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Full Length Research Paper

Combining ability analysis of days to silking, plant height, yield components and kernel yield in maize breeding lines

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The present study was carried out to determine the combining ability for yield and yield associated traits by crossing 8 diverse maize inbred lines in a half diallel mating design. Twenty eight F_1 progenies along with their parents were planted in randomized complete block design with four replications in two environments. Combined analysis of variance showed significant mean squares of general combining ability (GCA) and specific combing ability (SCA) for days to ear silking (DS), plant height (PH), 1000-kernel weight (KW), number of kernels in ear row (KR), number of rows in ear (NR), kernel length (KL), cob to ear weight ratio (CR) and kernel yield (KY) indicating the importance of both additive and non additive genetic effects for these traits. However, high narrow-sense heritability estimates, low degree of dominance and the ratio of estimates of GCA to SCA effects for DS, KW, NR and CR indicated that additive genetic effect were more important for these traits. Most of the crosses with significant SCA effects for DS and KY had at least one parent with significant GCA effects for the same traits. Significant positive correlations were detected between KY and other yield components which included; KW, KR and KL. Therefore, these traits can be used as indirect selection criteria for seed yield improvement. The crosses MO17 × L8, MO17 × L12 and MO17 × L24 had high KY and were thus, considered as good combinations for improving the trait.

Key words: Additive, combined analysis, correlation, dominance, heritability.

INTRODUCTION

Maize is the most important cereal crop in the world after wheat and rice. It has great yield potential and attained the leading position among cereals based on production as well as productivity (Keskin et al., 2005). Advances in maize genomics, breeding and production have significant role on the lives of a large proportion of the world's population (Xu and Crouch, 2008). Every part of the plant has economic value; the grain, leaves, stalk, tassel are used to produce hundreds of food and non-food products. The main purpose of maize breeding is to develop new inbred lines and hybrids that will outperform the existing hybrids with respect to a number of traits. In working towards this objective, particular attention is paid to grain yield as the most economically important traits in maize (Vasic et al., 2001). Grain yield is a complex quantitative trait that depends on a number of factors that are inherited in a quantitative manner (Zivanovic et al., 2007). As a quantitative trait, it is greatly influenced by environmental conditions, has a complex mode of inheritance and low heritability (Bovanski et al., 2009). It is also affected by a number of components, including kernel row number and kernel number per row.

The recognition of parental inbred lines that can be used for developing superior hybrids is the most costly and time consuming phase in maize hybrid development. *Per se* performance of maize inbred lines does not

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predict the performance of maize hybrids for grain yields (Hallauer and Miranda, 1988). Predictors of single cross hybrid value or heterosis between parental inbred lines could therefore increase the efficiency of hybrid breeding programs (Betran et al., 2003). The main goal of maize breeding is obtaining new hybrids with high genetic potential for yield and positive features that exceed the existing commercial hybrids (Secanski et al., 2005). Combining ability analysis is therefore an important method to deduce gene actions and it is frequently used by crop breeders to choose parents with a high general combining ability (GCA) and hybrids with high specific combining ability (SCA) effects (Yingzhong, 1999). Variance for GCA is associated with additive genetic effects, while that of SCA includes non-additive genetic effects, arising largely from dominance and epistatic deviations with respect to certain traits. In a systematic breeding program, it is essential to identify superior parents for hybridization and crosses to expand the genetic variability for selection of superior genotypes (Hallauer and Miranda, 1988). One essential step in hybrid development is testing of inbred lines for their GCA effects. Diallel crosses have been widely used in plant breeding to investigate combining abilities of the parental lines in order to identify superior parents for use in hybrid development programs (Fry, 2004; Griffing, 1956; Hayman, 1954). Combining ability has been investigated by several researchers in maize (Beck et al., 1990; Crossa et al., 1990; Vasal et al., 1992; Kang et al., 1995; Kim and Ayala, 1996; Xingming et al., 2001; Betran et al., 2002; Revila et al., 2002; Glover et al., 2005). Fry (2004) stated that heritability of a trait approaches its maximum in successive generations following hybridization.

