Maize Journal (April 2021) 10(1): 30-37

RESEARCH PAPER

Identification of stable genotypes across the ecologies using GGE analysis

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Abstract: Maize is an important cereal crop after wheat and rice. It is grown on a wide range of environments across the world. Genotype × environment interaction affects the relationship between phenotype and genotype in breeding programmes, particularly for quantitative traits. So, multi environment trials (MET) are used for identification of stable genotypes across the environments. To assess the differential performance of the 18 maize hybrids, an experiment was conducted under three different moisture regimes *viz.*, irrigated, rainfed and drought condition. Amongst tested hybrids ZH 161361, ZH 161311 and ZH 161083 were the most superior hybrids with grain yield 9.274, 7.845 and 7.774 t/ha across the environments. Four hybrids, *viz.*, ZH 161114, ZH 161276, ZH 161137 and ZH 161042 recorded > 70 per cent yield reduction under drought condition in comparison to optimum input level. The top performing genotypes, *viz.*, ZH 161038, ZH 161361 and ZH 161083 also performed poorly under rainfed and drought conditions. The yield reduction of these genotypes varied from 33.99 to 48.01 per cent under rainfed conditions, whereas the same was 46.2 to 70.7 per cent under drought conditions. Among the top performing hybrids ZH 161083 was the most stable hybrid across the locations, whereas ZH 161361 and ZH 161038 were less stable hybrids. ZH 161361 was the best performing genotype both under optimum and drought condition with grain yield 17.239 and 9.274 t/ha, whereas ZH 161083 out performed under rainfed condition than rest of the hybrids.

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Received: 07 October 2020/ Accepted: 15 February 2021

Keywords: Drought · Genotype × environment interaction · GGE · Grain yield · Rainfed

Introduction

Maize constitutes about 9 per cent of the total volume of cereals produced and is the third most important crop after rice and wheat. Maize cultivation is increasing day by day because of its high productivity, relative ease of cultivation, processing, storage and transportation. Superior maize hybrids need to be developed to meet the rising demand of maize. The development of new high yielding maize hybrid is a complex process consisting of evaluation of newly developed hybrids over the years and locations. It is highly impractical to meet all the demand of a crop during the growing period and provide all the inputs at optimum level. Most often, the crop experience limitation in different input levels and subjected to number of stresses during the period in farmer's field. The temperature rise due to the global climate change is expected to increases the risk of drought stress to the growing crops across the world. The global maize production decreased around 40 per cent due to the drought stress (Daryanto *et al.*, 2016). Haseeb *et al.* (2020) reported the minimum effects of drought were at control and 90 per cent irrigation water, whereas the adverse drought effects were observed under the treatment of drought at 20 per cent and 40 per cent irrigation water. Yield of maize crop is highly dependent to the amount of rainfall received, distribution, and duration, particularly in absence of assured irrigation. Further, most of the maize growing areas in India are rainfed without any assured irrigation. Identification of hybrids with high grain yield adapted to diverse environments and least affected under stress conditions is one of the most important objectives in maize breeding programs. The alternate strategy is to identify environment specific superior cultivars. Selection of genotypes purely based on yield may be misleading in presence of G × E interaction (Kang *et al.*, 1991), as the ranking of genotypes changes due to the cross over interaction. Thus, multi-environment yield trials are essential for estimation of genotype by environment (G × E) interaction and identification of superior stable genotypes (Yan *et al.*, 2000). Though different methods, *viz.*, analysis of variance (ANOVA), regression analysis, principal component analysis (PCA), cluster analysis are available to detect the G × E interaction, two models, *viz.*, AMMI (Additive Main Effects and Multiplicative Interaction) and GGE (Genotype and Genotype by Environment interaction) developed by Gauch and Zobel (1996) and Yan *et al*. (2000), respectively attracted much attention of plant breeders particularly for easy visualization and interpretation. AMMI analysis interprets the effect of the genotype (G) and environment (E) as additive effects and the G × E interaction as a multiplicative component, whereas GGE biplot uses both genotype (G) and GE interaction effects to extract the principal components (PCs) which are plotted to form different biplots, *viz.*, mean versus stability, which won where, discriminative versus representative etc. (Yan *et al.*, 2001). GGE biplot is an effective method based on principal component analysis (PCA) to fully explore MET data. The objective of this study was to evaluate stability and adaptability of experimental maize hybrids using GGE biplot and identify the outperforming genotypes under specific environments.

