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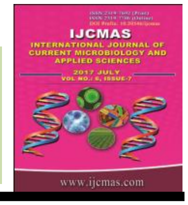

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Exploring Relationship between Combining Ability and Stability in Maize

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A B S T R A C T

An investigation was carried out to explore relationship, if any between combining ability and stability of 27 maize inbred lines. To obtain the general combining ability effects 27 newly developed inbred lines were crossed with four testers in a line × tester mating design and the progenies along with parents were evaluated for three seasons namely summer-2014, rainy season-2014 and summer-2015. The data were recorded on seven quantitative traits (QTs). The general combining ability (GCA) effects of lines and testers for seven QTs were estimated. The data on seven QTs of the parents (lines and testers) across three seasons were used to estimate AMMI stability value (ASV) and stability index (SI). The correlation coefficients of GCA effects with the estimates of ASV, and SI of were estimated and tested for their significance using t- test. The correlation coefficients of GCA effects of lines and testers with estimates of ASV and SI scores for all QTs were non-significant. The results indicated lack of any relationship between gca effects of inbred lines and their stability estimates. It is possible that gca effects and stability of inbred lines could be under independent genetic control.

Keywords

Maize, combining ability, GCA, AMMI stability, ASV, SI.

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Introduction

Due to the availability of stable cytoplasm-nuclear-genetic male sterility system and/or ease of hand-emasculation coupled with high rate of natural cross pollination and large number of seed set, F_1 hybrid has been the major cultivar option for enhancing maize production. The efficiency of development of heterotic hybrids however, depends on development and identification of suitable parents. The behavior of parents in cross/hybrid combination is routinely assessed through the estimation of general combining ability (*gca*) and specific combining ability (*sca*) effects as suggested by Sprague and Tatum (1942).

It was hypothesized that the genotypes which exhibits stable performance across years/seasons also display good general combining ability. Assessment of stability of genotypes does not require development of cross combinations and hence can be accomplished in 2-3 cropping seasons. Evaluation of genotypes for their gca effects across seasons require a minimum of four to five cropping seasons. Thus, if there is positive and strong relationship between combining ability and stability of genotypes, duration of development of hybrid could be substantially reduced. Under these premises, the objective of present study was to explore the relationship if any between combining ability and stability of a set of inbred lines.

Materials and Methods

The material for the study consisted of 27 inbred lines (used as females) and four testers (used as males) developed at the College of Agriculture (CoA), V C Farm, Mandya. These inbred lines were planted in a single row of 4m length and crossed with four testers (CM500, CM202, MAI105 and NAI137) using line × tester mating design (Kempthorne, 1957) during *kharif* 2013.

The 108 hybrids so produced were evaluated along with their parents at the experimental plots of College of Agriculture (CoA), V C Farm, Mandya in randomized block design with two replications for three seasons (*summer* 2014, *kharif* 2014 and *summer* 2015). The experimental plot represent southern dry zone (Zone 6) located at latitude of $12^{o}30^{I}$N, longitude of $76^{o}50^{I}$ E and altitude of 694.65 meters above MSL.

Each entry was sown in two rows of 4 m length following 0.6 m between rows and 0.3 m within a row between the plants. The recommended management practices were followed during the crop growth period to raise the healthy crop.

The data were recorded on five randomly chosen plants in each replication on six morpho-metric traits, namely, anthesis-silking interval, ear length (cm), ear circumference(cm),kernel rows ear^{-1}, kernels row^{-1} and grain yield plant^{-1}.The traits means of the five plants of hybrids and parents were subjected to statistical analysis.

Combining ability analysis

Combining ability of lines and testers was estimated using the following linear model (Arunachalum, 1974).

$Y_{ij} = \mu + g_i + g_j + s_{ij} + r_k + e_{ijk}$, Where, Y_{ij} is trait value of ijth hybrid, μ is population mean, $g_i$isgca effect of ith line, g_j is gca effect of jth tester, s_{ij} is sca effect of ijth hybrid, r_k is replication effect and e_{ijk} is error associated with (ijk)th observation.

The general combining ability effects of lines and testers were estimated using the following formulae.

$$\hat{g}_i = \frac{Y_{i..}}{mr} - \frac{Y_{...}}{mfr}$$

Where, $\hat{g}_i$ is general combining ability effect of ith line, $Y_{i..}$is total of ith line over t testers and r replications and $Y_{...}$ is total of all hybrids over r replications.

$$\hat{g}_j = \frac{Y_{.j.}}{rf} - \frac{Y_{...}}{mfr}$$

Where, $\hat{g}_j$ is general combining ability effect of jth tester, $Y_{.j.}$ is total of jth tester over l lines and r replications and $Y_{...}$ is total of all hybrids over r replications.

