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STABILITY ANALYSIS OF AGRONOMIC TRAITS FOR MAIZE (*ZEA MAYS* L.) GENOTYPES BASED ON AMMI MODEL

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Abstract

Stability and adaptability of promising maize hybrids in terms of three agronomic traits (grain yield, ear weight and 100-kernel weight) in multi-environments trials were evaluated. The analysis of AMMI model indicated that the all three agronomic traits showed highly significant differences ($p < 0.01$) on genotype, environment and genotype by environment interaction. Results showed that genotypes Hengyu321 (G9), Yufeng303 (G10) and Huanong138 (G3) were of higher stability on grain yield, ear weight and 100-kernel weight, respectively. Genotypes Hengyu1587 (G8) and Hengyu321 (G9) showed good performance in terms of grain yield, whereas Longping208 (G2) and Weike966 (G12) showed broad adaptability for ear weight. It was also found that the genotypes with better adaptability in terms of 100-kernel weight were Zhengdan958 (G5) and Weike966 (G12). The genotype and environment interaction model based on AMMI analysis indicated that Hengyu1587 and Hengyu321 were the ideal genotypes, due to extensive adaptability and high grain yield under both testing sites.

Introduction

Maize (*Zea mays* L.) is one of the world's largest food crops, and the global maize production was 1.04 billion tons in 2017, accounting for about 35% of the world's total amount of grain yield. Among them, China's maize production in 2017 was about 260 million tons, accounting for about 25% of global maize production (FAOSTAT 2018). Due to its wide ecological adaptability and high yielding, the harvest years can be used as feed, the reduced years can be used as grain, and it is the main feed transformed into meat and milk eggs. Maize has become more and more important in China's agricultural production and national economic development. The level of maize grain yield and the quality of production directly affect the future of China's food security and agricultural production (Ye *et al*. 2019).

Maize hybrids have undergone many years of screening tests in multiple locations since they were bred by combination, so as to select promising hybrids that are suitable for a certain ecological type (Oliveira *et al*. 2017). The analysis of the interaction effects between maize hybrids and locations and the selection of locations in multi-environments trials (METs) can provide scientific basis for the selection, promotion and application of maize genotypes (Cooper *et al*. 2016). The terms 'adaptability' or 'stability' refers specifically to genotypes that perform consistently in various environments (Abera *et al*. 2004). Agronomic traits are mostly qualitative and quantitative and are susceptible to environmental influences. This trait is usually controlled by many genes and is affected by major environmental conditions. In order to screen the most stable, adaptable, and high yielding genotypes, METs is necessary for maize breeders (Safari *et al*. 2010, Yue *et al*. 2019a).

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The genotype (G), environment (E), and genotype by environment interaction (GEI) of the tested agronomic traits are reflected in indicators stability, adaptability and high yielding (Hossain *et al.* 2018). In addition to the need for accurate, reliable, and representative test data, a comprehensive and reasonable evaluation of genotypes is also inseparable from reasonable and effective test analysis models and methods. Plant breeders have done a lot of work in studying crop stability and GEI analysis, proposed and analyzed numerous stability analysis statistical models and methods. Among them, using the additive main effect and multiplicative interaction (AMMI) model, the traits obtained from this method provide a very important convenience for the plant breeders in terms of the performance of GEI (Kendal *et al.* 2019). The AMMI model provides researchers with more information about genotype stability from grain yield and trait performance (Yue *et al.* 2019b).

There a number of reports for using the AMMI model to analyze the stability and adaptability of maize grain hybrids. However, it is rare to analyze the grain yield and agronomic traits to comprehensively evaluate the adaptability and stability of maize hybrids in multiple environments. Therefore, the objectives of this study were to evaluate the performance of three agronomic traits on maize hybrids over a diverse set of environments using the AMMI model, and to rank test environments according to the distinguishing ability and representativeness, and to identify the most stable genotypes as candidates and to take advantage of this method to show the plant breeders.

Materials and Methods

Twelve promising maize genotypes were evaluated across two years (2017 and 2018) and eight locations in north-central China. The information of genotypes and locations is presented in Table 1. In this study, Zhengdan958 (G5) was used as control, because Zhengdan958 is the largest hybrid in the country and has wide adaptability in north-central China.

Table 1. Description of the 12 maize genotypes and 8 environments.