Materials and methods

Genetic material

The experimental material consists of 18 hybrids include ZH 161038, ZH 161042, ZH 161050, ZH 161053, ZH 161063, ZH 161066, ZH 161077, ZH 161083, ZH 161093, ZH 161114, ZH 161129, ZH 161137, ZH 161276, ZH 161289, ZH 161311, ZH 161361, ZH 161409 and ZH 161434. These hybrids were supplied by CIMMYT under the CRMA project (Table 3).

Field trials

The 18 maize hybrids were evaluated at three different locations, *viz.*, Ludhiana, Godhra and Varanasi. During *kharif* season of 2017, the material was evaluated under irrigated and rainfed conditions at Ludhiana and Godhra, respectively whereas, the same was evaluated under drought conditions at Varanasi during winter 2017. All India Coordinated Research Programme (AICRP) on maize has identified five agro-ecological zones in the country. The selected three locations belong to three different zones, *viz.*, Ludhiana represents North Western Plain Zone (NWPZ), Varanasi represents North Eastern Plain Zone (NEPZ) and Godhra represents Central West Zone (CWZ). Irrigation was withheld for one week before onset of flowering to create the water stress conditions at Varanasi. The latitude, longitude, altitude, soil type, rainfall, relative humidity and temperature of these test locations are presented in Table 1. The trials were arranged in a randomized complete block design with two replications. The row to row distance was 60 cm and 30 cm distance was maintained between the plants. The standard agronomic practices were followed according to the local agro-ecological conditions. The grain yield in tonnes/hectare (t/ha) was estimated at 15 per cent moisture for each of the entry in each location.

Table 1. Climatic and geographical information of the testing sites

S.No.	Locations	Geographic Position		Altitude	Soil Type	Rainfall	Humidity	Temperature
		Latitude	Longitude					
1.	Ludhiana	30.91°N	75.85°E	262 m	Sandy loam to clayey	876 mm	51%	19–36°C
2.	Godhra	22.77°N	73.62°E	73m	Loam sandy	530.3 mm	35%	24–40°C
3.	Varanasi	25°19′08″N	83°00′46″E	80.71m	Alluvial	1110 mm	57%	22–46°C

Statistical analysis

The analysis of variance (ANOVA) was performed in SPSS 16.0 software. Analysis of variance was calculated using the model:

$$Y_{ij} = m + G_i + E_j + GE_{ij}$$

Where, Y_{ij} is the corresponding variable of the i-th genotype in j-th environment (location), μ is the total mean, G_i is the main effect of i-th genotype, E_j is the main effect of j-th environment, GE_{ij} is the effect of G × E interaction. Different biplots, *viz*., discriminative versus representative plot, mean versus stability plot and which won where biplot were derived using the GEA-R software (Pacheco *et al*., 2015).

Results and discussion

Variation for grain yield

The combined ANOVA revealed significant variation for genotype, environment and their interaction (G × E) effect for grain yield (Table 2). The most promising hybrids were ZH 161038, ZH 161361, ZH 161083, ZH 161276, ZH 161289, ZH 161042, ZH 161311, ZH 161050, ZH 161409, ZH 161114, ZH 161053, ZH 161434 and ZH 161093 with grain yield >10.0 t/ha under optimum condition. Out of these 13 entries, two hybrids, *viz*., ZH 161038 and ZH 161053 revealed superior performance under rainfed condition also, with grain yield 11.429 and 10.048 t/ha, respectively. Though most of the hybrids recorded