Stability analysis

The trait mean of lines and testers in each of the two replications were used to assess their relative stability following Additive Main effects and Multiplicative Interaction (AMMI) model (Gouch and Zobel, 1988).

$$Y_{ij} = \mu + g_i + e_j + \sum_{k=1}^{n} \lambda_k \alpha_{ik} \gamma_{ij} + \varepsilon_{ij}$$

Where, Y_{ij} is performance of i^{th} line/tester in j^{th} environment, μ is the experimental mean, g_i and e_j are the i^{th} line/tester and j^{th} environmental mean deviation from experimental mean, respectively. λ_k is the square root of eigen value of the k^{th} PC axis, α_{ik} and γ_{jk} are the interaction PC scores for k^{th} PC of i^{th} line/tester and j^{th} environment, respectively and ε_{ij} is the residual. The parameters of AMMI model were estimated using least square principle implemented by GENSTAT software, version 15.

To facilitate an objective method of identification of stable genotypes across three seasons, the AMMI stability value (ASV) was estimated using following equation (Purchase *et al.*, 2000).

$$ASV = \sqrt{\left[\frac{SSIPC1}{SSIPC2}(IPC1\ score)\right]^2 + (IPC2\ score)^2}$$

Where, SSIPC1 and SSIPC2 are sum of squares attributable to first two IPC's. Greater ASV indicates the higher stability of line/tester across seasons (Purchase, 2000). To facilitate simultaneous selection of genotypes for a trait and stability, stability index (SI) which incorporates both trait mean and stability in a single criterion (Farshadfar, 2011) was estimated as SI= RASV+RY (*i.e.*, rank of line/tester based on ASV added to rank of line/tester based on trait mean over season).

Relationship between gca and stability of lines and testers

To explore relationship between gca effects and stability of lines/testers the correlation coefficients between gca effects and ASV, and between gca effects and SI were calculated using Pearson's correlation coefficient approach. The coefficient was calculated using the following formula.

$$r = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{\sqrt{[N\Sigma X^2 - (\Sigma X)^2][N\Sigma Y^2 - (\Sigma Y)^2]}}$$

Where, r is correlation coefficient, N is total number of pairs of observations, ∑XY is sum of products of the paired observations, ∑X is sum of X (here it is GCA) observations, ∑Y is sum of Y (ASV or SI) observations, $\sum X^2$ is sum of squared X observations and $\sum Y^2$ is sum of squared Y observations.

The significance of the correlation coefficients was tested using t test at 5% and 1% level of significance using the following formula.

$$t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

Where, r is correlation coefficient and t is test statistic.

Results and Discussion

Combining ability effects of lines and testers

The significant means squares attributable to seasons indicated the greater ability of environments to discriminate lines and testers for their gca effects. The significant mean squares attributable to line × tester interaction indicated the importance of specific combining ability. The mean squares due to lines were of a larger magnitude than those of testers for all traits indicating greater differences among lines for their gca effects compound to those of testers. Significance of first order interaction of lines and testers with seasons and second order interaction of lines × testers with seasons suggested differential gca effects of lines and testers and sca effects of hybrids across three seasons (Tables 1 and 2).

Table.1 Combined analysis of variance for combining ability over three season

Source of variation	DF	ASI	EL	EC	no.kr	no.kpr	Grain Yield plant^{-1}
Replications	01	0.03	8.51	3.93	2.35	51.90	2908.75
Environments	02	16.38**	91.31**	0.39	173.72**	841.69 **	262867**
Rep*Env	02	0.38	0.06	0.02	0.23	1.89	2070.78
Crosses	107	1.34 **	6.93 **	1.86 *	4.69 **	31.05 **	4650.93 **
Line effect	26	1.96 *	10.74 *	3.36 **	9.94 **	55.17 **	7873.01 **
Tester effect	03	0.40	3.46	0.07	4.14	13.21	2042.36
Line * Tester effect	78	1.17	5.80 **	1.43	2.96 **	23.70 **	3677.23 *
Env * Crosses	214	1.54 **	7.28 **	1.97 **	4.25 **	30.44 **	5983.10 **
Env * Line effect	52	1.70	8.13	1.46	2.93	23.65	4586.68
Env * Tester effect	06	1.00	20.07 **	3.59	9.18	59.67	27602.80 **
Env * L * Teffect	156	1.52 **	6.50 **	2.07 **	4.51 **	31.57 **	5617.05 **
Error	414	0.94	2.18	1.35	1.24	10.90	2621.67
Total	833	1.19	5.24	2.36	3.32	33.66	7816.12

