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Research Article

G × E interaction studies under natural farming and inorganic production system in maize (*Zea mays* L.)

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Abstract
A study was conducted to analyze the interaction of twelve maize genotypes with the environment for fourteen traits. The crop was grown during the *kharif* season of 2021 and 2022 in six different environments using two production systems, natural farming and the inorganic production system, in Palampur and Kangra using randomized block design with three replications. G × E interaction and stability analysis following AMMI model exhibited significant variation due to genotypes and environments for all the traits, indicating the presence of sufficient variability among the genotypes and environments. In contrast, G × E interaction was significant for all the traits except for number of kernel rows per cob and ear circumference (cm). Results showed that significant variation was present among the genotypes and environments. The environment had greater impact on most traits, except number of kernel rows per cob, ear circumference (cm), 100- grain weight (g), harvest index (%) and protein (%).The mean squares for the IPCA 1, IPCA 2 and IPCA 3 cumulatively contributed more than 80% of the total G × E interaction for all the traits. Overall,Girija was found to be the most stable genotype for the maximum number of traits, followed by L-315 and L-316.Girija was most stable for grain yield per plant followed by L-315, L-316 and L-318 under the inorganic production system. Bajaura Makka followed by L-315 and L-316 were stable genotypes under the natural farming production system with high grain yield per plant. Both L-315 and L-316 were found to be suitable for cultivation under both farming methods.

Keywords: Maize, AMMI, natural farming, natural farming vs. inorganic farming

INTRODUCTION

Maize (*Zea mays* L.) is the most extensively grown crop in the world. Because of its greater genetic production potential, maize is regarded as the 'queen of cereals' globally. Aside from being directly consumed by people, maize is also used to make corn ethanol, animal feed and other maize-based products like corn syrup and starch (Foley, 2013). Agriculture in India has mostly relied on chemical fertilizers and pesticides since the Green Revolution in the 1960s. Additionally, harmful effects of its excessive application include harm to local biodiversity, groundwater, soil and human health. Alternative agroecological farming methods are becoming more popular due to the inherently unsustainable nature of chemical-based agriculture and its role in the ecological and agricultural crises, which promise a wide range of environmental and social advantages.

One such substitute for agriculture reliant on chemical fertilizers and agriculture with significant input costs is Natural Farming, a sustainable agricultural system. The emphasis is on "improved soil conditions by controlling organic matter and soil biological activity; diversity of genetic resources; enhanced biomass recycling; and enhanced biological interactions," which are examples of key agroecological principles (Khadse *et al*., 2018). The method emphasizes the application of natural mixtures created from cow dung, cow urine, jaggery, pulse flour, etc., mulching practices and symbiotic intercropping in place of all synthetic chemical inputs (fertilizer and insecticides).

Almost all of the major crops have provided evidence of the significance of genotype × environment interaction in cultivar evaluation and breeding programmes. One of the varietal development program's most important goal is to develop varieties with the greater flexibility to diverse habitats enhanced with high grain yield. Identifying genotypes with a stable and high productivity adaptable to various situations is the foundation for the success of genetic improvement of breeding programs. The Additive Main Effects and Multiplicative Interaction (AMMI) model is a new model used for multivariate statistical analysis (Gauch 2006). The AMMI method integrates analysis of variance (ANOVA) and principal component analysis (PCA) into a unified approach that can be used to analyze multilocation trials (Zobel *et al*., 1988; Gauch 2006). The GEI matrix is divided by individual genotypic and environmental scores using AMMI analysis (Zobel *et al*., 1988). AMMI Stability Value (ASV), a quantitative stability value created by is used to rank genotypes using the AMMI model. ASV is the best single metric that describes stability when ranking genotypes(Purchase *et al*., 2000). Therefore, the current study was undertaken to get information on the G x E interaction and stability parameters in light of the aforementioned facts and to choose stable maize genotypes for both production systems.

