International Journal of Agriculture and Plant Science
www.agriculturejournal.in
Online ISSN: 2664-7664
Received: 29-07-2026, Accepted: 28-08-2026, Published: 12-09-2026
Volume 8, Issue 3, 2026, Page No. 442-446

Genotype× environment interaction and stability of different genotypes for different characters in Maize (*Zea mays* L.)

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DOI: https://doi.org/10.66856/ijaps.2026.8.3.8261

Abstract

Genotype × Environment interaction consists of the different response of individual genotypes resulting from changing environmental condition. Stability parameters help in understanding the adaptability of a genotype for its performance over a wide range of environments. In the present field work, 7 inbred lines, 21 single cross hybrids and one check (DKC-9162) were evaluated under three different environments (three different season i.e., Rabi 2024-25, Zaid 2025 and Kharif 2025) for their stability. Analysis of variance for stability revealed that mean sum of square due to genotype x environment (linear) were significant for plant height, ear placement, cob weight and biological yield per plant and significant for pooled deviation for all characters indicating that the differences in stability for these characters due to linear (bi) and non-linear (S^2di) parameters. Among the hybrids, HUZM-27 x HUZM-25, HUZM-26 x HUZM-25 and HUZM-23 x HUZM-22 showed non- significant deviation from regression line (S^2di) and regression coefficient greater than unity (bi>1) along with high mean value than the population mean for grain yield per plant, thereby indicating stability under favourable environments and suitability for maximum grain yield per plant. Hybrids HUZM-26 x HUZM-22 and HUZM-26 x HUZM-21 showed non-significant deviation from regression line (S^2di) and regression coefficient lower than unity (bi<1) along with high mean value than population mean for grain yield per plant, thereby indicating stability under unfavourable environments and suitability for maximum grain yield per plant.

Keywords: Genotype × environment interaction, G × E interaction, stability analysis, adaptability, maize, inbred lines, single cross hybrids

Introduction

Maize is one of the most important crop among the cereals. Globally, it is grown over an area of 33.547 million hectare with an annual production of 377.63 million tonnes and productivity of 11.26 tonnes/hectare (USDA 2025). In India its production is 434.09 lakh tonnes and the area is 120.91 lakh hectares with a productivity of 3590 kg/ha (Department of Agriculture & Farmer Welfare 2024-25). Maize (*Zea mays* L.) is a cereal crop belonging to the tribe Maydeae, of the grass family, Poaceae and has 2n=2x=20 chromosomes. It was domesticated over the past 10,000 years from the grass teosinte (*Zea mays* L. variety Mexicana) in Central America and has been subject to cultivation and selection (Doebley *et al.*, 2006) [5]. It is originated in Mexico and Central America, but it is cultivated worldwide in various conditions due to its greater productive potential and wide range of adaptability (Yousuf *et al.*, 2021) [13]. Therefore, maize is regarded as Queen of cereals and Miracle Crop.However there is lack of high yielding stable genotypes that can perform better under different environmental condition. Testing open pollinated maize varieties in more seasons could enhance breeding efficiency with respect to genotype stability and less interaction with environments (Abate, 2020) [1]. All the above points in the present investigation were carried out for most stable high yielding hybrids.

Material and Methods

The experimental material for the present investigation comprises of 7 inbred lines, 21 single cross hybrids and one check (DKC-9162). These hybrids along with their parents and check variety were evaluated in randomized block design under three different seasons namely, Rabi 2024-25, Zaid 2025 and Kharif 2025 with three replications at experimental field Department of Genetics and Plant Breeding, Faculty of Agriculture, Kamla Nehru Institute of Physical and Social Sciences, Faridipur, Sultanpur U.P.228118 India. The plot size was 4 m and the spacing was 60 × 25 cm. All the observations were recorded on five randomly selected plant from each replication. The data on flowering (Tasseling and silking) and maturity traits were recorded on plot basis. The model which is used for the analysis of stability is Eberhart and Russell model (1966) [6].