Table 2. Analysis of variance for yield at three environments

Source of variation	DF	SS	MS	F	Probability
Genotype (G)	17.00	44334.51	2607.91	34.11	0.00
Replication (R)	1.00	210.90	210.90	2.76	0.10
Environment (E)	2.00	82659.57	41329.78	540.59	0.00
G × E	34.00	32068.74	943.20	12.34	0.00
Error	53.00	4052.03	76.45		
CD	20.36				
CV (%)	10.73				

Table 3. Mean grain yield of maize hybrids at different locations

S.No.	Genotype	Grain yield (t/ha)			Mean yield
		Optimum (E1)	Rainfed (E2)	Drought (E3)	(t/ha)
1.	ZH 161038	17.314	11.429	5.071	11.271
2.	ZH 161042	13.469	8.762	3.917	8.716
3.	ZH 161050	12.843	3.929	5.976	7.583
4.	ZH 161053	11.004	10.048	7.631	9.561
5.	ZH 161063	9.79	7.738	7.417	8.315
6.	ZH 161066	5.049	6.19	2.726	4.655
7.	ZH 161077	6.952	5.714	5.107	5.924
8.	ZH 161083	16.945	8.81	7.774	11.176
9.	ZH 161093	10.415	7.857	5.786	8.019
10.	ZH 161114	11.513	7.262	2.00	6.925
11.	ZH 161129	9.788	2.619	7.298	6.568
12.	ZH 161137	7.95	4.762	1.893	4.868
13.	ZH 161276	15.638	7.976	3.50	9.038
14.	ZH 161289	15.562	8.624	6.679	10.288
15.	ZH 161311	12.964	5.409	7.845	8.739
16.	ZH 161361	17.239	9.286	9.274	11.933
17.	ZH 161409	11.989	5.976	4.036	7.334
18.	ZH 161434	10.589	8.69	5.143	8.141

reduced grain yield under drought condition, the top three entries were ZH 161361, ZH 161311 and ZH 161083 with grain yield 9.274, 7.845 and 7.774 t/ha (Table 3).

Performance of genotypes under different ecologies for flowering and anthesis silking interval (ASI)

Observations on 50 per cent pollen shedding, silking and anthesis silking interval were recorded for all genotypes during the time of flowering. Significant differences in anthesis silking interval were observed under optimum, rainfed and drought conditions. ASI is highly correlated with grain yield as the adverse conditions i.e. drought causes a delay in silk emergence thus reduction in yield occurs. With the drought stress, ASI was severely affected due to non-availability of water during flowering period. There was not any visible differences in ASI reported under optimum and drought conditions (Table 4). However, under drought conditions, larger and prolonged anthesis silking interval (>8 days) was observed for the genotypes ZH 161137, ZH 161042, ZH 161066 and ZH 161409. Genotypes ZH 161050, ZH 161077 and ZH 161311 have shorter ASI.

