49	1.24	15	26	14

Table 2. Continued.

Sl.		Kernals row^{-1}								Plant height (cm)							
No	Hybrids	Mean	Rank	IPC1	IPC2	ASV	Rank	SI	Rank	Mean	Rank	IPC1	IPC2	ASV	Rank	SI	Rank
1	KDMI 16×MAI 283	32.84	9	-0.26	-0.57	0.64	4	13	6	183.70	14	-2.33	0.27	13.50	13	27	14
2	KDMI 16×BGUDI 118	32.36	10	0.38	-0.10	0.44	2	12	5	192.10	8	1.65	1.13	9.63	11	19	10
3	BGUDI 88×MAI 349	29.89	13	-1.04	-0.68	1.37	12	25	14	209.00	3	1.97	1.92	11.55	12	15	7
4	BGUDI 120×VL109252	34.96	2	-1.07	0.37	1.26	9	11	4	184.10	13	-1.38	1.32	8.11	8	21	11
5	MAI 394×BGUDI 88	33.42	8	0.55	-1.17	1.33	11	19	11	190.40	9	-1.33	0.25	7.69	7	16	8
6	MAI 283×KDMI 16	34.89	3	-0.53	0.13	0.62	3	6	1	184.90	12	-1.47	-0.27	8.51	9	21	12
7	MAI 349×MAI 283	36.56	1	0.83	0.63	1.13	8	9	3	214.40	1	0.04	0.03	0.22	1	2	1
8	MAI 283×BGUDI 120	26.59	15	-1.91	1.09	2.43	15	30	15	192.60	7	0.29	-0.17	1.67	2	9	3
9	Arjun	33.61	6	-0.28	0.06	0.32	1	7	2	175.20	15	-4.20	0.29	24.25	15	30	15
10	CP 818	34.53	4	1.01	1.11	1.60	13	17	9	203.50	6	1.15	-0.49	6.67	5	11	4
11	NK 6240	33.56	7	-0.07	-1.67	1.67	14	21	13	211.00	2	0.45	1.10	2.85	3	5	2
12	Nityashree	31.67	11	0.45	-0.47	0.70	5	16	8	189.00	10	-1.07	-1.69	6.43	4	14	6
13	Hema	33.89	5	0.77	0.93	1.28	10	15	7	187.50	11	1.59	-2.90	9.62	10	21	13
14	DKC 9133	30.22	12	0.71	-0.18	0.83	7	19	10	204.90	5	1.14	-1.52	6.74	6	11	5
15	DKC 9150	29.69	14	0.46	0.53	0.75	6	20	12	206.70	4	3.51	0.73	20.32	14	18	9

Table 2. Continued.

		Shelling %							
Sl. No.	Hybrids	Mean	Rank	IPC1	IPC2	ASV	Rank	SI	Rank
1	KDMI 16×MAI 283	84.13	3	0.16	0.33	0.48	5	8	3
2	KDMI 16×BGUDI 118	84.91	1	-0.07	-0.50	0.52	6	7	2
3	BGUDI 88×MAI 349	81.57	12	-0.57	-0.20	1.27	8	20	11
4	BGUDI 120×VL109252	83.80	5	-0.15	-0.29	0.44	4	9	4
5	MAI 394×BGUDI 88	84.17	2	-0.03	0.08	0.10	1	3	1
6	MAI 283×KDMI 16	84.02	4	-0.89	-1.21	2.28	13	17	10
7	MAI 349×MAI 283	80.53	13	-0.66	0.55	1.54	11	24	13
8	MAI 283×BGUDI 120	79.52	15	-1.36	0.53	3.02	15	30	15
9	Arjun	82.95	10	1.12	-0.57	2.51	14	24	14
10	CP 818	83.43	7	0.65	-0.39	1.47	10	17	9
11	NK 6240	82.31	11	0.74	0.32	1.64	12	23	12
12	Nityashree	79.75	14	0.15	-0.08	0.34	2	16	8
13	Hema	83.22	9	0.18	0.04	0.38	3	12	5
14	DKC 9133	83.79	6	0.57	0.54	1.35	9	15	7
15	DKC 9150	83.35	8	0.17	0.85	0.92	7	15	6

Table 2. Continued.