*=Significant at P=0.05 and **=Significant at P=0.01
DF: degrees of freedom, ASI: anther silk interval, EL: ear length, EC: ear circumference, no.kr: number of kernel rows per earand no.kpr: number of kernels per row

Table.2 GCA effects of lines and testers estimated over three seasons

Lines	ASI	EL	EC	No.kr	No.kpr	Grain Yield plant^{-1}
MAI 1-1-1	0.50 *	-0.40	0.18	-0.35	-1.71 **	-6.27
MAI 1-5-2	-0.01	-0.55 *	-0.12	0.36	0.43	-6.49
MAI 1-8-3	-0.25	0.36	-0.02	0.31	-0.14	13.67
MAI 1-17-2	-0.04	-0.73 **	0.37	0.64 **	-1.16	10.16
MAI 1-17-11	0.08	1.81 **	-0.10	-0.39	0.59	26.08
MAI 1-21-4	-0.13	0.72 **	1.19**	0.00	-0.60	-13.01
MAI 1-22-1	0.04	-0.64 **	-0.08	-0.35	-1.02	-22.90
MAI 1-22-3	0.46 *	-0.25	0.12	1.48 **	-2.61 **	-15.77
MAI 1-31-2	-0.04	-1.50 **	-0.03	0.57 *	-3.86 **	-0.56
MAI 1-37-3	0.12	-0.21	-0.17	-0.15	0.75	17.55
MAI 1-41-3	-0.25	0.27	0.30	0.49 *	2.48 **	34.79
MAI 1-48-1	-0.33	1.26 **	-0.14	-0.50 *	0.28	5.23
MAI 1-77-1-1	-0.12	-0.01	-0.23	-0.98 **	-1.13	-18.69
MAI 1-91-3	0.24	0.21	-0.49	-0.85 **	1.40 *	22.16
MAI 1-97-3	0.24	-0.37	0.10	0.18	-0.03	23.24
MAI 1-98-3	0.45 *	0.30	-0.10	-0.38	0.06	1.49
MAI 1-108-2	0.04	-0.09	0.48	0.16	2.08 **	6.26
MAI 2-4-1-1	0.04	0.25	0.03	0.20	0.06	3.96
MAI 2-9-1-2	-0.16	-0.09	-0.06	-0.70 **	-1.69 **	-5.16
MAI 3-2-4-1	-0.37	0.04	-0.05	0.43	2.05 **	-2.68
MAI 3-2-5	-0.43 *	-0.23	-0.42	-0.20	2.17 **	17.54
MAI 3-13-6	-0.04	-0.72 **	-0.64 *	-0.52 *	-0.41	-7.91
MAI 4-5-2	-0.04	0.22	0.04	0.60 *	0.59	-19.51
MAI 4-10-3	-0.04	0.77 **	-0.06	1.28 **	1.40 *	-9.52
MAI 1-17-13	0.49 *	-0.47	0.46	0.37	-1.47 *	-37.84
MAI 1-58-3	0.16	-0.49 *	0.13	-0.46	0.68	15.76
MAI 2-16-3-1	-0.62 **	0.54 *	-0.72 **	-1.22 **	0.81	-31.50
Testers						
CM500	-0.03	0.04	0.01	0.19 *	-0.22	3.86
CM202	0.05	-0.21 *	0.01	-0.04	0.35	1.96
MAI105	-0.04	0.04	-0.03	0.05	-0.25	-3.95
NAI137	0.02	0.13	0.02	-0.20 *	0.12	-1.87

*=Significant at P=0.05 and **=Significant at P=0.01
ASI: anther silk interval, EL: ear length, EC: ear circumference, no.kr: number of kernel rows per earand no.kpr: number of kernels per row

Table.3 Combined AMMI analysis of variance over three seasons

Source	DF	ASI	EC	EL	no.kr	no.kpr	Grain Yield plant^{-1}
Genotypes	30	1.88*	6.23*	8.78*	8.97*	98.30**	13292**
seasons	02	0.02	1.82*	59.55*	50.42*	54.24*	3760*
Interactions	60	0.64*	0.79*	4.13*	0.35*	27.08*	2676*
IPCA 1	31	1.02*	1.53*	7.86*	0.65*	50.99*	5179*
IPCA 2	29	0.23*	0.00	0.13	0.04	1.51	987*
Residuals	00	0.00	0.00	0.00	0.00	0.00	0.00
Error	90	0.95	0.73	3.51	0.89	13.96	2906