Yield reduction under rainfed and drought condition

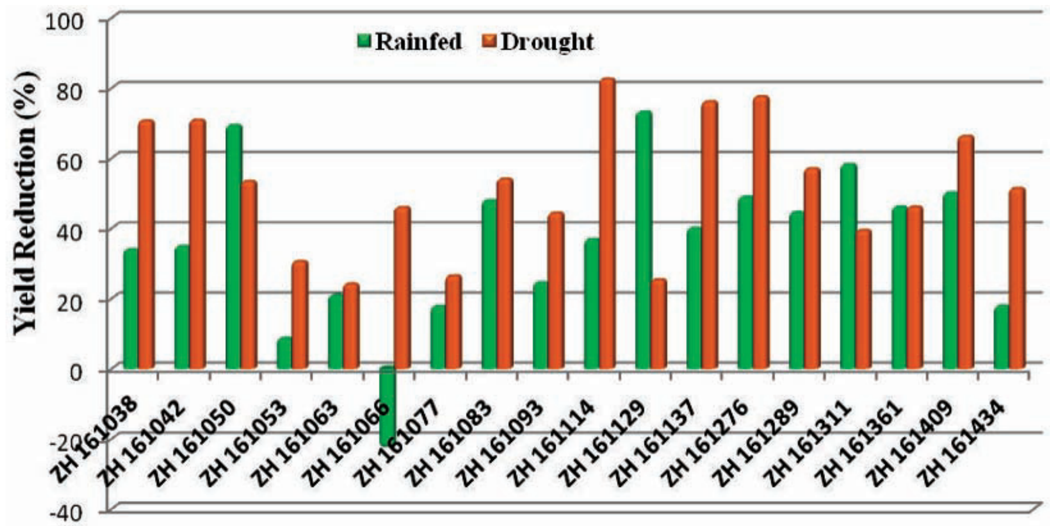
Performance of cultivars are expected to reduce under rainfed and drought condition in comparison to optimum input level, however variable response is expected for different genotypes. The most affected genotype under rainfed condition was ZH 161129 which recorded 73.24 per cent yield reduction followed by ZH 161050 (69.41 per cent) and ZH 161311 (58.28 per cent) (Figure 1). One hybrid *i.e.* 161066 recorded higher yield under rainfed condition (6.19 t/ha) than optimum condition (5.049 t/ha). Four hybrids, *viz*., ZH 161114, ZH 161276, ZH 161137 and ZH 161042 recorded >70 per cent yield reduction under drought condition in comparison when the crop was grown under optimum input level (Figure 1). The least affected hybrids under rainfed condition were ZH 161053, ZH 161077 and ZH 161434, whereas the hybrids, *viz*., ZH 161063, ZH 161129 and ZH 161077 were least affected under drought. The yield of ZH 161077 was most consistent across the locations, however it recorded average yield in all the three locations (optimum: 6.952 t/ha, rainfed: 5.714 t/ha and drought: 5.107 t/ha). The top performing genotypes, *viz*., ZH 161038, ZH 161361 and

Table 4. Days to anthesis and silking of the genotypes under different ecologies

S.No.	Genotype	Optimum (E1)			Rainfed (E2)			Drought (E3)		
		DA	DS	ASI	DA	DS	ASI	DA	DS	ASI
1.	ZH 161038	55	57	2	55	57	3	102	107	5
2.	ZH 161042	54	59	5	58	60	2	99	104	8
3.	ZH 161050	59	62	3	56	59	3	107	111	4
4.	ZH 161053	54	56	2	54	55	1	101	107	6
5.	ZH 161063	53	56	3	55	58	3	97	102	5
6.	ZH 161066	59	61	2	57	59	2	100	108	8
7.	ZH 161077	59	61	2	57	59	2	104	108	4
8.	ZH 161083	54	57	3	56	58	2	100	107	7
9.	ZH 161093	53	55	2	55	57	2	102	108	6
10.	ZH 161114	59	61	2	58	61	3	104	111	7
11.	ZH 161129	53	55	2	56	59	3	102	107	5
12.	ZH 161137	58	60	2	55	58	3	99	108	9
13.	ZH 161276	56	58	2	58	60	2	105	110	5
14.	ZH 161289	57	61	4	56	58	2	103	110	7
15.	ZH 161311	54	57	3	56	58	2	104	108	4
16.	ZH 161361	54	58	4	58	60	2	103	109	6
17.	ZH 161409	54	58	4	58	61	3	103	111	8
18.	ZH 161434	54	56	2	54	56	2	101	108	7

DA: Days to anthesis; DS: Days to silking; ASI: Anthesis-silking interval

Figure 1. Reduction in yield of maize hybrids under rainfed and drought condition compared to optimal condition



ZH 161083 also performed poorly under rainfed and drought condition, and reduction in yield in these genotypes varied from 33.99 to 48.01 per cent under rainfed and 46.20 to 70.71 per cent under drought. High yielding genotypes under well-watered conditions showed less amount of yield reduction under drought compared to less yielding genotypes in earlier findings also (Duvick, 1984; Castleberry *et al*., 1984; Frederick *et al*., 1989). However, in the present study, the genotypes could not reveal such specific trend and the high yielding hybrids also recorded yield loss even up to 70.71 per cent. Similar results were reported by Kamara *et al*. (2003), where the high yielding genotypes under optimum condition recorded about 70 per cent yield reduction in water-deficit conditions.