In addition, the presence of additive gene effects for a trait indicates the presence of additive variation, which means that selection could be successful for the trait (Fehr, 1991). Ojo et al. (2007) reported significant positive heterosis for grain yield and yield components including ear length and ear diameter in diallel crosses of seven white maize inbred lines. Additive gene action was also more important than non-additive gene action for grain yield. Ottaviano and Camussi (1981) examined several agronomic traits in diallel crosses of 10 inbred lines and their 45 F_1 hybrids to study their genetic relationships with grain yield.

Besides gene effects, breeders would also like to know how much of the variation in a crop is genetic and to what extent this variation is heritable, because efficiency of selection mainly depends on additive genetic variance, influence of the environment and interaction between genotype and environment (Novoselovic et al., 2004). Large genotype × environment effects tend to be viewed as problematic in breeding because the lack of a predictable response hinders progress from selection. Most of the literature about maize, the most extensively studied plant species, suggests that additive effects of genes with partial to complete dominance are more important than dominance effects in determining grain yield (Lamkey and Lee, 1993). Given the diversity of environments in which maize is cropped in Iran, the hybrid by environment interaction is normally expressive (Aguiar et al., 2003). Therefore it is necessary to identify hybrids that present not only wide adaptation, assessed by the mean yield, but also have high stability, that is, with homeostasis to adjust to environmental changes. Some studies have already compared stability in different types of hybrids (Cvarkovic et al., 2009). However, there is little information regarding stability of the GCA and SCA effects. Probably, when identifying single-crosses with higher stability in the GCA and SCA, the hybrid combinations obtained from these parents also present higher homeostasis for environmental variations.

The objectives of the present study were to evaluate GCA and SCA effects of seven maize inbred lines over two environments and also other genetic parameters including degree of dominance and narrow-sense heritability estimates for days to silking and yield components in order to determine superior breeding lines and cross combinations.

MATERIALS AND METHODS

The material under study consisted of eight maize inbred lines; L8, L10, L12, L21, L24, L33, L36 and MO17 which were selected based on different agronomic characters. These lines were crossed in a half diallel mating scheme in 2010. The resulting 28 F_1 progenies along with their parents were evaluated using a randomized complete block design with four replications at two locations; Dashtenaz Agronomy Research Station located in Sari, Iran (53° 11′ E longitude and 36° 37′ N latitude, 10.5 m above sea level) and Qarakheil Agronomy Research Station located in Qaemshahr, Iran (52° 46′ E longitude and 36° 27′ N latitude, 14.7 m above sea level) during spring 2011. The plots consisted of 3 rows, 5 m long and 75 cm apart and intra-row spacing of 20 cm. Crop management practices which included land preparation, crop rotation, fertilizer, and weed control were followed as recommended for each site. All the plant protection measures were adopted to make the crop free from insects. Ten plants from the middle of each row were sampled and the following traits were recorded for each cross at each location: days to silking, plant height in cm, 1000-kernel weight in gram, number of kernels in ear row, number of rows in ear, kernel length in cm, cob to ear weight ratio, kernel yield in ton per hectare. Data were analyzed using the following statistical model:

$$Yijkl = \mu + \alpha l + bkl + vij + (\alpha v)ijl + eijkl,\ vij = gi + gj + sij$$

Where Yijkl = observed value from each experimental unit; μ = population mean; αl = location effect; bkl = block or replication effect within each location; vij = F1 hybrid effect = gi + gj + sij (where gi = general combining ability (GCA) for the *i*th parent; gj = GCA effect of *j*th parent; sij = specific combining ability (SCA) for the *ij*th F1 hybrid); (αv)ijl = interaction effect between *ij*th F1 hybrid and location; eijkl = random residual effect.