		Test weight (g)								Grain yield plant^{-1} (g)							
No	Hybrids	Mean	Rank	IPC1	IPC2	ASV	Rank	SI	Rank	Mean	Rank	IPC1	IPC2	ASV	Rank	SI	Rank
1	KDMI 16×MAI 283	32.96	5	-0.29	-0.29	0.56	3	8	1	189.00	4	0.73	1.55	2.37	5	9	3
2	KDMI 16×BGUDI 118	30.93	7	0.59	0.55	1.12	6	13	4	179.40	8	0.93	0.02	2.28	4	12	5
3	BGUDI 88×MAI 349	27.81	13	0.70	0.40	1.24	7	20	11	158.40	13	1.35	-1.43	3.60	8	21	11
4	BGUDI 120×VL109252	27.11	14	0.06	0.02	0.10	1	15	7	159.40	12	2.44	-2.60	6.52	13	25	14
5	MAI 394×BGUDI 88	28.04	12	0.25	0.03	0.42	2	14	6	155.60	14	-0.76	0.86	2.05	2	16	7
6	MAI 283×KDMI 16	29.53	9	0.73	0.44	1.29	8	17	9	189.50	3	-0.52	3.27	3.51	7	10	4
7	MAI 349×MAI 283	28.57	11	-0.02	0.62	0.62	4	15	8	188.80	5	-0.64	1.51	2.18	3	8	2
8	MAI 283×BGUDI 120	26.14	15	0.11	-0.96	0.97	5	20	12	164.30	10	1.67	0.39	4.11	9	19	10
9	Arjun	33.59	2	-0.92	0.23	1.55	10	12	2	176.00	9	2.45	-0.73	6.04	12	21	12
10	CP 818	32.98	4	1.06	-0.90	1.98	13	17	10	204.80	1	2.56	2.59	6.79	14	15	6
11	NK 6240	34.88	1	-0.91	1.19	1.93	12	13	5	200.60	2	0.70	-0.86	1.92	1	3	1
12	Nityashree	29.06	10	-0.53	-1.36	1.63	11	21	13	142.70	15	-1.27	0.50	3.15	6	21	13
13	Hema	29.73	8	1.52	-0.10	2.54	14	22	15	161.70	11	-6.99	-0.29	17.11	15	26	15
14	DKC 9133	32.59	6	-1.66	-0.85	2.90	15	21	14	186.30	6	-1.92	-0.52	4.73	11	17	8
15	DKC 9150	33.43	3	-0.67	0.96	1.48	9	12	3	179.90	7	-0.74	-4.25	4.62	10	17	9

to environment can be assessed using the bi-plot graphical representation that scatters the genotypes according to their interaction principal component (IPC) scores. GGE bi-plot displaying which-won-where pattern of the data, help to identify high yielding stable cultivars and discriminate the test environments (Yan *et al*. 2001). Among GGL bi-plots, polygon view of bi-plot is the best way to visualize GLI patterns (Yan *et al*. 2000).

The polygon is formed by connecting the markers of the hybrids that are further away from the origin in a way that all other genotypes are contained in the polygon. Hybrids located on the vertices of the polygon performed either the best or the poorest in one or more locations as the longest distance mapped by them from the origin. Contribution of PC1 and PC2 towards total variation for different characters is presented in Fig. 1 -11. Hybrids, NK 6240 and Hema are vertex hybrids in E I and E II, CP 818 and MAI 283×BGUDI 120 in E III for days to anthesis. The vertex hybrids for days to silking are NK 6240 and Nityashree in E I and E II and CP 818 in E III. The vertex hybrids for ASI in E I and E II are Nityashree and MAI 283×BGUDI 120 and for E III, it was CP 818. Hybrids, MAI 283×KDMI 16 and DKC 9150 for ear length, DKC 9133 for ear circumference, NK 6240 for kernel rows ear^{-1}, KDMI 16×BGUDI 118 for kernels row^{-1}, MAI 283× BGUDI 120 for plant height, Hema and DKC 9150 for shelling % are the vertex hybrids.