MATERIALS AND METHODS

The experimental material comprised 12 different genotypes of maize (**Table 1**), including composites and landraces. The seeds were procured from Hill Agricultural Research and Extension Centre (HAREC), Bajaura and were evaluated in six environments (**Table 2)**

The trials were conducted in a randomized block design with three replications during *kharif* of 2021 and 2022 over two locations *viz*., Kangra and Palampur have two different production systems *viz.,*natural farming and inorganic production systems in each location. Each plot comprised of four lines of 3m with spacing of 60 cm × 20 cm. The crop was raised following the standard agronomic package of practices in inorganic conditions and natural farming as proposed by SubhashPalekar (Palekar 2006). Five competitive plants were chosen at random from each plot in each replication and the observations were recorded on plant height, cob height, kernel rows per cob, kernels per row, ear length, ear circumference, grain yield per plant, shelling (%), 100-grain weight, harvest index (%) and protein (%). Data on days to 50% tasseling, days to 50% silking and days to 75% maturity were recorded on a plot basis. After recording the observations from each genotype and replication, their mean values were used for the statistical analysis.

Statistical analyses: Analysis of variance (ANOVA) was performed for individual environments to identify the genotypes that differed significantly in each environment. The pooled ANOVA for all of the traits across environments was done to estimate the variations in the genotypes under study and partitioning of G x E interaction. The Additive Main Effect and Multiplicative Interaction (AMMI) model was used to estimate the G × E interaction and stability. The analysis in the current investigation was done by software **'R'** (RStudio, 2022) using package **'metan'** (Multi environmental trail analysis) (Olivoto and Lucio 2020).

AMMI stability index (ASI): Jambhulkar *et al*. (2015) proposed AMMI stability index (ASI) to quantify the result based on first two PCAs has been calculated as follows:

$$ASI=\sqrt{\left[\left(IPCA1_{score}\right)^2 \times \left(IPCA1_{\%\,explained\,mean\,sum\,of\,square}\right)^2\right] + \left[\left(IPCA2_{score}\right)^2 \times \left(IPCA2_{\%\,explained\,mean\,sum\,of\,square}\right)^2\right]}$$

The genotype with the lowest ASI value is the most stable. AMMI stability value (ASV): The AMMI model does not make provision for a quantitative stability measure, and as such a measure is essential in order to quantify and rank genotypes in terms of yield stability, the following measure proposed by Purchase *et al*. (2000) was used:

$$ASV=\sqrt{\left[\frac{IPCA1_{sum\,of\,squares}}{IPCA2_{sum\,of\,squares}}\left(IPCA1\right)^2 + \left(IPCA2\right)^2\right]}$$

AMMI biplots: The biplot's ordinates correspond to the IPCA 1 scores that show the G × E of the genotypes and environments, while the abscissa of the biplot represents the main effects. Displacements from the X-axis indicate differences in the main (additive) effects. Meanwhile, deviation from the Y-axis denotes variations in the interactions. The main influence for environments indicates the general comparison of environments, while the main effect for genotypes reflects breeding advancements.

RESULTS AND DISCUSSION

Individual ANOVA revealed significant differences among the genotypes for all the traits studied at each environment, indicating the presence of sufficient genetic variability among the genotypes (Tonk *et al*., 2011; Kumar *et al*., 2014; Singh *et al*., 2018). In pooled ANOVA, the mean sum of squares due to environments and genotypes were found to be highly significant for all the traits across environments. These results were found in general agreement with the findings of (Boreddy *et al*., 2020;Singh *et al*., 2020 and Kumawat *et al*., 2023).The mean sum of squares due to G × E interaction was also significant for all the traits except for kernel rows per cob and ear circumference.