Identification of stable hybrids across the locations

G × E interactions possess paramount importance to breeders to develop location specific and generally adapted cultivars (Kang *et al*., 1994). The mean versus stability biplot can measures the influence of environments on a specific trait and identify the most promising genotypes across or specific location. The PC1 and PC2 explained 69.45 per cent and 18.11 per cent variation, respectively of total G + GE variation, together PC1 and PC2 could explain 87.56 per cent of variation (Figure 2). The direction of the arrow shown on the axis of the Average Environment Coordination (AEC) abscissa indicates the higher mean performance of the genotypes. Hence, the high yielding genotypes can be identified from the biplot by seeing the placement of genotypes with respect to the direction of arrow. The AEC ordinate marks the contributions to G × E interaction and represents the stability of genotypes across the locations. The genotypes near to origin are more stable compared to the outermost genotypes. An ideal genotype should possess the highest mean performance and absolute stability. Among the top performing hybrids, ZH 161083 was the most stable hybrid across the locations, whereas ZH 161361 and ZH 161038 were less stable hybrids. Further, ZH 161289 and ZH 161053 also revealed more stability with moderate mean (10.288 and 9.561 t/ha, respectively). Shiri and Bahrampour (2015) also used GGE biplot and reported the better performing maize hybrids across the environments. It is important to develop higher yielding hybrids for drought stress and rainfed condition which can equally perform under optimum moisture conditions. Maize hybrids of such calibre will reduce the risk of farming communities living in drought-prone areas and also contribute to increase the national maize productivity.

Which won where biplot

The "which-won-where" view of the GGE biplot helps to easily identify the best performing genotype(s) in each of the environments (Yan *et al*., 2002). The perpendicular lines initiating from the origin, divide the polygon into different sectors (Figure 3). The vertex genotype is the best performing genotype in the environments falling in the same sector. ZH 161066, ZH 161129, ZH 161361, ZH 161038 and ZH 161114 were the vertex genotypes of the polygon (Figure 3). Mafouasson *et al*. (2018) also identified stable genotypes across the ecologies using GGE

Figure 2. Average environment coordination views of the GGE-biplot for the mean performance and stability of genotypes