*=Significant at P=0.05 and **=Significant at P=0.01; DF: degrees of freedom, ASI: anther silk interval, EL: ear length, EC: ear circumference, no.kr: number of kernel rows per earand no.kpr: number of kernels per row

Table.4 GCA effects, ASV scores and SI scores of maize inbred lines and testers

	ASI			EC			EL			no.kr			no.kpr			Yield/ plant		
Genotype	**GCA**	**ASV**	**SI**	**GCA**	**ASV**	**SI**	**GCA**	**ASV**	**SI**	**GCA**	**ASV**	**SI**	**GCA**	**ASV**	**SI**	**GCA**	**ASV**	**SI**
MAI 1-1-1	0.50	3.33	34	0.18	4.93	33	-0.40	22.07	26	-0.35	1.50	27	-1.71	43.45	8	-6.27	18.00	38
MAI 1-5-2	0.00	4.22	28	0.12	5.50	28	-0.55	47.99	6	0.36	0.06	12	0.43	48.88	24	-6.49	6.48	6
MAI 1-8-3	-0.25	2.45	35	0.02	8.58	14	0.36	35.11	27	0.31	8.72	22	-0.14	37.51	34	13.67	42.94	21
MAI 1-17-2	-0.04	0.84	30	0.37	2.55	45	-0.73	6.10	31	0.64	5.83	45	-1.16	2.47	31	10.16	6.08	35
MAI 1-17-11	0.08	0.66	33	0.10	14.12	54	1.81	1.86	30	-0.39	5.01	23	0.59	19.02	20	26.08	26.27	25
MAI 1-21-4	-0.13	0.87	42	1.19	3.69	36	0.72	26.47	29	0.00	3.66	30	-0.60	8.00	26	-13.01	21.97	38
MAI 1-22-1	0.04	0.06	56	0.08	0.33	28	-0.64	47.34	43	-0.35	2.94	31	-1.02	2.55	47	-22.90	1.45	33
MAI 1-22-3	0.46	3.33	24	0.12	0.82	60	-0.25	33.12	32	1.48	12.36	24	-2.61	54.76	36	-15.77	36.20	31
MAI 1-31-2	-0.04	0.06	31	0.03	11.45	22	-1.50	23.81	10	0.57	6.45	40	-3.86	24.58	26	-0.56	6.64	45
MAI 1-37-3	0.12	1.13	14	0.17	2.63	3	-0.21	11.43	35	-0.15	5.83	42	0.75	34.35	47	17.55	29.50	36
MAI 1-41-3	-0.25	0.87	23	0.30	0.33	40	0.27	50.00	25	0.49	5.73	40	2.48	20.46	6	34.79	19.78	44
MAI 1-48-1	-0.33	0.30	37	0.14	2.05	37	1.26	76.60	36	-0.50	4.29	25	0.28	44.09	43	5.23	26.22	32
MAI 1-77-1-1	-0.13	1.64	17	0.23	6.65	57	-0.01	10.10	32	-0.98	7.18	20	-1.13	13.92	12	-18.69	19.14	21
MAI 1-91-3	0.25	0.06	44	0.49	8.09	22	0.21	17.42	31	-0.85	4.29	43	1.40	19.50	44	22.16	29.48	40
MAI 1-97-3	0.25	0.96	21	0.10	0.25	23	-0.37	6.67	40	0.18	2.94	29	-0.03	55.57	24	23.24	23.25	25
MAI 1-98-3	0.46	0.96	36	0.10	6.94	33	0.30	44.02	49	-0.38	0.06	30	0.06	12.31	19	1.49	2.50	35
MAI 1-108-2	0.04	0.61	26	0.48	0.33	46	-0.09	31.38	58	0.16	2.94	15	2.08	16.15	46	6.26	20.37	25
MAI 2-4-1-1	0.04	2.56	27	0.03	1.97	28	0.25	1.86	16	0.20	5.11	40	0.06	3.70	46	3.96	18.46	59
MAI 2-9-1-2	-0.17	0.84	38	0.06	0.25	15	-0.09	112.92	36	-0.70	7.18	32	-1.69	77.12	21	-5.16	12.79	46
MAI 3-2-4-1	-0.38	1.01	21	0.05	3.69	7	0.04	75.01	33	0.43	7.28	42	2.05	26.21	36	-2.68	19.58	33
MAI 3-2-5	-0.44	0.96	34	0.42	13.83	43	-0.23	1.05	14	-0.20	4.29	33	2.17	60.22	39	17.54	23.36	12
MAI 3-13-6	-0.04	0.87	42	0.64	1.40	54	-0.72	22.45	43	-0.52	0.77	12	-0.41	26.49	16	-7.91	7.66	27
MAI 4-5-2	-0.04	1.86	34	0.04	10.02	27	0.22	29.79	26	0.60	7.28	50	0.59	55.23	27	-19.51	2.03	27
MAI 4-10-3	-0.04	1.86	33	0.06	2.05	8	0.77	4.79	48	1.28	10.17	32	1.40	16.15	41	-9.52	6.98	47
MAI 1-17-13	0.50	0.34	37	0.46	1.11	36	-0.47	18.08	23	0.37	1.50	41	-1.47	21.89	39	-37.84	11.33	37
MAI 1-58-3	0.17	0.06	38	0.13	5.50	41	-0.49	20.74	48	-0.46	0.67	56	0.68	23.33	32	15.76	20.68	20
MAI 2-16-3-1	-0.63	0.06	31	0.72	10.10	11	0.54	19.15	43	-1.22	1.50	26	0.81	15.47	26	-31.50	2.72	49
Testers																		
CM500	-0.04	3.44	31	0.00	10.59	32	0.04	16.53	29	0.19	8.62	33	-0.22	34.01	39	3.86	33.33	8
CM202	0.06	2.56	20	0.01	0.25	39	-0.21	6.52	39	-0.04	7.90	25	0.35	8.00	50	1.96	5.63	18
MAI105	-0.05	1.74	25	0.03	14.61	41	0.04	30.46	33	0.05	2.84	37	-0.25	46.13	52	-3.95	57.39	39
NAI137	0.02	0.06	50	0.02	12.14	29	0.13	20.08	21	-0.20	8.72	35	0.12	7.81	35	-1.87	18.18	40