The combining ability analysis was performed using mean values of the F_1 generation along with parents by using Griffin's method 2. The statistical t-student test was applied to examine the effects of GCA and SCA. Pearson coefficient of correlation was detected based on means values of the traits as:

Table 1. Combined analysis of days to silking, plant height, yield components and kernel yield of maize based on Griffin's method 2.

S.O.V	DF	DS	PH	KW	KR	NR	KL	CR	KY
Environments (E)	1	10964**	6452.5**	28082.5**	2.17^{ns}	6.0^{ns}	0.07^{ns}	20.0^{ns}	1.058^{ns}
E (REP)	6	41.92	1497.3	6530.6	52.0	9.1	0.02	3.74	22.93
Genotypes (G)	35	60.79**	4627.5**	4573.4**	146.4^{ns}	17.3^{ns}	0.05^{ns}	18.8^{ns}	32.2**
E*G	35	9.5^{ns}	764.7^{ns}	1325.0^{ns}	12.7^{ns}	3.5^{ns}	0.005^{ns}	5.27^{ns}	2.18^{ns}
GCA	7	208.2**	4883.7**	10804.6**	192**	54.3**	0.047**	70.4**	18.47**
SCA	28	22.71**	4748.7**	3126.6**	139.6**	7.8**	0.049**	6.93^{ns}	13.91**
GCA*E	7	12.61^{ns}	1075^{ns}	232.5^{ns}	10.46^{ns}	4.9^{ns}	0.002^{ns}	8.5^{ns}	1.148^{ns}
SCA*E	28	8.16^{ns}	698^{ns}	1562.1^{ns}	14.1^{ns}	3.1^{ns}	0.005^{ns}	3.14^{ns}	0.977^{ns}
Error	210	11.31	654.6	1243.9	18.2	3.3	0.006	5.207	2.268
MSGCA/MSSCA		9.17**	1.028^{ns}	3.46**	1.38^{ns}	1.75^{ns}	0.96^{ns}	10.16**	1.33^{ns}
D		0.76	3.11	1.4	2.64	0.939	3.24	0.51	2.68
H^2		0.63	0.16	0.62	0.22	0.57	0.06	0.65	0.07

DS: Days to ear silking, PH: plant height, KW: 1000-kernel weight, KR: number of kernels in ear row, NR: number of rows in ear, KL: kernel length, CR: cob to ear weight ratio, KY: kernel yield; ns,* and **: Non significant, significant at 5 and 1% levels, respectively.

Table 2. General combining effects of eight maize lines for kernel yield and related traits across two environments using Griffin's method 2.

Traits Lines	DS	PH	KW	KR	NR	KL	CR	KY
L8	1.229^{ns}	13.982**	7.865^{ns}	0.461^{ns}	0.828**	0.049**	-0.736**	1.087**
L10	0.229^{ns}	7.604**	-11.370**	2.148**	-0312^{ns}	-0.014^{ns}	-1.164**	0.178^{ns}
L12	-1.053^{ns}	-3.356^{ns}	9.278*	-0.867^{ns}	0.75**	0.018*	1.351**	0.232^{ns}
L21	-0.1^{ns}	-8.642**	-3.331^{ns}	-1.43**	0.505*	-0.01^{ns}	0.843**	-0.542**
L24	-0.225^{ns}	1.098^{ns}	-2.481^{ns}	-0.398^{ns}	0.078^{ns}	-0.003^{ns}	0.508*	-0.091^{ns}
L33	-1.381^{ns}	3.866^{ns}	-8.916*	-0.898^{ns}	0.646**	0.004^{ns}	-0.081^{ns}	-0.623**
L36	-2.037*	-5.53^{ns}	-13.13**	-1.664**	-1.078**	-0.038**	0.583*	-1.126**
MO17	3.338**	-9.021**	22.084**	2.648**	-1.672**	-0.007^{ns}	-1.300**	0.885**

DS: Days to ear silking, PH: plant height, KW: 1000-kernel weight, KR: number of kernels in ear row, NR: number of rows in ear, KL: kernel length, CR: cob to ear weight ratio, KY: kernel yield; ns,* and **: Non significant, significant at 5 and 1% levels, respectively.

$$r = [\text{Covarince (XY)}/\sqrt{\text{(Variance (X). Variance (Y)}}],$$

Where X and Y were considered as different traits under study.