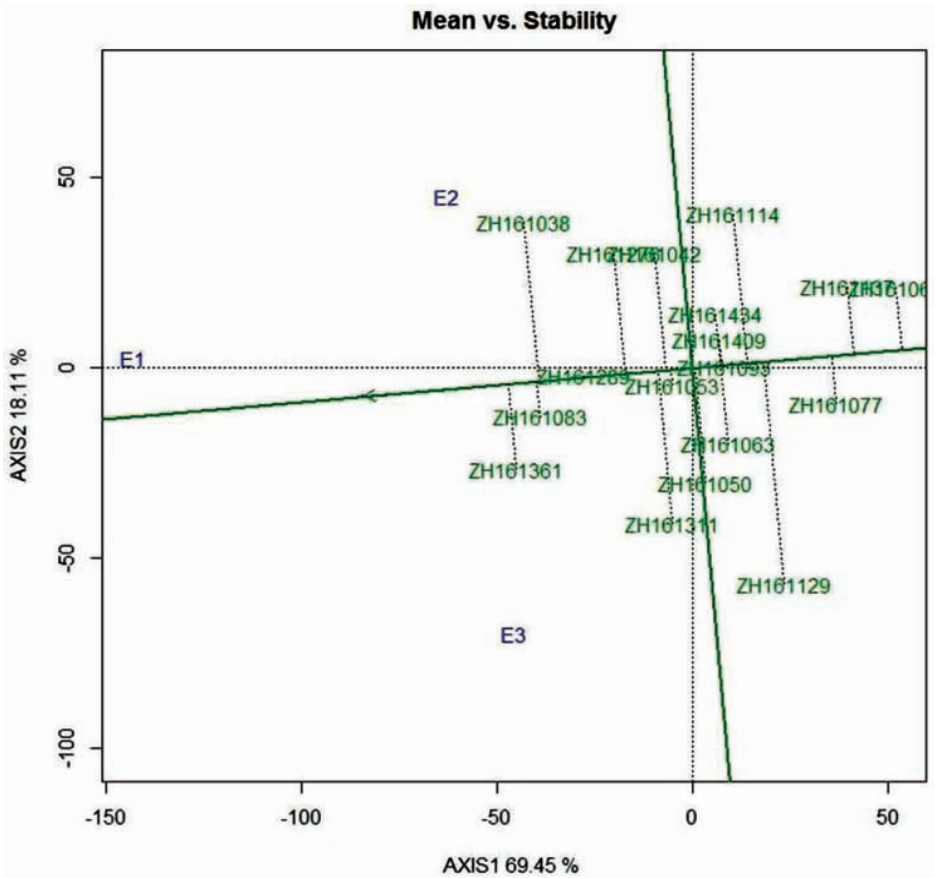
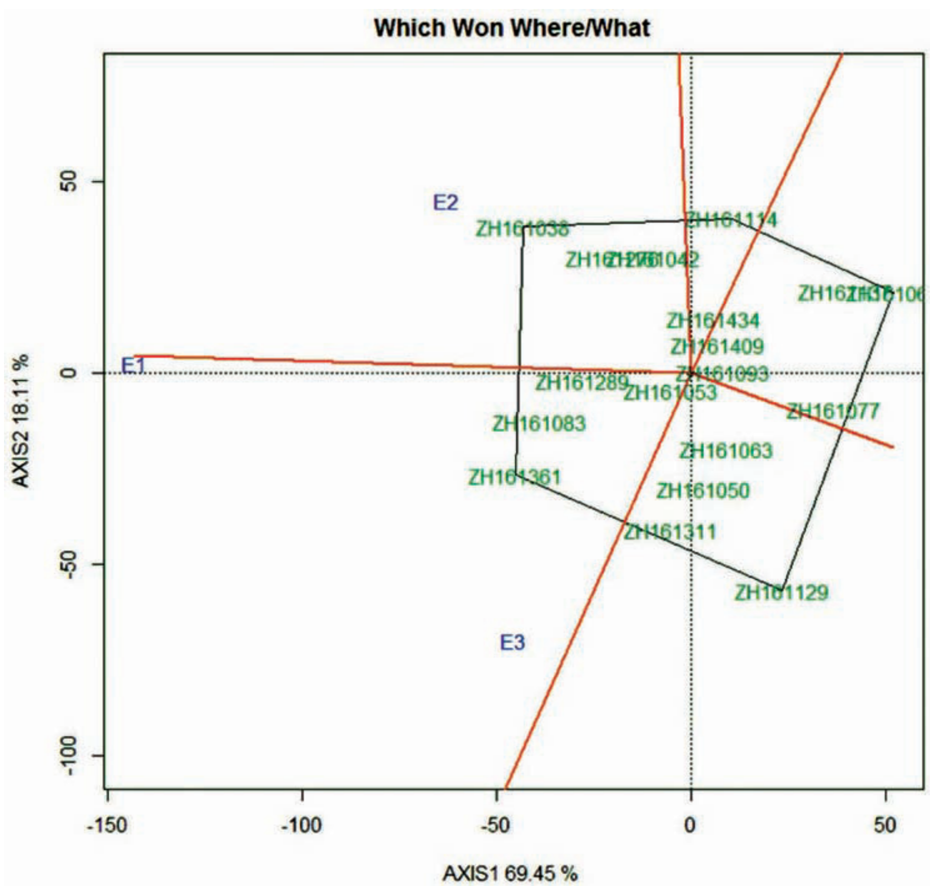


