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Research Article

Examining the Combinability of Morphological Characteristics and Grain Yield of Maize (*Zea mays* L.) Lines

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Abstract

Objective: The purpose of corn improvement is to develop inbred lines and new hybrids to improve the existing cultivars according to different traits. Success in the commercial production of hybrid corn depends on the extensive evaluation of inbred lines.

Methods: This research was carried out in order to determine the superior line, tester and hybrid of grain corn using the line x tester analysis method in the agricultural year of 1401 on the farm of Khoy Agricultural Research Station.

Results: Lines L6 and L7 were the first lines for the number of days to physiological maturity, and hybrids T1×L18, T2×L23, and T3×L3 had the most special adaptation.

Conclusion: Based on this, Lines L6 and L7 were the earliest ones for the number of days until physiological maturation. Also, T1×L18, T2×L23, and T3×L3 crosses had the highest specific compatibility.

Keywords: maize, line, tester, general combining ability, specific combining ability

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1 INTRODUCTION

Zea mays *L.* has received a lot of attention due to its special nutritional value. Progress in genomics, improvement and production of corn plays an important role in the life of a large part of the world's population[1]. Iran is classified as a dry region with an average rainfall of 240mm[2]. Severe and very dry weather limits the production of plants in these areas. Drought stress is one of the most crucial factors that reduce corn yield. The purpose of corn breeding is to develop inbred lines and new hybrids to develop existing numbers according to various traits.

Investigating the general and specific combining ability (SCA) of lines in order to use them as parents in creating new hybrid varieties is necessary. In addition, the type of inheritance of traits can help in making a decision to determine appropriate breeding methods and predicting the amount of genetic progress caused by selection. The purpose of corn improvement is to develop inbred lines and new hybrids to develop the existing cultivars according to different traits. Success in the commercial production of hybrid corn depends on the extensive evaluation of inbred lines[3] and the basic step in this direction is to test inbred lines based on their capabilities. The ability of combinability provides information about the inheritance of genetic control mechanisms of quantitative traits and enables breeders to choose suitable parents for further improvement and achieving commercial goals[4-15]. For the production of hybrid varieties, the main condition is to find a line as a parent, which has the best combination with a set of lines for the production of hybrid varieties, synthetic varieties or composites general combinability ability (GCA) or possesses the best combination against another line[5-14]. SCA includes section incremental and the non-incremental part of the variance, which is largely caused by dominance deviations and epistasis.

Wang et al.[6], Lorenzo et al.[7], Ahangar and Ghojogh[8], Kempthorn[9], and Bidgoli et al.[10], in performing genetic analysis of traits number of days to corolla emergence, plant height, ear height and grain yield in inbred corn lines, found that dominance and incremental components play an important role in controlling all traits. They have a grain yield component. In most studies, the role of both additive and dominance effects has been reported significantly in the studied traits, but the dominance or non-incremental component of genetic variance was more than the incremental component for most of the traits that had this genetic variance. In an experimental study with four selected testers and six selected lines, Lorenzo et al.[7], Ahangar and Ghojogh[8], Kempthorn[9], Bidgoli et al.[10], and Sharma et al.[11] concluded that the ratio σ^2gca/σ^2sca indicates the existence of additive effects for plant height and number of seeds per ear, while for grain yield traits. 1000-seed weight, ear height, ear length and early maturity were more important. Existence of additive and non-additive genetic effects indicates the need to use different components of genetic variance to increase production in maize. Results of cross-linking of 23 near-inbred lines (from S2 to S4) obtained from CIMMYT germplasm with four synthetic testers with a wide genetic base by Kumar et al.[12] and Rahimi[13] evaluated grain yield in six different environments by line × tester analysis. Combined analysis of variance for grain yield on six media showed significant effects of GCA and SCA for lines and testers. The present study was performed using a cross of pure maize testers that are widely used in breeding programs of Seed and Plant Breeding Research Institute and 9 pure lines used by S4 population obtained from CIMMYT germplasm.