Result and Discussion

A reliable method of estimation of stability was proposed by Finlay and Wilkinson in 1963 using regression analysis.According to Eberhart and Russell model 1966 for estimation of stability the regression coefficient and deviation from regression line are used.

Analysis of variance for stability (Table 1) revealed that the variance due to genotypewas significant for all the characters except anthesis-silking interval, days to 75% dry husk, 100-grain weight and shelling percentage, while the genotype x environment (linear) showed significant for plant height, ear placement, cob weight, biological yield per plant and grain yield per plant, suggesting that the genotypes differ greatly in their linear response to the different environments.Genotype x Environment interaction (linear) for plant heightwas also reported by Raj *et al.,* (2019) [10], Gami *et al.,* (2017) [8] and Kumar *et al.,* (2020) [9].The mean due to pooled deviation were found highly significantfor all the characters under study which suggested that the genotypes varied considerably for stable performance. Similarly, Synrem*et al.,* (2017) [12], Sowmya *et al.,* (2018) [11] and Dev *et al.,*(2009) [4] reported significant differences of maize genotype for grain yield.

The stability was assessed by considering the mean performance of the genotype over the environments (xi), the linear regression of the genotypes over environment indices (bi) and the deviation from this regression (S^2di). The stable hybrid is that one which exhibited a high mean, a regression coefficient (bi) around or equal to unity (bi=1) and a deviation from the regression (S^2di) as small as possible or approaching zero. If the regression coefficient (bi) is greater than unity, the genotype is highly susceptible to environmental instability but adopted to high yielding environments. If the regression coefficient (bi)is equal to unity, it indicates medium susceptible to environmental instability but adopted in all environments. If the regression coefficient (bi) less than unity, it indicates less susceptible to environmental change and the genotype is better adopted in unfavourable environments. The stability parameters such as mean (X), regression coefficient (bi) and deviation from regression line (S^2di) as suggested by Eberhart and Russell (1966) [6] model.

Out of 29 genotypes, 16 genotypes showed non-significant deviation from regression (S^2di) for grain yield per plant (Table 2.). Among the hybrids, HUZM-27 x HUZM-25, HUZM-26 x HUZM-25 and HUZM-23 x HUZM-22 showed non-significant deviation from regression line (S^2di) and regression coefficient greater than unity (bi>1) along with mean value higher than the population mean, thereby indicating below average stability under favourable environments and suitability for maximum grain yield per plant. Hybrids, HUZM-26 x HUZM-22 and HUZM-26 x HUZM-21 showed non-significant deviation from regression line (S^2di) and regression coefficient lower than unity (bi<1) along with mean value higher than the population mean, thereby indicating above average stability under unfavourable environments and suitability for maximum grain yield per plant. The genotypes which are found stable for one or more characters are given in Table no. 3. Synrem *et al.,* (2017) [12], Sowmya *et al.,* (2018) [11] and Kumar *et al.,* (2020) [9] also reported stable performance for grain yield per plant and other characters.

Table 1: Analysis of Variance for Stability

Source of Variance	Genotype (G)	E+ (G×E)	E(Linear)	G×E(Linear)	Pooled Deviation	Pooled Error
D.F	28	58	1	28	29	168
D50%T	12.99**	2031.28	117586.45	4.1	3.89**	1.12
D50%S	15.018**	2004.48	116015.63	4.24	4.34**	1.14
ASI	0.34	0.38	6.25	0.26	0.29**	0.09
D75%DH	2.03	2445.54	141733.12	2.07	1.73*	1.04
PH	758.02**	4299.85	233881.08	458.23**	92.41**	26.89
EP	382.71**	2898.44	160031.66	257.08**	30.33**	15.22
100GW	12.29	14.52	432.98	5.41	8.89**	1.91
CW	568.99**	1040.4	39284.11	565.88**	179.81**	50.59
SHELLING %	86.15	90.95	650.02	98.62	64.27**	33.33
BY/P	11804.98**	41659.06	1983221.51	12653.65**	2713.86**	310.22
GY/P	625.99**	591.1	16737.12	406.49*	212.59**	33.99

*,** indicate the level of significance at 5% and 1%, respectively.