Figure 3. Polygon views of the GGE biplot for the genotype by environment 2-way data



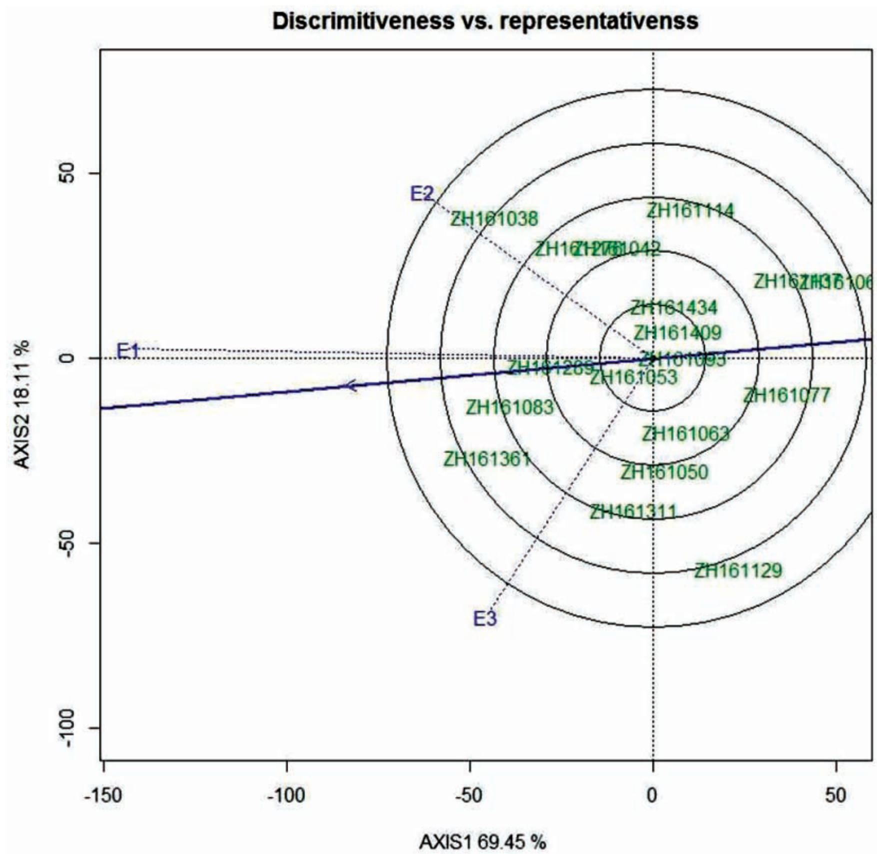


Figure 4. Discrimitiveness vs. representativenss of test environments

biplots. ZH 161361 was the best performing genotype both under optimum and drought condition with grain yield 17.239 and 9.274 t/ha, whereas ZH 161083 out performed under rainfed condition than rest of the hybrids.

Discriminating power versus representativeness of test environments

The power of an environment to differentiate among genotypes is known as discriminative power, whereas representativeness is how efficiently it can represent the mega environment. Superiority of an environment for discriminative and representative power is indicated by longer vector length of the environment and smaller angle with the average-environment axis. E1 (optimum) revealed the longest vector length as well as the smallest angle with average-environment axis. Hence, E1 is the ideal test environment among the three, as full expression of genotypes is expected under optimum condition only which is oppressed under any stress condition (Figure 4).

Conclusion

The present study could identify stable hybrids across the different environments, *viz*., irrigated, rainfed and drought and at the same time genotype suitable for particular environment. However, the identified hybrids need to be tested in more number of replicated environments to validate the findings.

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