Code	Genotypes	Parentage	Code	Environments	Province	Longitude (E)	Latitude (N)
G1	Nonghua106	8TA60/S121	E1	Dingxing	Hebei	115°48′	39°15′
G2	Longping208	L238/L72-6	E2	Zhaoxian	"	114°46′	37°45′
G3	Huanong138	B105/J66	E3	Yongnian	"	114°29′	36°47′
G4	Qiule218	NK05/NK07	E4	Luoyang	Henan	112°26′	34°37′
G5	Zhengdan958	Z58/C7-2	E5	Zhoukou	"	114°41′	33°35′
G6	Heng110	H58/H59	E6	Bozhou	Anhui	115°46′	33°44′
G7	Nonghua101	NH60/S121	E7	Anqiu	Shandong	119°13′	36°30′
G8	Hengyu1587	H78/H79	E8	Laizhou	"	119°56′	37°11′
G9	Hengyu321	H14/H13					
G10	Yufeng303	CT1669/CT3354					
G11	Xianyu335	PH6WC/PH4CV					
G12	Weike966	WK3958/WK898					

Field trials were carried out using RCBD with three replicates. Each genotype was planted in five rows with a length of 6.7 m and spaced 60 cm apart between the two rows. The field management of each plot was more intensive than ordinary field management (Yue *et al.* 2020), and chemical weeding and pest control were required done time. In special weather conditions, onsite management and measurement were completed on the same day in order to reduce test errors. Comprehensive pest management methods, including the use of bait to trap rats were used. Thrips and armyworms are the most important pests in the maize seedling stage. The control measure was to use 4.5% lambda cypermethrin 15,000 times liquid spray per hectare. Weed control was divided into two stages. In the first stage, the weeds were controlled by chemicals before emergence (methalamin 3000 ml/ha plus 450 kg/ha). The second stage was to spray 225 ml/ha of nitrocellulose when 3 - 5 leaves of maize were emerged. The planting date was from June 12 to 20 at each location, and the harvest period was controlled from October 1 to 10 in 2017 - 2018. The fertilizer application in each location was arranged reasonably according to the soil measurement conditions (the soil has low nitrogen and phosphorus content, and high potassium content) and 160 - 200 kg N/ha and 100 - 130 kg P_2O_5/ha were applied, respectively, at the time of sowing date. The temperature of the whole maize growth period was more suitable. The high temperature and high humidity weather prevailed in each location from the end of July to the beginning of August. Because of this, watering was carried out during this period.

Three rows in the middle of each plot were artificially harvested and the grain yield (GY) was measured on an 14% moisture basis. The two side rows were used to determine the ear weight (EW) and 100-kernel weight (KW) at the time of harvest in each location.

In this study, the additive main effect and multiplicative interaction (AMMI) model adopted by Duma *et al*. (2019), and AMMI stability value (ASV) calculation formula were used following the method of Verma *et al*. (2017). In the AMMI model, the effects of the genotype, environment and their interactions were calculated by analysis of variance (ANOVA) using Data Processing System (DPS) software (Tang and Zhang 2013).

Results and Discussion

General analysis of variance for grain yield (GY), ear weight (EW), and 100-kernel weight (KW) of the twelve maize hybrids evaluated across eight environments using AMMI model was presented in Table 2. ANOVA analysis result showed that genotypes (G) effect, environments (E) effect and genotype by environment interaction (GEI) effect were highly significant ($p < 0.01$) on all tested traits. This indicated that there were significant differences among the traits of the twelve genotypes in the eight test environments. It can also be seen from the results that since the GEI significantly affects traits, it is necessary to evaluate the stability of each genotype (Nzuve *et al*. 2013).

Table 2. AMMI model analysis for agronomic traits of 12 maize genotypes across 8 different locations.

Source	D.F.	GY			EW				KW	
		S.S.	MS	%SS	SS	MS	%SS	SS	MS	%SS
Total	95	197213750	2075934.2		48110	506.4		664.0	6.9	
Genotypes	11	36520810	3320073.7^{**}	18.52^{a}	23744	215.8^{**}	49.35^{a}	193.5	17.6^{**}	29.14^{a}
Environments	7	120041748	17148821^{**}	60.87^{a}	31346	4477.9^{**}	65.15^{a}	237.9	34.0^{**}	35.83^{a}
GEI	77	40651191	527937.6^{**}	20.61^{a}	14391	186.8^{**}	29.91^{a}	232.6	3.0^{**}	35.03^{a}
IPCA1	17	21983061	1293121.3^{**}	54.08^{b}	5375	316.1^{**}	37.35^{b}	87.0	5.1^{**}	37.40^{b}
IPCA2	15	7378458	491897.2^{*}	18.15^{b}	3117	207.8	21.66^{b}	57.6	3.8^{*}	24.76^{b}
Residuals	45	11289672	250881.6		5898	131. 1		87.9	2.0	

GEI - Genotype and environment interaction. IPCA - Interaction principal component axis. DF- degrees of freedom. SS- sum of squares. MS - Mean square. GY- Grain yield. EW- Ear weight. KW- 100-kernel weight. *and **significant at $p < 0.05$ and $p < 0.01$, respectively; a - Percentage of total SS; b - Percentage of sum of squares of GEI.