Table 2: Estimations of stability parameters for different characters in maize.

Genotypes	Days to 50% tasseling			Days to 50% silking			Anthesis silking interval		
	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
HUZM-27	88.67	1.00	-1.10	92.00	1.00	-1.11	3.33	1.01	-0.09
HUZM-26	90.22	1.01	-0.03	93.00	1.00	-0.01	2.78	2.07	-0.05
HUZM-25	87.44	0.95	-0.78	90.56	0.94	-1.03	3.11	2.63	0.26*
HUZM-24	88.67	0.96	-0.73	92.00	0.97	-0.29	3.33	0.44	0.09
HUZM-23	90.33	1.05	1.80	93.89	1.02	0.79	3.56	3.69	0.60**
HUZM-22	89.33	0.95	-0.80	92.33	0.94	1.07	3.00	3.48	0.18
HUZM-21	87.78	0.98	5.55*	90.67	0.98	9.93**	2.89	1.42	0.44*
HUZM-27 × HUZM26	86.00	1.05	7.84**	88.89	1.05	18.30**	2.89	0.21	1.75**
HUZM-27 × HUZM25	85.44	1.05	4.16*	87.78	1.05	4.08*	2.33	1.01	-0.09
HUZM-27 × HUZM24	84.56	1.04	9.62**	87.33	1.04	6.55**	2.78	0.93	0.24
HUZM-27 × HUZM23	83.22	1.01	3.93*	86.00	1.00	2.08	2.78	2.51	-0.04
HUZM-27 × HUZM22	84.67	0.99	16.74**	87.78	1.00	10.75**	3.11	0.36	0.84**
HUZM-27 × HUZM21	83.44	1.03	-0.67	86.33	1.03	-1.13	2.89	0.08	0.20
HUZM-26 × HUZM25	83.56	0.97	-1.04	86.33	0.97	0.93	2.78	0.17	1.09**
HUZM-26 × HUZM24	85.56	0.98	4.47*	88.00	0.98	5.53*	2.44	1.05	-0.03
HUZM-26 × HUZM23	84.33	1.01	4.99*	86.89	1.02	5.29*	2.56	-0.04	-0.02
HUZM-26 × HUZM22	84.78	1.00	-0.39	87.44	1.00	-1.00	2.67	1.46	0.12
HUZM-26 × HUZM21	83.33	1.01	1.23	85.78	1.01	1.35	2.44	0.49	-0.07
HUZM-25 × HUZM24	83.22	1.01	-1.11	86.11	1.01	-1.10	2.89	0.97	0.01

HUZM-25 × HUZM23	84.33	0.96	-1.10	87.00	0.98	-1.07	2.67	-0.57	0.06
HUZM-25 × HUZM22	86.78	0.98	0.27	89.22	0.99	1.44	2.44	0.04	-0.02
HUZM-25 × HUZM21	87.78	1.02	2.66	90.56	1.01	2.72	2.78	2.07	-0.05
HUZM-24 × HUZM23	85.56	1.00	-0.79	88.11	1.01	-1.10	2.56	-0.49	-0.07
HUZM-24 × HUZM22	85.89	0.97	-1.08	88.11	0.98	-1.06	2.22	-0.04	-0.02
HUZM-24 × HUZM21	85.44	1.07	3.09	87.78	1.08	0.79	2.33	-0.44	0.09
HUZM-23 × HUZM22	86.89	0.95	-1.01	89.22	0.95	-0.99	2.33	1.01	-0.09
HUZM-23 × HUZM21	86.00	1.02	14.42**	88.67	1.02	18.54**	2.67	1.46	0.12
HUZM-22 × HUZM21	87.67	0.99	7.20**	90.11	1.00	10.43**	2.44	0.93	0.24
DKC-9162	85.89	0.97	3.18	89.00	0.97	2.32	3.22	1.10	0.17
Mean	86.07			88.83			2.75		

*,** indicate the level of significance at 5% and 1%, respectively.