A special SAS software (version 9) tool for diallel analysis developed by Zhang et al. (2005) was used to determine GCA effects, SCA effects, and their interaction effects with locations and also coefficient of correlation.

RESULTS AND DISCUSSION

Combined analysis of variance

Significant mean squares of GCA and SCA at 1% probability level were detected for all the traits including days to silking (DS), plant height (PH), 1000-kernel weight (KW), number of kernels in ear row (KR), number of rows in ear (NR), kernel length (KL), cob to ear weight ratio (CR) and kernel yield (KY) indicating the importance of both additive and non additive genetic effects for these traits (Table 1). The narrow-sense heritability estimates ranged from 0.06 to 0.65 for KL and CR, respectively and the degree of dominance for these traits were 0.51 and 3.24, respectively. The ratio of the GCA to SCA effects for the same traits was more than unity (Table 1). Therefore, due to the moderately high narrow-sense heritability estimates, low degree dominance for DS, KW, NR and CR it was concluded that the additive genetic effect was more important for these traits. Additive genetic effect is important in order to plant breeder can improved suitable traits in maize by transfer these genes in plant. Significant mean square of environments for DS, PH and KW at 1% probability level revealed significant differences between the two environments for these traits. Significant mean square of genotypes for DS, PH, KW and KY indicated significant genetic difference among parents and crosses for these traits. Non significant interaction effects of GCA and environments and also SCA and environments revealed that the trend of GCA effects of parents and SCA effects of the crosses over the environments were similar. Similarly, in earlier

Table 3. Means of eight maize lines for days to silking, plant height, yield components and kernel yield across two environments.

Traits / Lines	DS	PH (cm)	KW (g)	KR	NR	KL (cm)	CR (%)	KY (t/ha)
L8	64.5	159.9	277.9	29.8	16.0	0.95	15.9	6.15
L10	64.7	160.0	233.1	32.0	15.0	0.82	17.4	5.80
L12	64.3	142.9	291.3	29.1	16.5	0.94	18.4	6.69
L21	62.9	146.5	297.2	30.9	15.5	0.85	19.5	6.05
L24	63.4	148.1	254.2	27.4	15.0	0.83	17.4	4.95
L33	58.7	169.6	269.5	33.6	16.0	0.83	17.2	5.86
L36	58.7	153.4	213.8	24.9	13.0	0.75	18.2	3.79
MO17	68.0	146.0	261.3	32.9	12.5	0.83	14.7	5.71
LSD5%	3.297	24.98	34.65	4.18	1.77	0.07	2.22	1.48

DS: Days to ear silking, PH: plant height, KW: 1000-kernel weight, KR: number of kernels in ear row, NR: number of rows in ear, KL: kernel length, CR: cob to ear weight ratio, KY: kernel yield.

studies (Beck et al., 1990; Crossa et al., 1990; Vasal et al., 1992; Kang et al., 1995; Kim and Ayala, 1996; Xingming et al., 2001; Betran et al., 2002; Revila et al., 2002; Glover et al., 2005) were recorded as significant mean square of GCA and SCA effects of yield components in maize.