2 MATERIALS AND METHODS

In this study, 9 corn lines along with 4 testers were crossed as paternal lines in the experimental farm of Khoy Agricultural Research Center. The lines used in the S4 population of foreign early genetic material were selected These lines were:

L1=Ms14
L2=48.1.1
L3=H2.1.9
L4=2.7.1
L5=2.1.40
L6=H1.9.12
L7=Ms17.3
L8=2.5.17
L9=1.9.4

The four testers were A=2.10.25, Mo17 B=2.29.14, C and D=1.55.1, which were desirable in terms of combinability and desired traits. Seeds of 36 genotypes obtained from line × tester crossing with control cultivar (SC704) in August 2021 were evaluated and evaluated in the framework of a preliminary yield comparison design. A total of 36 genotypes obtained from crossing line × tester were cultivated in the form of randomized complete block design with three replications on two 5-meter lines with a density of 6 plants per square meter. Irrigation was done in the form of shallow furrows. Each experimental plot consisted of 3 rows with a length of 6m with spacing between planting rows of 75cm and plant spacing on the row of 17cm. The seeds were planted on May 15, 2020. Corn was harvested when the color of the seeds was yellow and its content had a milky liquid or it was at the end of the pasty stage. After harvesting grain corn, cob seeds contained a lot of water and need to be dried, so it was necessary to increase the humidity to 15% after harvesting so that the seeds are not damaged during storage. The measured traits were randomly measured on 3 competing plants in the middle lines and included grain yield based on moisture content of 14% and in $t.ha^{-1}$, 1000-seed weight, number of seeds per row, number of ear per rows, number the days were up to physiological maturity and the grain filling period. The method of measurement was done according to the instructions of the Corn and Forage Plants Research Department of the Seed and Plant Breeding Research Institute. The significance of the mean squares of the line × tester in the corresponding analysis of the variance table provides a direct test for the significance of the incremental component and the dominance of genetic variance, respectively. Compton[9] showed that the variance effects of public and private combinability are related to the components of genetic variance based on the following relationship:

$$\sigma^2 gi=\sigma^2_f=CovHS(female) \quad (1)$$

$$\sigma^2 gj=\sigma^2 m=CovHS(male) \quad (2)$$

$$\sigma^2 gca=CovHS(Average)=[(1+4)/F]\times\sigma^2_A \quad (3)$$

$$\sigma^2_{sca}=\sigma^2_{mf}=Cov_{FS}-Cov_{HS}(female)-Cov_{HS}(male)=[(1+F)/2]^2\times\sigma^2_D \quad (4)$$

F is a coefficient of self-assembly. In this experiment, because the lines were completely pure, F=1 was considered, HAA[5]. The ratio σ^2gca/σ^2sca provides an estimate of the ratio of additive to non-additive effects of genes controlling the desired traits. Estimation of general GCA through maternal parents or lines and through paternal parents or testers was as follows:

$$\Sigma g_i=0, GCA(Lines)=g_i=Y_{i..}/t-Y_{i..}/lt \quad (5)$$

$$\Sigma gj=0, GCA(Testers)=g_j=Y_{.j.}/l-Y_{i..}/lr \quad (6)$$

And to estimate the effects of private SCA, it was:

$$SCA=S_{ij}=Y_{ij.}/tr-Y_{i..}/tr-Y_{.j..}/lr+Y_{..}/lt \quad (7)$$

Along with the MS (GCA) / MS (SCA) ratio, the importance of the genetic variance components, the best general combinability, and the best hybrid composition were calculated for each of the studied traits.

3 RESULTS AND DISCUSSION

The variance analysis of traits showed that the effect of crosses for all traits is significant at the 1% probability level (Table 1) and this indicates the existence of sufficient genetic diversity between crosses in terms of these traits. Therefore, line × tester analysis was performed to study the combinability and gene effects. Analyzing the effect of crosses into its components based on line × tester analysis showed that the difference between lines and testers was significant at the 1% level for all traits. The significant difference observed between the lines and testers for different traits indicates the existence of the role of genetic additive effects in the control of traits. Also, the significance of the mean square of line × tester indicates the role of dominance and non-incremental effect in controlling the mentioned traits.