G, E and GEI effects contributed 18.52, 60.87 and 20.61%, respectively to the total variation measured in GY. Interaction principal component axis (IPCA) was decomposed into IPCA1 and IPCA2. It can be found that the two principal component analysis axes of GY reached significant ($p < 0.05$) differences, explaining 54.08 and 18.15% of the total GEI, respectively. For EW, G, E and GEI accounted for 49.35, 65.15 and 29.91% of the total variation, respectively. Only IPCA1 reached a highly significant level of variation, and the IPCA1 and IPCA2 scores accounted for 37.35 and 21.66% of the total GEI, respectively. For KW, E main effect explained 35.83% of the total variation, compared with 35.03% for GEI effect and 29.14% for G main effects in the analysis of sum of squares. The effect ratios of the first two IPCAs of KW were 37.40 and 24.76% of the total GEI, respectively, and both reached significant levels ($p < 0.05$). According to the proportion of each variability effect in the total variation, the environmental effect accounted for the highest proportion among the three agronomic traits, followed by the GEI effect, and the genotype effect was the lowest. This phenomenon has been confirmed in two agronomic traits, such as GY and KW, whereas G had a more effect than GEI in EW. This indicated that the environment, genotype and GEI make a significant contribution to the observed variations of three agronomic traits. This demonstrates the importance of the needful for multi-environmental trails to be demonstrated by variation amongst environments. Due to the environments, huge agronomic trait differences are related to genotype assessment and environmental analysis, and larger GEI also indicate that different mega-environments may exist compared to genotype contributions. This finding is in consistent with previous research results (Nachit *et al.* 1992, Badu-Apraku *et al.* 2012, Liu *et al.* 2017).

The IPCA scores of a genotype in the AMMI model indicate the stability of the genotype in the entire environment. Extensive IPCA scores (negative or positive) indicate genotypes adapted to a particular environment, and the IPCA scores is close to zero, indicating the most stable and adaptive genotype across the environments. Based on this theory, the genotype with the lowest AMMI stability values (ASV) is more stable across mega-environments, while the genotypes with a high ASV are unstable (Purchase *et al.* 2000). AMMI stability values (ASV) revealed differences in the stability performance of agronomic traits among the 12 genotypes (Table 3). For GY, G9 had the lowest ASV, with value of 11.58, indicating that G9 was highly stable, followed by G1 (12.39) and G8 (12.72), and G12 (117.93) was the least stable genotype, other genotypes were moderately stable. The mean performance of GY ranged from 8907 to 11010 kg/ha. Combining ASV value and average grain yield performance, genotype G8 had lower ASV value and higher grain yield indicating that G8 belongs to genotype with good stability and high yielding. For EW, genotypes G1 and G10 had highly stable performance with ASV values of 2.06 and 2.19, respectively, whereas genotype G4 had the highest ASV value (7.46) than other genotypes.

Genotype G10 had a high average EW performance and the lowest ASV value, which indicated that G10 belongs to a genotype with good stability and high yielding, whereas genotype G2 had the highest EW mean performance with higher ASV value, this means that G2 was a genotype with high yielding and poor stability. For KW, genotype G3 was the most stable among twelve maize hybrids, with ASV value of 0.21, whereas G12 was the least stable genotype, with ASV value of 2.97. G12 was the highest mean KW among the twelve genotypes. However, it was the least stable genotype with a 100-kernel weight of 35.05g. The most stable and high yielding genotype was G7 with a 100-kernel weight of 36.48g and ASV of 0.51. The stability is based on whether it is high yielding. If genotypes had good stability but poor yielding, it also had no promotion value, but if genotypes had poor stability but good yielding, it means that the genotypes had special adaptation regions with certain promotion value (Rakshit *et al.* 2012 and Neisse *et al.* 2018). The mean agronomic performance and ASV of each environment are different (Table 4). E2

Table 3. IPCAs scores, deviation, ASV value and mean performance for 3 agronomic traits of 12 maize genotypes across 8 locations.