General combining ability of the parents

The mean of combining ability effects of parents for all the traits across the environments is presented in Table 2. Due to importance of early maturity and lower values of DS; L36 which had significant negative GCA effects were considered as good combiners for this trait. The parents; L33 and L36 with mean of 58.7 for DS are more profitable for improving this trait (Table 3). Due to lower plant height, it makes the plant more tolerant to lodging, therefore, the parents L12, L21 and MO17 with means of 142.9 146.5 and 146 cm of PH, respectively were suitable parents for this trait. The mean of KW ranged from 213.8 to 297.2 g and the parents L12 and L21 with 297.2 and 291.3 g mean of KW had high mean values for this trait. Parents L12 and MO17 had significant positive GCA effects for KW and thus, were considered to be good combiners for improving this trait. Parents L10 and MO17 had significant positive GCA effects for KR, hence, were good combiners for increasing this trait. The mean value for NR varied from 12.5 to 16.5, with parents L8, L12 and L33 having the highest values and significant positive GCA affects for the trait. Parents L8 and L12 had significant positive GCA effects for KL making them good combiners for improving the trait.

In addition, these two parents had high mean values for KL (Table 3). The parents L8, L10 and MO17 had significant negative GCA effects for CR and were, therefore, good combiners for reduction of this trait. The Low means of CR were observed for MO17 and L8. The parents L8 and MO17 which had significant positive GCA effects for KY were good combiners for improving the trait. Inbred lines L8, L12 and L21 had high means for KY (Table 3). Ojo et al. (2007) reported significant GCA effects for grain yield and yield components including ear length and ear diameter in a diallel crosses of seven white maize inbred lines.

Specific combining ability of the crosses

The results of SCA effect of crosses across the two environments for the different traits are presented in Table 4. Across the environments, only a few crosses had significant SCA effects for some of the traits. None of the crosses had significant SCA effects for DS. This could be due to the relatively high narrow-sense heritability estimates that were observed for the trait, an indication that additive genetic effects were more important. The DS means varied from 57.2 to 65.8 for L24 × L36 and MO17 × L8, respectively (Table 5). The crosses with low value for DS had at least one parent with significant negative GCA effect for this trait. The parents can, therefore be used in breeding for early maturity. Out of 28 crosses, 4 crosses had significant SCA effects for PH. The cross MO17 × L21 with significant negative SCA effects for PH was the best cross combination for this trait. Low values for plant height were observed for MO17 × L21 (153.3 cm), L12 × L36 and L21 × L36 (182.1 cm), respectively.

Significant positive correlations were observed for KW with DS, KR, KL (Table 6), implying that crosses with high means value of these traits can be used for KW. Improving KW is one of the most important traits in order to increase kernel yield. Among the crosses, only MO17 × L8 had significant positive SCA effect for KW and this cross had the highest mean for KW. Significant positive correlations were detected for KR with KY and KL. Therefore, the genotypes with high value for KR will in more KL and high KY. The crosses MO17 × L8, MO17 ×

Table 4. Specific combining effects of maize lines for kernel yield and related traits across two environments using Griffin's method 2.