Table 1. List of maize genotypes

Genotype Code	Genotype	Source
G_1	L-315	HAREC, CSKHPKV, Bajaura
G_2	L-316	HAREC, CSKHPKV, Bajaura
G_3	L-317	HAREC, CSKHPKV, Bajaura
G_4	L-318	HAREC, CSKHPKV, Bajaura
G_5	VL-78	HAREC, CSKHPKV, Bajaura
G_6	Girija	HAREC, CSKHPKV, Bajaura
G_7	BajauraMakka	HAREC, CSKHPKV, Bajaura
G_8	Bajaura Popcorn	HAREC, CSKHPKV, Bajaura
G_9	Sainj local	Sainj, Distt. Kullu
G_{10}	Dehra local	Dehra, Distt. Kangra
G_{11}	Jwalapur local	Jwalapur, Distt. Mandi
	Check	
G_{12}	Early Composite	HAREC, CSKHPKV, Bajaura

Table 2. List of environments

Environment Code	Environment
E_1	Kangranatural farming– *kharif*, 2021
E_2	Kangra inorganic – *kharif*, 2021
E_3	Palampurnatural farming– *kharif*, 2022
E_4	Palampur inorganic – *kharif*, 2022
E_5	Kangranatural farming– *kharif*, 2022
E_6	Kangra inorganic – *kharif*, 2022

The AMMI analysis of variance pooled over six environments (**Table 3**) for 14 traits exhibited significant variance due to genotypes, environments and G × E interaction (except for kernel rows per cob and ear circumference) indicating presence of sufficient variability among the genotypes and the environments under study as well as differential response of genotypes in each of the environment for these traits (Chandel *et al*., 2019; Abate, 2020; and Katsenios *et al*., 2021). The contribution of the environment main effect was greater than 50% for all the traits except kernel rows per cob, ear circumference, 100-grain weight, harvest index (%) and protein (%). The contribution due to genotype main effect was more than 50% for ear circumference and 100-grain weight. G × E interaction was further partitioned into five interaction principal component axis (IPCA). IPCA 1 was found significant for all the traits except for ear circumference. IPCA 2 was found significant for all traits excluding kernel rows per cob and ear circumference. IPCA 3 was significant for traits *viz*., days to 50% tasseling, days to 50% silking, days to 75% maturity, cob height, kernels per row, shelling (%), 100-grain weight, harvest index (%) and protein (%). IPCA 4 was significant for days to 50% tasseling, cob height and protein (%). The mean squares for the IPCA 1, IPCA 2 and IPCA 3 cumulatively contributed more than 80% of the total G × E interaction for all the traits (**Table 3**).

The maximum contribution to the total variation for grain yield per plant was contributed by environment sum of squares (53.72%) followed by genotype sum of squares (32.12%) and G × E interaction sum of squares (13.24%). Only the first two IPCAs were significant, contributing 55.6% and 28.4% to the total variation. (**Table 3**). This indicated sufficient approximation of data by the two PC scores for grain yield of genotypes in different environments.

The AMMI 1 and AMMI 2 biplot of grain yield per plant is given in **Fig. 1**. AMMI 1 biplot revealed that L-315, L-318, Girija and Bajaura Makka had IPCA 1 scores near to zero and had high mean indicating that they are stable. As per AMMI 2 biplotL-315, L-316, Girija, Bajaura Makka and Jwalapur local were closer to the origin and thus were less sensitive to the environment. Girija, Bajaura Makka and Jwalapur local were most suitable for Kangra under both production system during 2021. While L-318, Sainj local and Dehra local were best suited for Palampur under production system. The most suitable genotype at Kangra under both production system during 2022 was VL-78 and at Palampur under inorganic production system, it is L-315, L-316, L-317 and Early Composite.

The values of yield and different stability parameters *viz*; ASV and ASI for the 12 maize genotypes for grain yield