Genotypes	GY (kg/ha)					EW (g)					KW(g)				
	$IPCA_{g1}$	$IPCA_{g2}$	Deviation	ASV	Mean	$IPCA_{g1}$	$IPCA_{g2}$	Deviation	ASV	Mean	$IPCA_{g1}$	$IPCA_{g2}$	Deviation	ASV	Mean
G1	0.40	12.33	483.66	12.39	10664	–0.87	–1.59	–1.31	2.19	146.93	–0.99	–0.68	–1.80	1.64	33.03
G2	–16.90	–29.01	228.60	58.1	10409	–3.72	–2.19	7.71	6.77	**155.95**	–0.64	0.88	–0.59	1.31	34.56
G3	–7.81	–3.60	438.62	23.55	10619	–1.58	–0.93	2.70	2.89	150.94	0.27	–0.30	0.39	**0.21**	32.25
G4	29.17	–0.28	298.52	86.92	10479	–4.07	2.52	4.06	7.46	152.31	0.00	0.85	1.65	0.85	36.23
G5	–12.50	3.09	184.36	37.37	10365	2.69	2.37	–2.32	5.21	145.92	–0.63	–0.11	2.21	0.95	34.23
G6	–24.29	–22.26	–275.94	75.72	9905	1.06	–3.19	0.74	3.67	148.98	–0.57	–0.50	0.37	1.00	35.22
G7	24.03	3.72	–567.83	71.68	9613	2.46	1.40	–4.95	4.46	143.29	–0.30	0.23	–1.81	0.51	**36.48**
G8	–0.50	12.63	829.36	12.72	**11010**	0.23	–2.88	–6.15	2.91	142.10	0.40	–0.66	0.81	0.89	37.04
G9	3.65	4.00	749.03	**11.58**	10930	3.37	1.42	–0.80	5.99	147.44	–1.22	0.12	0.22	1.85	35.20
G10	–19.21	28.95	–764.91	64.13	9416	1.19	0.14	3.94	**2.06**	152.18	0.65	1.28	–0.27	1.62	33.02
G11	–15.39	3.33	–329.88	45.97	9851	2.09	–0.64	–9.59	3.66	138.66	1.11	–1.68	–2.58	2.37	35.64
G12	39.35	–12.90	–1273.59	117.93	8907	-2.84	3.58	5.96	6.06	154.20	1.93	0.57	1.40	2.97	35.05

IPCA: Interaction principal component axis; ASV: AMMI stability value; GY- Grain yield; EW - Ear weight; KW - 100-kernel weight; G1: Nonghua106; G2: Longping208; G3:Huanong138; G4: Qiule218; G5: Zhengdan958; G6:Heng110; G7: Nonghua101; G8: Hengyu1587; G9: Hengyu321; G10:Yufeng303; G11: Xianyu335; G12: Weike966.

Table 4. IPCAs scores, deviation, ASV value and mean performance for 3 agronomic traits of 8 environments in maize genotypes.

Environ-ments	GY (kg/ha)					EW (g)					KW(g)				
	$IPCA_{e1}$	$IPCA_{e2}$	Deviation	ASV	Mean	$IPCA_{e1}$	$IPCA_{e2}$	Deviation	ASV	Mean	$IPCA_{e1}$	$IPCA_{e2}$	Deviation	ASV	Mean
E1	22.21	35.57	–739.42	41.93	9441.36	–1.04	–0.87	–15.57	**1.36**	132.67	–0.87	1.08	–1.21	1.39	33.62
E2	2.81	6.75	1743.13	**7.31**	11923.92	1.37	2.62	–10.85	2.96	137.39	–0.39	0.05	1.91	**0.39**	36.74
E3	–10.87	-28.94	682.99	30.91	10863.78	4.70	0.74	26.31	4.75	174.55	0.70	–1.17	0.32	1.37	35.15
E4	–53.69	8.52	1438.60	54.37	11619.39	0.19	2.51	24.00	2.52	172.24	–0.61	0.70	0.68	0.93	35.51
E5	15.95	0.23	49.09	15.95	10229.88	-6.13	–0.43	14.79	6.14	163.03	–0.42	–0.06	0.49	0.42	35.32
E6	26.29	-20.47	–500.29	33.32	9680.50	-0.19	–5.10	0.41	5.10	148.65	–0.39	–1.92	–0.54	1.96	34.29
E7	9.54	-6.97	–1172.70	11.81	9008.08	-1.70	3.00	–20.13	3.45	128.11	–0.64	0.61	1.65	0.88	36.48
E8	–12.23	5.32	–1501.41	13.34	8679.38	2.79	–2.49	–18.96	3.74	129.28	2.61	0.70	–3.30	2.71	31.53

IPCA: Interaction principal component axis; ASV: AMMI stability value; GY - Grain yield; EW - Ear weight; KW - 100-kernel weight; E1: Dingxing; E2: Zhaoxian; E3:Yongnian; E4: Luoyang; E5: Zhoukou; E6:Bozhou; E7: Anqiu; E8: Laizhou.

had low ASV performance for GY and KW, and E1 had low ASV for EW, hence the best discrimination environments were E1 and E2. The AMMI model is an effective tool for analyzing multi-environment trials (MET) data and interpreting complex genotype and environment interaction. So screening the maize hybrids with environmental adaptability provides a basis for crop breeding.

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