Table 2: Conti….

Genotypes	Days to 75% Dry Husk			Plant Height			Ear Placement		
	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
HUZM-27	128.44	1.04	1.55	172.43	0.58	255.27 **	65.02	0.69	37.81
HUZM-26	127.89	1.01	-1.04	170.55	0.77	257.60 **	58.31	0.79	97.94 **
HUZM-25	126.78	0.98	-0.93	202.28	0.79	-26.64	76.41	0.78	-11.55
HUZM-24	127.00	0.96	-0.90	178.64	0.68	450.86 **	62.06	0.72	49.78 *
HUZM-23	128.11	0.97	2.10	212.50	1.09	-6.46	93.43	1.18	-11.21
HUZM-22	129.00	1.00	0.47	175.77	0.88	-22.51	68.68	0.74	-4.73
HUZM-21	126.22	0.98	-0.33	186.17	0.79	-23.38	70.29	0.93	15.56
HUZM-27 × HUZM26	127.89	1.02	-0.16	210.52	1.15	115.71 *	79.94	1.03	-6.57
HUZM-27 × HUZM25	126.78	1.02	-0.15	230.49	1.58	-25.91	98.60	1.52	-14.65
HUZM-27 × HUZM24	126.89	1.00	-1.03	212.43	1.03	25.32	76.77	0.86	55.23 *
HUZM-27 × HUZM23	126.89	1.00	4.30 *	211.68	1.17	5.08	88.41	1.07	-11.99
HUZM-27 × HUZM22	127.44	1.01	0.32	217.39	1.11	65.16	88.21	0.99	26.39
HUZM-27 × HUZM21	126.78	1.01	-0.56	210.01	1.30	513.91 **	80.52	1.05	161.13 **
HUZM-26 × HUZM25	126.11	1.00	1.12	227.99	1.19	1.57	93.27	1.24	-2.58
HUZM-26 × HUZM24	126.33	1.00	3.67 *	197.49	0.47	101.91 *	69.96	0.55	-12.34
HUZM-26 × HUZM23	126.44	1.03	-0.20	216.17	1.07	-21.09	88.93	1.13	-5.88
HUZM-26 × HUZM22	127.11	1.03	-0.98	215.78	1.06	-20.54	92.41	1.12	-15.21
HUZM-26 × HUZM21	126.78	1.01	-0.10	212.79	0.75	-26.55	81.54	0.92	83.36 *
HUZM-25 × HUZM24	125.44	1.02	-0.81	213.14	1.07	-4.13	86.03	1.05	-15.17
HUZM-25 × HUZM23	126.44	1.01	-0.20	202.68	0.95	-24.95	80.04	0.95	6.42
HUZM-25 × HUZM22	126.33	0.99	2.76	199.63	0.87	45.19	80.82	0.99	-10.60
HUZM-25 × HUZM21	125.67	0.98	1.23	201.18	0.78	8.23	88.58	1.14	49.93 *
HUZM-24 × HUZM23	125.89	0.98	0.15	217.49	1.19	29.62	94.38	1.32	15.73
HUZM-24 × HUZM22	127.33	0.97	0.64	198.84	0.91	-2.51	73.27	0.74	-9.82
HUZM-24 × HUZM21	126.78	1.02	0.96	214.13	1.09	-26.74	89.01	1.23	-10.30
HUZM-23 × HUZM22	126.78	0.99	1.46	221.58	1.20	51.27	97.29	1.14	21.34
HUZM-23 × HUZM21	125.78	0.97	0.66	217.31	1.11	63.41	102.21	1.26	-12.55
HUZM-22 × HUZM21	126.67	0.98	0.71	203.78	1.06	101.57 *	88.60	0.95	-12.46
DKC-9162	126.89	0.99	5.37 *	219.73	1.30	39.79	86.10	0.94	-14.75
Mean	126.86			205.26			81.94		

*,** indicate the level of significance at 5% and 1%, respectively.