Table 3. AMMI analysis of variance over six environments

Source	df	Days to 50% tasseling		Days to 50% silking		Days to 75% maturity		Plant height (cm)		Cob height (cm)	
		MSS	% Explained	MSS	% Explained	MSS	% Explained	MSS	% Explained	MSS	% Explained
ENV	5	2253.19*	63.26	3674.05*	73.54	3982.48*	81.76	37116.17*	61.97	17103.04*	71.51
REP(ENV)	12	16.64*	1.12	39.51*	1.9	14.14	0.7	1578.91*	6.33	155.34*	1.56
GEN	11	382.65*	23.63	347.45*	15.3	226.36*	10.22	5537.50*	20.34	1557.03*	14.32
G × E	55	38.81*	11.99	42.09*	9.27	32.41*	7.32	618.73*	11.36	274.14*	12.61
PC1	15	94.38*	66.3	92.87*	60.2	83.12*	70	1249.42*	55.1	501.88*	49.9
PC2	13	21.96*	13.4	37.58*	21.1	21.40*	15.6	593.41*	22.7	232.52*	20
PC3	11	20.77*	10.7	28.84*	13.7	16.21*	10	361.39	11.7	180.44*	13.2
PC4	9	17.15*	7.2	8.75	3.4	5.82	2.9	252.72	6.7	194.03*	11.6
PC5	7	7.24	2.4	5.37	1.6	3.82	1.5	189.3	3.9	113.65	5.3

* Significant at a 5 % probability level

Table 3.*cont.*

Source	df	Number of kernel rows per cob		Number of kernels per row		Ear length (cm)		Ear circumference (cm)		Grain yield per plant (g)	
		MSS	% Explained	MSS	% Explained	MSS	% Explained	MSS	% Explained	MSS	% Explained
ENV	5	24.37*	19.34	1274.90*	70.19	242.80*	59.45	48.47*	26.76	63486.57*	53.72
REP(ENV)	12	4.16*	7.93	16.24	2.15	7.40*	4.34	5.06*	6.7	453.24	0.92
GEN	11	28.26*	49.34	90.63*	10.98	36.19*	19.49	45.72*	55.54	17252.73*	32.12
G × E	55	2.68	23.39	27.55*	16.68	6.20*	16.72	1.81	10.99	1422.53*	13.24
PC1	15	6.05*	61.6	49.80*	49.3	11.27*	49.5	4	60.3	2901.91*	55.6
PC2	13	2.59	22.8	24.52*	21	6.36*	24.2	1.76	22.9	1710.72*	28.4
PC3	11	1.17	8.7	19.43*	14.1	3.81	12.3	0.96	10.6	545.38	7.7
PC4	9	0.75	4.6	17	10.1	3.22	8.5	0.42	3.8	480.51	5.5
PC5	7	0.49	2.3	11.79	5.4	2.68	5.5	0.34	2.4	306.75	2.7

* Significant at a 5 % probability level

Table 3.*cont.*

Source	df	Shelling (%)		100-grain weight (g)		Harvest index (%)		Protein (%)	
		MSS	% Explained	MSS	% Explained	MSS	% Explained	MSS	% Explained
ENV	5	2971.49*	74.04	371.06*	29.35	841.64*	25.5	3.58*	13.08
REP(ENV)	12	22.2	1.33	5.86	1.11	34.72	2.52	0.35	3.08
GEN	11	149.56*	8.2	321.08*	55.88	538.05*	35.87	1.37*	11.03
G × E	55	59.94*	16.43	15.70*	13.66	108.30*	36.1	1.81*	72.81
PC1	15	86.07*	39.2	25.01*	43.4	188.50*	47.5	2.46*	37.1
PC2	13	92.55*	36.5	25.20*	37.9	168.32*	36.7	2.15*	28.6
PC3	11	47.35*	15.8	9.49*	12.1	47.33*	8.7	1.77*	19.5
PC4	9	19.37	5.3	4.36	4.5	31	4.7	1.26*	11.4
PC5	7	15.28	3.2	2.43	2	20.15	2.4	0.48	3.4