Crosses	DS	PH	KW	KR	NR	KL	CR	KY
L8 × L10	1.13^{ns}	36.43**	-4.37^{ns}	1.29^{ns}	0.84^{ns}	0.08**	-1.27^{ns}	0.71^{ns}
L8 × L12	-0.59^{ns}	7.12^{ns}	-3.2^{ns}	-1.57^{ns}	0.41^{ns}	-0.04^{ns}	0.88^{ns}	-0.17^{ns}
L8 × L21	-0.67^{ns}	6.9^{ns}	-5.5^{ns}	2.24^{ns}	0.15^{ns}	0.03^{ns}	-0.29^{ns}	1.18*
L8 × L24	-1.17^{ns}	-0.11^{ns}	7.4^{ns}	0.21^{ns}	0.33^{ns}	0.04^{ns}	-0.54^{ns}	0.78^{ns}
L8 × L33	-0.38^{ns}	9.65^{ns}	-12.8^{ns}	0.59^{ns}	0.76^{ns}	0.03^{ns}	-0.22^{ns}	0.34^{ns}
L8 × L36	0.27^{ns}	6.68^{ns}	14.1^{ns}	1.48^{ns}	0.11^{ns}	-0.03^{ns}	0.46^{ns}	-0.33^{ns}
L10 × L12	-2.2^{ns}	-7.92^{ns}	-0.51^{ns}	2.24^{ns}	0.92^{ns}	-0.03^{ns}	-0.27^{ns}	0.94^{ns}
L10 × L21	-1.92^{ns}	4.0^{ns}	1.66^{ns}	0.68^{ns}	-0.46^{ns}	0.015^{ns}	-0.35^{ns}	0.45^{ns}
L10 × L24	0.33^{ns}	7.53^{ns}	0.77^{ns}	-0.1^{ns}	-0.91^{ns}	-0.04^{ns}	0.55^{ns}	-0.53^{ns}
L10 × L24	0.33^{ns}	7.53^{ns}	0.77^{ns}	-0.1^{ns}	-0.91^{ns}	-0.04^{ns}	0.55^{ns}	-0.53^{ns}
L10 × L33	-0.01^{ns}	3.09^{ns}	6.4^{ns}	-1.1^{ns}	0.4^{ns}	0.01^{ns}	0.1^{ns}	0.14^{ns}
L10 × L 36	-0.48^{ns}	7.92^{ns}	5.38^{ns}	1.04^{ns}	0.25^{ns}	0.018^{ns}	-0.83^{ns}	0.45^{ns}
L12 × L21	0.62^{ns}	15.8^{ns}	4.72^{ns}	2.2^{ns}	0.48^{ns}	0.03^{ns}	0.21^{ns}	0.59^{ns}
L12 × L24	-1.26^{ns}	9.97^{ns}	1.82^{ns}	-0.59^{ns}	0.53^{ns}	0.024^{ns}	0.46^{ns}	-0.13^{ns}
L12 × L33	-1.6^{ns}	6.66^{ns}	-2.03^{ns}	-2.84*	0.46^{ns}	0.07**	-0.55^{ns}	0.36^{ns}
L12 × L36	-0.45^{ns}	-7.23^{ns}	-10.2^{ns}	0.18^{ns}	-1.06^{ns}	-0.025^{ns}	-0.54^{ns}	-0.92^{ns}
L21 × L24	0.66^{ns}	9.64^{ns}	-5.92^{ns}	1.35^{ns}	0.65^{ns}	0.022^{ns}	-0.42^{ns}	0.47^{ns}
L21 × L33	1.19^{ns}	9.12^{ns}	-7.27^{ns}	1.48^{ns}	-0.029^{ns}	0.019^{ns}	-1.13^{ns}	0.63^{ns}
L21 × L36	-0.28^{ns}	3.42^{ns}	18.46^{ns}	2.24^{ns}	0.18^{ns}	0.06*	1.13^{ns}	0.84^{ns}
L24 × L33	-0.68^{ns}	1.22^{ns}	-2.31^{ns}	-0.05^{ns}	1.01^{ns}	0.04^{ns}	0.33^{ns}	0.24^{ns}
L24 × L36	-0.53^{ns}	8.39^{ns}	5.89^{ns}	2.96*	-0.02^{ns}	0.015^{ns}	0.01^{ns}	1.11*
L33 × L36	-0.37^{ns}	-8.89^{ns}	0.48^{ns}	0.71^{ns}	-0.83^{ns}	0.037^{ns}	-0.12^{ns}	0.4^{ns}
MO17 × L8	0.27^{ns}	-5.74^{ns}	23.78*	2.66*	-0.93^{ns}	0.02^{ns}	0.14^{ns}	2.21**
MO17 × L10	-0.1^{ns}	-2.97^{ns}	16.52^{ns}	3.98**	-0.66^{ns}	0.064**	-1.09^{ns}	1.1*
MO17× L12	0.05^{ns}	18.85*	18.38^{ns}	5.37**	-0.6^{ns}	0.04^{ns}	0.68^{ns}	1.81**
MO17 × L21	-1.78^{ns}	-19.85*	-28.42*	-8.2**	0.81^{ns}	-0.06*	-0.46^{ns}	-2.6**
MO17 × L24	-0.28^{ns}	10.27^{ns}	14.9^{ns}	3.77**	-0.43^{ns}	0.04^{ns}	-0.2^{ns}	1.6**
MO17 × L33	1.38^{ns}	10.14^{ns}	11.88^{ns}	1.65^{ns}	-0.12^{ns}	-0.05*	0.79^{ns}	-052^{ns}
MO17 × L36	0.037^{ns}	18.12*	7.51^{ns}	-1.09^{ns}	2.48**	0.07**	-0.58^{ns}	1.12*