Table 2: Conti….

Genotypes	100-Grain Weight			Cob Weight			Shelling%		
	Mean	bi	S^2di	Mean	bi	S^2di	Mean	bi	S^2di
HUZM-27	31.39	0.34	34.61**	100.84	1.61	1035.55**	57.20	-0.68	-22.30
HUZM-26	32.54	1.72	-1.84	94.20	1.52	177.31*	54.74	1.31	-31.89
HUZM-25	28.60	0.59	-1.02	124.19	1.70	585.14**	65.32	2.58	-25.58
HUZM-24	27.87	-0.22	1.29	93.73	0.50	190.45*	59.82	5.53	28.80
HUZM-23	30.85	1.10	8.64*	106.60	0.49	-40.13	64.04	2.00	19.91
HUZM-22	27.17	0.91	10.94*	93.27	1.08	81.85	67.97	-2.35	313.63**
HUZM-21	30.77	1.39	0.65	112.23	2.43	-42.86	71.91	0.06	-22.38
HUZM-27 × HUZM-26	33.06	0.58	-0.92	114.43	0.31	196.05*	63.73	1.53	2.65
HUZM-27 × HUZM-25	29.96	0.63	37.01**	126.86	2.42	-42.90	65.79	0.61	-28.09
HUZM-27 × HUZM-24	32.77	0.16	1.40	116.99	1.42	-38.63	72.68	2.69	-5.37
HUZM-27 × HUZM-23	33.27	2.03	1.08	115.31	0.78	-9.10	67.73	-4.02	64.47
HUZM-27 × HUZM-22	32.54	2.55	-1.81	136.64	0.94	474.38**	66.71	0.42	344.46**
HUZM-27 × HUZM-21	35.06	0.82	-1.86	124.62	1.11	80.65	69.44	0.03	-32.4
HUZM-26 × HUZM-25	33.76	1.08	-0.94	150.17	1.97	231.55*	77.33	1.87	161.80*
HUZM-26 × HUZM-24	31.72	1.62	14.17**	113.81	-0.47	-45.17	64.07	1.93	302.18**
HUZM-26 × HUZM-23	33.51	0.90	0.37	131.39	0.48	165.15*	76.32	-0.26	302.18**

HUZM-26 × HUZM-22	34.70	1.00	9.08*	139.46	0.88	29.6	71.25	-0.12	-33.14
HUZM-26 × HUZM-21	34.79	0.55	5.38	131.20	0.51	508.38**	69.34	2.97	-33.21
HUZM-25 × HUZM-24	31.00	1.39	5.69*	113.38	0.47	-48.01	70.83	-2.61	-26.84
HUZM-25 × HUZM-23	32.30	0.52	7.43*	125.78	0.67	-47.89	72.04	3.50	-30.56
HUZM-25 × HUZM-22	31.89	1.42	4.03	108.52	0.98	31.78	72.72	3.31	-14.58
HUZM-25 × HUZM-21	29.94	1.27	6.72*	112.74	0.08	34.02	75.12	0.60	-10.09
HUZM-24 × HUZM-23	31.39	0.88	11.14**	113.14	1.18	-41.53	67.64	0.82	-11.31
HUZM-24 × HUZM-22	33.42	1.22	25.47**	106.48	1.07	129.22	67.20	3.29	-32.91
HUZM-24 × HUZM-21	32.71	1.24	-0.67	103.33	1.04	-17.70	70.66	3.80	-18.81
HUZM-23 × HUZM-22	32.98	0.92	15.42**	125.48	1.25	-39.07	64.01	-0.38	-33.33
HUZM-23 × HUZM-21	31.30	0.22	-1.25	109.60	0.64	270.58*	75.24	-1.27	15.96
HUZM-22 × HUZM-21	32.94	0.42	13.92**	111.08	0.68	-11.12	67.71	1.64	1.88
DKC-9162	35.32	1.73	-1.6	110.72	1.29	-50.06	68.91	0.19	86.73
Mean	31.99			115.30			67.98		

*,** indicate the level of significance at 5% and 1%, respectively.