Therefore, in general, both additive and non-additive effects play a role in controlling these traits. It should be noted that in order to have a strong meaning of the effect of intersections related to an attribute, it is not necessary that all the components of online, testers and line × tester become meaningful, but the meaning of even just one component can cause meaning. It can be changed, but the opposite is not true[9]. Lines and testers showed significant differences in general compatibility for most of the traits. Regarding grain yield, L4 and L8 lines and testers B and C showed positive and significant compatibility (Table 2). In the case of the L4 line and B and C testers, the high performance is due to the general combinability of their performance components. Lines L1, L2, and L4 for the weight of a thousand seeds; L6 for the number of seeds in a row; L4, L7 and L8 showed significant compatibility for the number of cob rows. Therefore, the mentioned lines can be considered as promising lines in the direction of improving the mentioned traits. Considering that one of the main goals in early corn is to reduce the length of the growing season, as a result, negative general composability is desirable for the trait of the number of days to physiological maturity. Accordingly, L6 and L7 lines were the earliest ones for the number of days to physiological maturation. Considering that one of the important goals in this study is to comprehensively review the lines and testers, therefore, lines should be selected in which the grain filling period is not reduced and at the same time they are at an early stage.

Accordingly, lines L1, L2, L3 and L9 with GCA positive and significant can be appropriate. The four testers used, although the inbred lines were modified and successful, in this experiment showed different conditions for different traits. Tests B and C performed higher than the other two testers, and this situation was observed relatively similarly for other GCA traits.

The results of the SCA of the various intersections are given in Table 3. Regarding seed yield, L4×B, L9×B and L4×C crosses had positive and better private compatibility (Table 3). And it is the best combination for cultivation in Azerbaijan province. In this experiment, if the goal is to select lines for the next stage of inbreeding in the breeding program, it is expected that the selected lines will have acceptable GCA traits. Based on this and considering that the selection of lines for the next stage of inbreeding should be to prevent genetic erosion and maintain diversity, L4 and L8 lines can thus be introduced as the best lines. Since the two testers B and C have a better condition than the other testers, so at the end of the breeding program, the mentioned lines can be used to obtain the best early hybrid combination. In the process of corn breeding, the goal should not be to find the best pure line, but to find the best hybrid combination that is appropriate from the point of view of genotyping and phenotyping, because it has been observed that the combination of the best lines will not always produce the best hybrid in terms of general acceptability. In plants such as corn, where the final goal is mainly grain yield, emphasis on grain yield and also the results obtained from the analysis of data related to this trait can be used as one of the most efficient tools. However, in cases where fodder yield or other uses of the plant is desired and the breeder is faced with several traits of different nature, by emphasizing only one trait, it is not possible to prepare a suitable hybrid, and different plant traits and characteristics may be taken into consideration, each of which may have its own genetic structure. Having a high performance requires the positive combination of general acceptance and private acceptance in these traits, while sometimes these traits are not compatible with each

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Table 1. Analysis of Variance of Different Traits of Corn Based on the Intersection of Line × Tester

S.O.V df Seed Yield Kgha^{-1}		M.S					
		Seeds Per Row	Seeds Per Ear	1000 Seed Weight (g)	Day to Physiological Maturity (Days)	Seed Filling Period	
Block	18	5.6	263.61	1.44	1164.16	12.5	21.6
Crosses	35	676.95**	1015.7**	77.25**	45745**	980.1**	822.85**
Line	8	90**	322**	130**	2393.2**	917.5**	1510.2**
Tester	3	4964.6**	5247.9**	8949.2**	10547**	1647.9**	184.41**
Line × tester	24	336.65**	71.8**	117.34**	45550**	917.5**	949.75**
Error	30	6.5	41.63	1.56	77289.77	15.48	3.67
C.V		18.9	15.95	7.13	6.38	3.03	2.97

Notes: *and** are significant at the five and one percent probability levels, respectively.