Table 3. Estimates of environmental indices for grain yield and its component traits in maize across three locations.

Trait	Environment I (E I) GKVK, UAS, Bengaluru (Zone 5)	Environment II (E II) ARS, Bheemarayanagudi (Zone 3)	Environment III (E III) Village: Kudapali Dist: Haveri (Zone 8)
Days to anthesis	-0.55	1.24	-0.68
Days to silking	-0.25	0.83	-0.57
ASI	0.22	-0.34	0.12
Ear length (cm)	-2.87	1.98	0.88
Ear circumference (cm)	1.02	-0.93	-0.09
Kernel rows ear^{-1}	-0.43	0.28	0.14
Kernels rows^{-1}	-2.64	2.6	0.05
Plant height (cm)	-13.6	9.3	4.4
Shelling %	1.2	0.02	-1.24
Test weight (g)	-1.95	2.65	-0.71
Grain yield plant^{-1} (g)	-9.8	20.3	-10.5

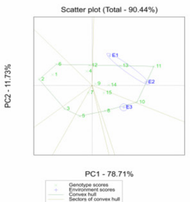


Fig 1.

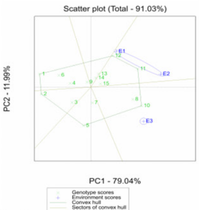


Fig 2.

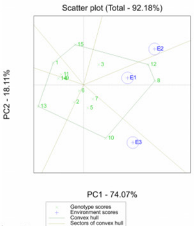


Fig. 3

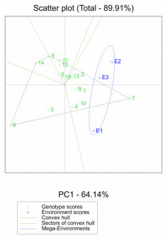


Fig. 4

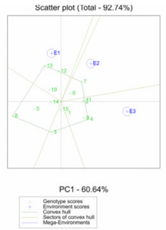
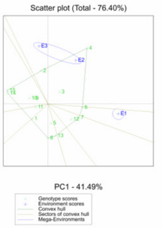


Fig. 5



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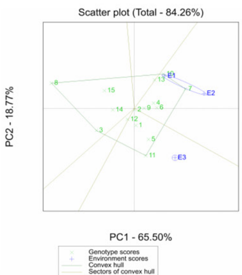

Fig. 7

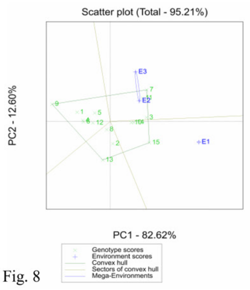

Fig. 8

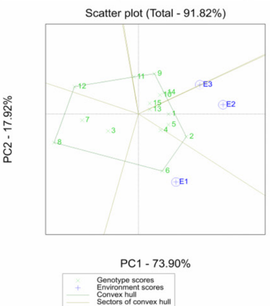

Fig. 9

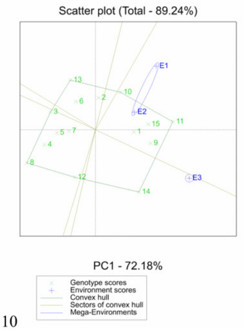

Fig. 10

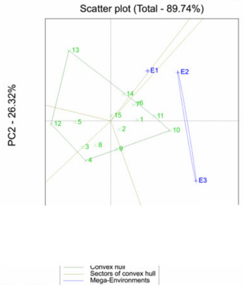

Fig. 11

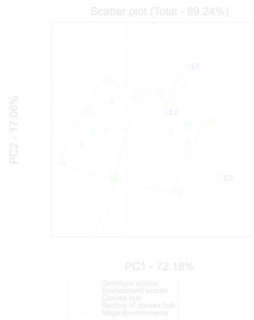

Fig. 1. GGE bi-plot for days to anthesis. **Fig. 2.** GGE bi-plot for days to silking. **Fig. 3.** GGE bi-plot for ASI. **Fig. 4.** GGE bi-plot for ear length. **Fig. 5.** GGE bi-plot for ear circumference. **Fig. 6**. .GGE bi-plot for kernel rows ear^{-1}. **Fig. 7.** GGE bi-plot for kernels row^{-1}. **Fig. 8**. GGE bi-plot for plant height. **Fig. 9**. GGE bi-plot for shelling %. **Fig. 10**. GGE bi-plot for test weight. **Fig. 11**. GGE bi-plot for grain yield plan^{t-1} .