DS: Days to ear silking, PH: plant height, KW: 1000-kernel weight, KR: number of kernels in ear row, NR: number of rows in ear, KL: kernel length, CR: cob to ear weight ratio, KY: kernel yield; ns,* and **: Non significant, significant at 5 and 1% levels, respectively.

L10, MO17 × L12 and MO17 × L24 had significant positive SCA effect for KR were considered good cross combinations for KR. All of the crosses with significant positive SCA effect for KR had at least on parent (MO17) with significant positive GCA effect for KR. Significant positive correlation was determined between KL and KY therefore, this trait can also be used as indirect selection criterion for improving KY. Out of 28 crosses, 5 crosses had significant SCA effects for KL. The cross MO17 × L21 which had significant negative SCA effects for PH makes lower value for this trait, therefore, it was the best cross combination for PH. The crosses including MO17 × L8, MO17 × L12, L8 × L10, L8 × L21 and L12 × L33 had high means for KL. None of the crosses had significant SCA effects for CR. This could be explained by the fact that the narrow-sense heritability estimate for this trait was high, implying that additive genetic effects were predominant. The correlation coefficients for CR with KY, PH, KR and DS were significant and negative. This suggests that low CR will be more profitable. The crosses MO17 × L8, MO17 × L10 and L8 × L10 with low CR were considered as good cross combinations (Table 5). Out of 28 crosses, 7 crosses had significant SCA effects for KY. Most of the crosses with SCA effects for KY had at least one parent (MO18 and L8) with significant GCA effect for this trait. The crosses MO17 × L8, MO17 × L12 and MO17 × L24 had high KY were considered as good combinations for improving the trait. Significant SCA effects were reported for kernel yield and yield components in diallel crosses of maize breeding lines (Revila et al., 2002; Glover et al., 2005; Fan et al., 2008). MO17 × L8 was the best hybrid in kernel yield in the two locations, therefore, it can be further investigated for use in the same conditions. L8 has the highest combining ability in more traits, as such it can used in maize breeding program.

Table 5. Means of half diallel crosses of eight maize lines across two environments for days to silking, plant height, yield components and grain yield.