Table 2: Conti….

Genotypes	Biological yield per plant			Grain yield per plant		
	Mean	bi	S^2di	Mean	bi	S^2di
HUZM-27	342.44	0.93	1617.49*	58.09	1.69	82.42
HUZM-26	303.36	0.50	242.7	50.19	1.11	88.62
HUZM-25	469.79	1.45	2167.38**	89.49	1.41	392.99**
HUZM-24	287.89	0.75	134.26	56.60	0.26	1175.32**
HUZM-23	367.10	0.96	-172.21	67.58	0.53	52.48
HUZM-22	301.34	0.86	436.54	58.44	0.58	24.58
HUZM-21	401.11	1.53	800.74	76.32	2.25	-28.49
HUZM-27 × HUZM-26	414.38	1.18	2896.31**	72.16	0.47	388.29**
HUZM-27 × HUZM-25	485.90	1.88	-32.79	79.69	2.05	-33.73
HUZM-27 × HUZM-24	409.47	0.96	1536.10*	84.84	1.42	143.28*
HUZM-27 × HUZM-23	458.64	1.35	2917.62**	82.80	2.00	643.07**
HUZM-27 × HUZM-22	429.81	0.83	3907.71**	90.22	-0.24	606.54**
HUZM-27 × HUZM-21	409.23	0.92	4579.40**	94.64	1.81	417.31**
HUZM-26 × HUZM-25	552.41	1.69	2084.06**	117.88	2.77	-15.08
HUZM-26 × HUZM-24	309.31	0.22	-28.24	73.69	-1.35	-30.53
HUZM-26 × HUZM-23	460.51	1.32	12176.09**	99.11	0.42	141.94*
HUZM-26 × HUZM-22	402.33	0.83	1435.04*	98.60	0.92	67.95
HUZM-26 × HUZM-21	359.04	0.14	109.07	90.58	0.32	-17.07
HUZM-25 × HUZM-24	419.66	1.47	10660.32**	84.80	1.28	248.85**
HUZM-25 × HUZM-23	366.39	0.42	7717.22**	92.06	0.54	154.87*
HUZM-25 × HUZM-22	344.54	0.84	-223.87	77.16	0.47	-20.79
HUZM-25 × HUZM-21	322.60	0.47	5526.34**	84.56	0.28	117.33*
HUZM-24 × HUZM-23	337.88	0.74	4428.05**	74.31	0.80	-28.92
HUZM-24 × HUZM-22	359.12	0.94	-148.52	75.13	1.11	258.59**
HUZM-24 × HUZM-21	419.32	1.46	764.59	72.49	0.83	344.71**
HUZM-23 × HUZM-22	410.74	0.81	-301.43	81.67	1.38	54.03
HUZM-23 × HUZM-21	417.73	0.98	1825.40**	92.16	2.03	-25.59
HUZM-22 × HUZM-21	437.14	1.06	541.97	77.29	0.93	-32.83
DKC-9162	453.29	1.49	2108.11**	74.67	0.94	9.08
Population mean	390.10			78.95		

*,** indicate the level of significance at 5% and 1%, respectively.

Conclusion

The analysis of variance for stability revealed that the mean sum of squares due to G x E (linear) components was highly significant for the plant height, ear placement, cob weight and biological yield per plant. The significant variance due to pooled deviation for all the characters indicates that the differences in stability for these traits due to linear (bi) and non-linear (S^2di) parameters. Among the hybrids, HUZM-27 x HUZM-25, HUZM-26 x HUZM-25 and HUZM-23 x HUZM-22 were found to be stable under favourable environments and suitable for maximum grain yield per plant.

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