The vertex hybrids for grain yield per plant^{-1} in E I, E II and E III are DKC 9133, NK 6240 and CP 818, respectively (Fig. 11). The near origin positioning of the hybrids, MAI 349×MAI 283 and Arjun for days to anthesis; Arjun and MAI 283×KDMI 16, respectively, for days to silking and ASI and KDMI 16× BGUDI 118 and DKC 9150 for grain yield plant^{-1} in the bi-plot suggested their wide adaptation across locations. Earlier, Sserumaga *et al.* (2016) and Lalisa Ararsa *et al.* (2016) reported the vertex genotype in each sector representing the highest yielding genotype in the location and Shrestha (2013) found ideal maize genotypes that have both high mean yield and stability, located at the centre of the GGE bi-plot. Thus, GGL bi-plot provided an effective means for visual interpretation of GLI patterns and identification of adaptable genotypes. However, it does not provide an objective means to identify genotypes with specific/ wide adaptation. Therefore, AMMI stability value (ASV) (Purchase *et al*. 2000) and Stability index (SI) (Farshadfar 2011) are considered for assessment of stability/adaptability and identification of specifically/ widely adapted genotypes.

AMMI stability values (ASV)

An ideal genotype should have high mean grain yield and low magnitude of ASV. Based on ASV the hybrids MAI 349×MAI 283, DKC 9150 and BGUDI 120×VL 109252 were identified with least ASV for days to anthesis, days to silking and ASI, respectively. Hybrid MAI 349 × MAI 283 for cob length; MAI 283 × KDMI 16 for cob circumference; BGUDI 88 × MAI 349 for kernel rows ear^{-1}; Arjun for kernels row^{-1}; MAI 349 × MAI 283 for plant height; MAI 394 × BGUI 88 for shelling %; BGUDI 120 × VL 109252 for test weight and NK 6240 for grain yield plant^{-1} were identified as widely adaptable across the locations (Table 2).

Stability index (SI)

It is useful to identify stable genotypes based on both mean yield and stability. Low magnitude of SI indicates wide adaptability. Based on this criterion, hybrids MAI 349 × MAI 283, Arjun, BGUDI 120× VL 109252, were identified as widely adapted across the locations for days to anthesis, days to silking and ASI, respectively. Similarly, MAI 349 × MAI 283 for ear length, ear circumference and plant height and BGUDI 88 ×MAI 349 and MAI 283×KDMI 16 for kernel rows ear^{-1} and kernels row^{-1}, MAI 394× BGUDI 88 for shelling %, KDMI 16 × MAI 283 for test weight and NK 6240 for grain yield plant^{-1} were identified as widely adapted across the locations (Table 2). Earlier reports by Nzuve *et al.* (2013), Lalisa *et al.* (2016) and Faria Sirlene Viana *et al.* (2017) have recommended specific genotypes with specific/ wide adaptation in maize. Thus, it is evident from the discussion that, widely adaptable hybrids may not be the best performers for all the characters. On the contrary, the best performers may exhibit poor adaptability. Based on ASV and yield SI hybrids, MAI 349×MAI 283 and BGUDI 120×VL 109252 for flowering and MAI 349×MAI 283 and KDMI 16 × MAI 283 for grain yield were identified as widely adapted across locations.

Production environments are often classified as favorable or unfavourable based on the environmental index, where, production environments with a positive index are considered as favorable for expression of the characters. In the present study, production environment at location Agricultural Research Station, Bheemarayanagudi (E II) was found to be favorable for expression of most of the traits (Table 3). Previously, Emre *et al.* (2009) and Lalisa *et al.* (2016) have reported positive and negative environmental indices to indicate the favorable and unfavorable production environments for expression of different traits in maize.

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