Crosses	DS	PH (cm)	KW (g)	KR	NR	KL (cm)	CR (%)	KY (t/ha)
L8 × L10	63.5	250.8	273.8	39.7	17.5	1.09	13.3	10.7
L8 × L12	60.5	210.6	295.6	33.8	18.0	1.00	18.0	9.9
L8 × L21	61.4	205.1	280.8	37.1	17.5	1.04	16.3	10.4
L8 × L24	60.8	207.8	294.5	36.1	17.0	1.06	15.8	10.5
L8 × L33	60.4	220.3	267.9	35.9	18.0	1.06	15.5	9.5
L8 × L 36	60.4	208.0	290.5	36.0	16.0	0.96	16.8	8.3
L10 × L12	57.9	189.1	279.1	39.3	17.5	0.95	16.4	10.1
L10 × L21	59.2	195.8	268.6	37.2	16.0	0.97	15.9	8.8
L10 × L24	61.3	209.1	268.6	37.4	14.5	0.92	16.4	8.3
L10 × L33	59.8	207.4	267.8	35.9	17.0	0.98	15.4	8.4
L10 × L36	58.7	202.8	262.6	37.3	15.0	0.94	15.1	8.2
L12 × L21	60.4	196.7	292.4	35.7	17.5	1.02	18.9	9.0
L12 × L24	58.4	200.5	290.3	33.9	17.0	1.02	18.8	8.7
L12 ×L33	56.9	200.0	280.0	31.2	18.0	1.07	17.2	8.7
L12 × L36	57.4	176.7	267.6	33.4	14.5	0.93	17.9	6.9
L21× L24	61.3	194.9	270.0	35.3	17.5	0.99	17.5	8.5
L21 × L33	60.7	197.2	262.1	34.9	17.0	0.99	16.1	8.2
L21 × L36	58.5	182.1	283.7	34.9	15.5	0.98	19.1	7.9
L24 × L33	58.7	199.0	268.0	34.4	18.0	1.02	17.2	8.2
L24 × L36	58.2	196.8	272.0	36.7	15.0	0.95	17.6	8.6
L33 × L36	57.2	182.3	260.1	33.9	14.5	0.98	16.9	7.4
MO17× L8	65.8	192.0	335.4	41.6	14.5	1.04	14.6	12.9
MO17 × L10	64.4	188.5	308.9	44.5	13.5	1.02	12.9	10.9
MO17× L12	63.3	199.3	331.4	42.9	14.5	1.04	17.2	11.6
MO17× L21	62.4	155.3	272.0	28.8	15.5	0.90	15.6	6.5
MO17× L24	63.8	195.2	316.2	41.8	14.5	1.01	15.5	11.1
MO17× L33	64.3	197.8	306.7	39.2	15.0	0.92	15.9	8.4
MO17× L36	62.3	196.4	298.1	35.7	16.0	1.01	15.2	9.6
SC704CHEK	64.5	199.4	289.6	43.9	15.0	1.11	15.1	12.2
LSD5%	3.297	24.98	34.65	4.188	1.774	0.076	2.226	1.482

DS: Days to ear silking, PH: plant height, KW: 1000-kernel weight, KR: number of kernels in ear row, NR: number of rows in ear, KL: kernel length, CR: cob to ear weight ratio, KY: kernel yield.

Table 6. Correlation between the traits from a half diallel crosses of 8 parents of maize.

Traits	DS	PH	KW	KR	NR	KL	CR	KY
DS	1							
PH	-.025^{ns}	1						
KW	0.33*	0.27^{ns}	1					
KR	0.19^{ns}	0.63**	0.62**	1				
NR	-0.37*	0.49**	0.05^{ns}	-0.04^{ns}	1			
KL	-0.06^{ns}	0.76**	0.57**	0.63**	0.51**	1		
CR	-0.43*	-0.36*	-0.17^{ns}	-0.54**	0.17^{ns}	-0.33*	1	
KY	0.12^{ns}	0.72**	0.72**	0.87**	0.25^{ns}	0.85**	-0.45**	1

DS: Days to ear silking, PH: plant height, KW: 1000-kernel weight, KR: number of kernels in ear row, NR: number of rows in ear, KL: kernel length, CR: cob to ear weight ratio, KY: kernel yield; ns,* and **: Non significant, significant at 5 and 1% levels, respectively.

Conclusion

The non-significant interaction effects of GCA and SCA with environments revealed that the trend of GCA effects of parents and SCA effects of the crosses over the environments were similar. Among the yield components, KW, NR and CR had high narrow-sense heritability estimates; therefore, these traits were affected more by additive genetic effects.

A significant positive correlation was detected between KR and KY implying that genotypes with high KR will have high KY. Most of the crosses with SCA effects for DS and KY had at least one parent with significant GCA effect for same traits.

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