*Significant at a 5 % probability level

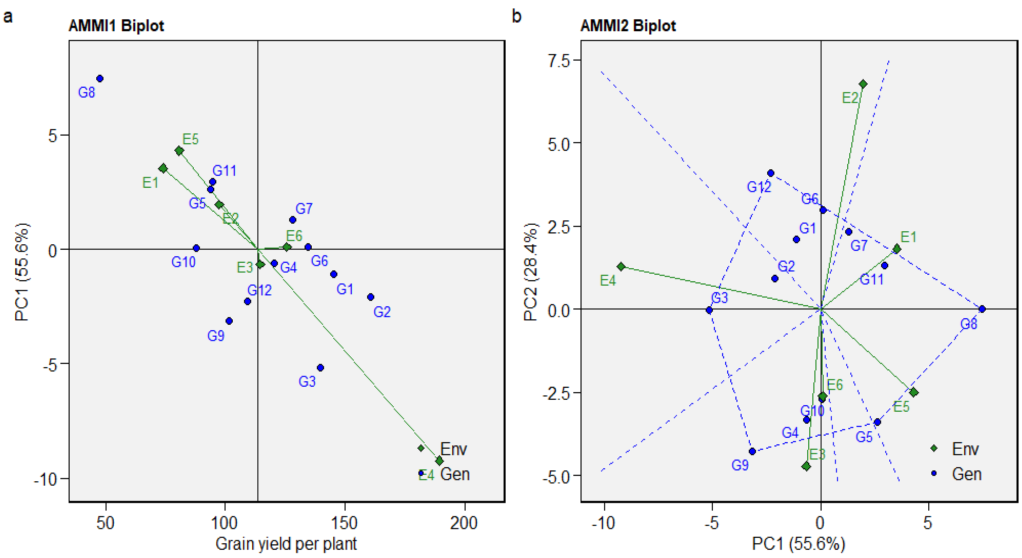

Fig. 1. AMMI biplots for grain yield per plant (g)

per plant are given in **Table 4**. Lower the value of ASV and ASI, greater the stability of genotype.

Table 5 depicts the most stable genotypes identified on the basis of AMMI analysis for different traits with mean grain yield per plant, grain color and texture. Girija was stable for maximum number of traits (six) followed by L-315 and VL-78 (five); BajauraMakka and Jwalapur local (four); L-316, Sainj local and Early Composite (three). L-315, L-316, L-317, L-318, Girija and BajauraMakka had higher mean grain yield per plant (g) than the check Early Composite.

Girija was identified as most stable genotype followed by L-315 and L-316 with high grain yield per plant across all environments.

ASI and ASV for grain yield per plant was done separately for each production system is presented in **Table 6**. In inorganic production system, Girija was most stable followed by L-315, L-316 and L-318. Whereas in NATURAL FARMING production system, VL-78 was most stable followed by BajauraMakka, Dehra local, L-315 and L-316. As inferred from the results Girija was found suitable for cultivation under inorganic production system only. L-315 and L-316 were suitable for cultivation under both production systems with high grain yield per plant.

The AMMI analysis of variance pooled over six environments for fourteen traits exhibited significant variance due to genotypes, environments and G × E interaction (except for kernel rows per cob and ear circumference) indicating presence of sufficient variability

Table 4. Grain yield per plant (g), AMMI stability value (ASV) and AMMI stability index (ASI) of 12 maize genotypes for grain yield per plant

S. No.	Genotype Code	Genotype	Grain yield per plant (g)	ASV	ASI
1	G_1	L-315	145.27	3.00	0.85
2	G_2	L-316	160.68	4.21	1.20
3	G_3	L-317	139.63	10.13	2.88
4	G_4	L-318	120.47	3.53	1.00
5	G_5	VL-78	93.89	6.17	1.75
6	G_6	Girija	134.59	2.98	0.85
7	G_7	BajauraMakka	128.02	3.42	0.97
8	G_8	Bajaura Popcorn	47.54	14.57	4.14
9	G_9	Sainj local	101.53	7.49	2.13
10	G_{10}	Dehra local	87.70	2.72	0.77
11	G_{11}	Jwalapur local	94.60	5.89	1.67
12	G_{12}	Early Composite (c)	109.14	6.07	1.72

Table 5. Most stable maize genotypes identified for different traits over six environments