ASI: anther silk interval, EL: ear length, EC: ear circumference, no.kr: number of kernel rows per earand no.kpr: number of kernels per row

Table.5 Correlation coefficients between GCA effects and ASV score, and GCA effects and SI scores

	lines		testers	
Traits	GCA/ASV	GCA/SI	GCA/ASV	GCA/SI
ASI	0.23	0.06	-0.25	0.05
EC	-0.37	0.17	-0.40	-0.78
EL	0.04	0.20	0.71	-0.91*
no.kr	0.55**	0.15	-0.20	0.03
no.kpr	-0.09	0.20	-0.92*	0.02
Yield	0.50**	-0.15	0.51	0.96**

*=Significant at P=0.05 and **=Significant at P=0.01
ASI: anther silk interval, EL: ear length, EC: ear circumference, no.kr: number of kernel rows per earand no.kpr: number of kernels per row

Stability patterns of lines and testers

The AMMI method is widely used in stability and adaptability analyses because it i) provides an initial diagnosis of the model and is well-suited for data with many environmental influences, ii) allows greater unfolding of the G × E interaction and summarizes the patterns and relationships between genotypes and environments, and iii) improves the accuracy of trait mean estimates (Gauch and Zobel, 1988; Crossa, *et al.*, 1990). The large environmental variances indicate the significant differences between environments, which caused most of the variation in the performance of inbred lines. IPCA 1 explained major proportion of inbred line × season interaction variance than IPCA 2.

AMMI analysis does not provide a quantitative measure of stability. For this reason, Purchase *et al.*, (2000) proposed an index referred to as ASV to quantify and classify genotypes according to their relative performance stability. The inbred lines MAI 1-22-1, MAI 1-98-3, MAI 2-16-3-1 and MAI 1-5-2 with low ASV, were considerably more stable. Similarly, testers CM 202 and NAI 137 with low estimates of ASV and were considered as stable across season (Table 3). The ASV has been used as an auxiliary criterion to define more stable genotypes in maize (Anley, *et al.*, 2013) and wheat (Farshadfar, *et al.*, 2011).

The SI which takes into both performance and stability in a single criterion was used classify the lines and testers for their relative stability (Oliveira and Godoy, 2006).The most stable lines according to the SI were MAI 1-5-2 followed by MAI 1-37-3 (Table 4).

Relationship between combining ability effects of lines and testers and their stability

Non-significant correlation coefficients between estimates of GCA effects with ASV and SI suggest the two properties of line × tester are independent (Table 5).

In conclusion, it is quite possible that the gca effects of lines and testers and their performance stability could be under independent genetic control.

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