Table 2. General Combinability Ability of Lines and Testers for Different Traits

GCA of Lines	Seed Yield Kgh^{a}1	Seeds Per Row	Seeds Per Ear	1000 Seed Weight (g)	Day to Physiological Maturity (Days)	Seed Filling Period
MS 14	1.33-^{**e}	2.3-^{**d}	0.25-^{cd}	3.78^{*b}	1.56^{**ab}	2.39^{**a}
48.1.1	0.2^{abc}	0.8-^{bcd}	0.5-^{**d}	28^{**a}	1.10^{*bc}	1.89^{**a}
H2.1.9	0.23-^{cd}	0.8-^{bcd}	0.05^{bcd}	3.47-^{*c}	1.10^{*bc}	0.14^{bc}
2.7.1	1.30^{**a}	0.7^{bc}	0.75^{**ab}	4.28^{*b}	0.1^{bc}	0.61-^{**cd}
2.1.40	0.9-^{**cde}	1.2^{b}	2-^{**e}	0.22-^{bc}	3.10^{**a}	0.36-^{cd}
H1.9.12	0.07-^{bc}	4.7^{**a}	0.25-^{cd}	5.72-^{**cd}	4.15-^{**d}	1.61-^{**e}
MS17.3	0.06^{bc}	1.2^{b}	1^{**a}	11.97-^{**de}	4.15-^{**d}	3.61-^{**e}
2.5.17	0.84^{**ab}	1.8-^{*cd}	1^{**a}	3.02^{b}	1.35^{**abc}	2.39^{**a}
1.9.4	0.21^{abc}	1.3-^{bcd}	0.25^{bc}	17.72-^{**e}	0.35^{bc}	0.61^{**b}
$S.E_{gi\ \%1}$ $S.E_{\%1}$ (gi– gj)	0.8 1.14	2.03 2.87	0.4 0.75	5.36 7.6	1.24 1.75	0.6 0.84
2/10/25	2.23-^{**c}	1.2-^{**b}	2.16-^{**c}	5.3-^{**c}	1.17-^{**c}	0.97^{**a}
MO17	0.99^{**b}	5.86^{**a}	3.72-^{**d}	23.25^{**a}	1.17^{**ab}	0.52^{**ab}
2.29.14	5.32^{**a}	0.8-^{b}	7.83^{**a}	2.14^{b}	2.51-^{**d}	1.8-^{**c}
1.551	3.34-^{**b}	3.46-^{**c}	1.72-^{**b}	20-^{**d}	2.15^{**a}	0.29^{b}
$S.E_{gi\ \%1}$ $S.E_{\%1}$ (gi – gj)	0.54 0.76	1.35 1.9	0.26 0.36	3.57 5.04	0.82 1.15	0.4 0.57

Notes: *and** are significant at the five and one percent probability levels, respectively.

other. The combination of private acceptance indicates non-incremental variance (dominance and epistasis) D and in this test for grain performance. Under favorable irrigation conditions, the hybrids obtained from crossing T1×L1, T2×L23, T3×L10, and T4×L21, and under drought stress, crossings T1×L18, T2×L23, and T3×L3 had the highest specific compatibility. The significance of the mean square line × tester in the corresponding analysis of the variance table provides a direct test for the significance of the additive component and the predominance of the genetic variance, respectively. Line × Tester mean square was significant for all traits in both environments. According to the results Kumar et al.[12], the significance of the mean square of line × tester shows that the reaction of lines with different testers for the respective traits is different and indicates the role of dominance and non-additive effect in the control of said traits. The significance of the mean square line × tester in the corresponding analysis of the variance table provides a direct test for the significance of the additive component and the predominance of the genetic variance, respectively. Line × tester mean square was significant for all traits in both environments. If the ratio of the variance of general compatibility to the variance of private compatibility is greater than one, it indicates additive genetic variance, and if it is less than one, it indicates the importance of non-incremental variance[15].

4 CONCLUSION

In reviewing the lines, the L4 line and testers B

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Table 3. Specific Combining Ability of Different Traits in Maize Hybrids