Genotypes	Grain yield per plant (g)	Stable traits	Grain color	Grain texture
L-316	160.68	Days to 50 % tasseling, days to 75 % maturity and harvest index (%)	Orange	Semi-flint
L-315	145.27	Days to 50 % silking, grain yield per plant (g), numbers of kernels per row, ear length (cm) and protein (%)	Orange	Dent
L-317	139.63	Ear length (cm)	Yellow	Dent
Girija	134.59	Days to 50 % tasseling, days to 75 % maturity, plant height (cm), cob height (cm), grain yield per plant (g) and 100-grain weight (g)	Orange	Flint
BajauraMakka	128.02	Days to 75 % maturity, numbers of kernels per row, shelling (%) and harvest index (%)	Orange	Flint
L-318	120.47	Shelling (%)	Orange	Semi-flint
Sainj local	101.53	Cob height (cm), harvest index (%) and protein (%)	Yellow	Semi-flint
Jwalapur local	94.60	Plant height (cm), cob height (cm), ear length (cm) and 100-grain weight (g)	Yellow	Semi-flint
VL-78	93.89	Days to 50 % tasseling, days to 50 % silking, plant height (cm), numbers of kernels per row and 100-grain weight (g)	Yellow	Semi-flint
Dehra local	87.70	Grain yield per plant (g)	Yellow	Semi-flint
Early Composite (c)	109.14	Days to 50 % silking, shelling (%) and protein (%)	Orange	Semi-flint

Table 6. AMMI stability value (ASV) and AMMI stability index (ASI) for grain yield per plant (g) in inorganic and natural farmingproduction system

Genotype	Grain yield per plant (g)			
	Inorganic production system		Natural farming production system	
	ASI	ASV	ASI	ASV
L-315	1.00	3.08	0.71	2.15
L-316	1.10	3.40	0.93	2.79
L-317	2.61	8.06	2.04	6.15
L-318	1.12	3.45	1.72	5.19
VL-78	1.37	4.22	0.24	0.74
Girija	0.95	2.93	1.65	4.98
BajauraMakka	1.81	5.58	0.49	1.49
Bajaura Popcorn	4.23	13.03	2.24	6.74
Sainj local	2.60	8.03	3.49	10.51
Dehra local	1.30	4.00	0.70	2.12
Jwalapur local	2.34	7.21	0.75	2.26
Early Composite (c)	1.69	5.21	1.77	5.33

among the genotypes and the environments under study as well as differential response of genotypes in each of the environment for these traits. AMMI stability index (ASI) and AMMI stability value (ASV) helped identify the stable genotypes for each of the traits. Girija was found most stable for maximum number of traits namely days to 50 % tasseling, days to 75 % maturity, plant height (cm), cob height (cm), grain yield per plant (g) and 100-grain weight (g) across all six environments followed by L-315 which was stable for days to 50 % silking, grain yield per plant (g), number of kernels per row, ear length (cm) and protein (%), whereas, L-316 was stable for days to 50 % tasseling, days to 75 % maturity and harvest index (%) and also had highest mean grain yield per plant across all environments. In inorganic production system, Girija was found most stable followed by L-315 and L-316. Innatural farming production system, BajauraMakka was found most stable followed by L-315 and L-316. Among the environments, Palampur under inorganic production system was most favourable for kernels per row, ear length, grain yield per plant and 100-grain weight. An average Kangra under inorganic production system, was found favourable for early tasseling, silking and maturity. It was also found favourable for shelling (%), harvest index

(%) and protein (%).Under natural farming production system, Palampurlocation was more favourable for plant height and cob height. Overall, the inorganic production system was a more favourable environment for maize production.

The top three genotypes suitable for both production systems were Girija, L-315 and L-316. The top three genotypes for natural farming were Bajaura Makka, L-315 and L-316, whereas, Girija, L-315 and L-316 were identified as suitable for inorganic production system for grain yield per plant. All these varieties outperformed the check Early Composite. Thus, these genotypes can be exploited after further evaluation at multi locations.

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