Crosses	Seed Yield ($Kg.h^{-1}$)	1000 Seed Weight (g)	Seeds Per Row	Seeds Per Ear	Day to Physiological Maturity (Days)	Seed Filling Period
L1×A	1.81^{**cdefg}	24.56**	-1.20	0.92**	-2.80**	-1.72^{**gh}
L2×A	1.29^{*cdefghi}	30.31**	1.30	-0.83**	-0.22	-2/22^{**h}
L3×A	1.27^{*cdefghi}	11.81**	1.30	0.17	4.28**	6.47^{**j}
L4×A	1.70^{**cdefg}	-15.94**	3.80*	1.92**	-2.47**	1.28^{**f}
L5×A	0.18^{cdefghijlmn}	-11.44**	1.30	0.67	0.03	4.78^{**cd}
L6×A	-1.00^{ijlmnop}	-20.94**	-4.20**	0.92**	0.78	-1.72^{**gh}
L7×A	-0.4^{ghijlmno}	-9.70*	-0.07	-0.33	-1.22**	1.28^{**f}
L8×A	-2.67^{**opq}	-14.70**	-0.07	-2.33**	2.78**	4.28^{**cd}
L9×A	-2.00^{**mnopq}	6.00	-1.20	-1.58**	-2.22**	0.28^{f}
L1×B	-2.03^{**nopq}	-51.00**	5.70**	-1.25**	1.38**	1.73^{**e}
L2×B	0.67^{cdefghij}	1.75	0.20	0.73	-1.92**	-1.77^{**gh}
L3×B	0.30^{defghijlm}	35.25**	4.20**	-2.27**	1.58**	0.98^{**f}
L4×B	6.60^{**a}	-29.50**	9.30**	-2.52**	2.83**	-0.27^{fg}
L5×B	-3.68^{**q}	-30.00**	-5.80**	0.23	3/33**	-1.77^{**gh}
L6×B	2.43^{**cde}	60.50**	4.70**	-1.52**	-1.92**	-1.72^{**gh}
L7×B	-0.14^{fghijlmn}	-28.25**	0.20	1.23**	2.08**	-6.27^{**j}
L8×B	2.71^{**bc}	31.75**	-3.80*	3.23**	-1.92**	6.73^{**b}
L9×B	6.18^{**a}	9.50*	3.70*	1.98**	-4.92**	1.73^{**e}
L1×C	1.30^{**cdefghi}	47.11**	2.30	-2.08**	0.58	-4.94^{**ij}
L2×C	-4.00^{**q}	-47.11**	-3.20*	-0.83**	-2.72**	4.56^{**cd}
L3×C	1.73^{**cdefg}	6.36	-1.20	2.17**	-1.22**	0.34^{f}
L4×C	5.00^{**b}	46.61**	3.80*	0.92**	0.03	8.06^{**a}
L5×C	2.39^{**cde}	11.11**	4.80**	-1.33**	1.53**	-4/44^{**i}
L6×C	-2.05^{**opq}	-33.40**	-2.70	-0.08	2.28**	-1.94^{**gh}
L7×C	-2.00^{**mnopq}	-17.40**	-5.20**	1.67**	-1.72**	1.06^{*f}
L8×C	0.53^{cdefghijl}	2.86	0.80	-0.33	4.28**	-5.94^{**ij}
L9×C	-2.43^{**opq}	-16.40**	0.30	-0.58	-2.72**	3.06^{**de}
L1×D	-1.11^{jlmnop}	-20.00**	-7.20**	2.48**	-0.62	4.95^{**c}
L2×D	2.00^{**cdef}	15.00**	1.50	0.73*	5.08**	-1.55^{**gh}
L3×D	-3.30^{**pq}	53.41**	-4.50**	-0.27	-4.72**	5.20^{**bc}
L4×D	0.10^{fghijlmn}	-1.16	2.00	-0.52*	-0.17	-9.05^{**k}
L5×D	1.11^{cdefghij}	30.34**	-0.50	0.23	-4.67**	1.45^{**ef}
L6×D	1.14^{cdefghij}	-6.16	2.00	0.48	-0.92	4.95^{**c}
L7×D	2.53^{**cd}	55.00**	5.50**	-2.77**	1.07**	3.95^{**cd}
L8×D	-0.59^{hijlmno}	-19.83**	3.50*	-0.77*	-4.92**	-5.05^{**ij}
L9×D	-1.70^{**lmnopq}	0.84	-3.00	-0.02	10.08**	-5.05^{**ij}
S.D(Sij)%1	1.61	10.47	4.07	0.78	1.37	1.20
S.D(Sij-Sji)	2.27	15.18	5.75	1.10	1.94	1.70

Notes: *and** are significant at the five and one percent probability levels, respectively.

and C were of high performance due to the general combinability of their performance components. Lines L1, L2, and L4 for the weight of a thousand seeds; L6 for the number of seeds in a row; L4, L7 and L8 had better combinability for the number of cob rows. Therefore, the mentioned lines can be considered as promising lines in the direction of improving the mentioned traits. Considering that one of the main goals in early corn is to reduce the length of the growing season, as a result, negative general composability is desirable for the trait of the number of days to physiological maturity. Based on this, Lines L6 and L7 lines were the earliest for the number of days until physiological maturity. Also, T1×L18, T2×L23, and T3×L3 crosses had the highest specific compatibility.

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Conflicts of Interest
The authors declared no conflict of interest.

Author Contribution
Aghdam MZ and Jalili F performed the experiments and wrote the manuscript.

Abbreviation List
GCA, General combinability ability
SCA, Specific combining ability

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