FULL DIALLEL CROSSES FOR ESTIMATION OF GENETIC PARAMETERS IN MAIZE

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ABSTRACT

This research was conducted to estimate some genetic parameters by using full diallel crosses in maize (*Zea mays* L.) at Grdarasha Agricultural Research Station, College of Agriculture, University of Salahaddin, Erbil. During the spring season of 2015, four diverse maize inbred line seeds were sown and exhibited full diallel cross between them. In fall season 2015، the F1 hybrids with their parental lines were sown in randomized complete block design with three replications. The results revealed there were highly significant differences among genotypes for almost all of the evaluated traits which were days to 50% tasseling, plant height, ear height, ear length, no. of rows ear^{-1}, 150-kernels weight and total yield except the character no. of ears plant^{-1}. GCA and SCA mean squares were highly significant for some traits, but mean squares for reciprocal combining ability were highly significant for traits plant height, ear height and 150-kernels weight. Pertaining the parents, Kr 640 revealed the best values among the parents for most of the traits, and for diallel and reciprocal hybrids the crosses 3007× Kr 640 and 5012× Kr 640 demonstrated more desired values respectively. Regarding the σ^2gca/σ^2sca ratio, for all the traits exclude no. of rows ear^{-1}, showed to be less than one, this showed the importance of non-additive gene effect in the inheritance of these traits, and the average degree of dominance were more than one in the same traits. Heritability estimation in both broad and narrow senses were proceed, the results submitted that heritability in broad sense was high for all the traits, it was recommended hybridization and selection method to improve these traits.

Keywords: Diallel Cross, General and Specific combining ability, Heritability

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ألتهجينات التبادلية الكاملة لتقدير المعالم الوراثية في الذرة الصفراء

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المستخلص

أُجري البحث لتقدير بعض المعالم الوراثية في الذرة الصفراء(.*Zea mays* L) باستعمال التهجينات التبادلية الكاملة، في حقل كرده ره شه للتجارب الزراعية التابع لكلية الزراعة، جامعة صلاح الدين/ أربيل. في الموسم الربيعي 2015، فقد تمت زراعة أربع سلالات من الذرة الصفراء أخذت من مصادر مختلفة. و أُجريت التهجينات التبادلية الكاملة بينها و و تم إستنباط 16 هجيناً فردياً. في الموسم الخريفي 2015، زرعت هجن الجيل الأول من ضمنها الهجن العكسية مع آبائها في تجربة مقارنة باستخدام تصميم القطاعات العشوائية الكاملة و بثلاث مكررات. أظهرت النتائج وجود فروقات عالية المعنوية بين التراكيب الوراثية المختلفة لكل الصفات المدروسة (عدد الأيام اللازمة إلى التزهير الذكري لِ 50% من النباتات، إرتفاع النبات، إرتفاع العرنوص، عدد العرانيص. نبات$^{-1}$، طول العرنوص، وزن 150 حبة و الحاصل الكلي (طن)) . كانت متوسط المربعات للقدرة العامة و الخاصة على الإئتلاف عالية المعنوية لأكثر من نصف عدد الصفات. أمّا قدرة الإئتلاف للتهجينات العكسية كانت عالية المعنوية للصفات، إرتفاع النبات، إرتفاع العرنوص و وزن 150 حبة. و بخصوص الآباء، تفوقت السلالة Kr 640 في معظم الصفات. تفوقت الهجينان(3007× Kr 640) في الصفات المدروسة. إن نسبة $\sigma^2gca/$ كانت أقل من واحد لمعظم الصفات مما يؤشر إلى أهمية تأثير فعل الجيني غير الإضافي لتوريث هذه الصفات. و كان معدل درجة السيادة أكبر من واحد لهذه الصفات. يمكن تحسين هذه الصفات باستخدام طريقتي التهجين ثم الإنتخاب.

كلمات مفتاحية: التهجينات التبادلية، للقدرة العامة و الخاصة على الإئتلاف، درجة التوريث.

INTRODUCTION

Diallel crosses have been widely used in genetic research to investigate the inheritance of important traits among a set of genotypes. These were devised, specifically, to investigate the combining ability of the parental lines for the purpose of identification, the superior parents for use in corn hybrid breeding programs, to improve productivity, one of the most important steps in a breeding program is the choice of suitable parents (1). Wattoo *et al.* (21) used 7×7 full diallel fashion in maize showed highly significant differences among the genotypes for number of days to tasselling, number of days to silking, plant height, number of ears plant^{-1}, number of rows ear^{-1}, number of kernels row^{-1}, 100-kernel weight and grain yield plant^{-1}. Over all maize possess extravagant variation for all traits and this variability can be easily used by the plant breeders to develop high yielding and early maturing genotypes for global food security (2). The combining ability analysis is an important method to know gene actions and it is frequently used by crop breeders to choose the parents with a high general combining ability (GCA) and hybrids with high specific combining ability (SCA) effects (23). Hasan (11) pointed out that gene action is a behavior or a gene expression method of itself in a genetic population. There are two types of gene action, additive gene action and non-additive gene action. The analysis of variance of combining abilities showed highly significant effects by additive and non-additive genes on grain yield plant^{-1}, with predominant impact of non-additive gene effect (GCA/SCA=0,684) (10). In a study using a partial diallel design, Balestre *et al.* (7) observed that the specific combining ability predictions varied from 0.61 to 0.70 and the overall mean grain yield for the 60 evaluated hybrids was 8.962 ton.ha^{-1}, with a broad sense heritability value of 0.741. GCA variance was low magnitude by (0.002) in relation to SCA variance (1.622). The analysis of variance showed no significant difference for GCA and SCA for days to male and female flowering; height of plant and ear (6). GCA and SCA effects were significant for grain yield, number of rows ear^{-1}, kernel number row^{-1} and thousand-kernel weight, and the variations due to GCA, SCA and their interaction with environment for all traits were highly significant (9). Wannows *et al.* (20) predicted high narrow sense heritability for number of kernel row^{-1} (86%), plant height (85%), ear height (83%), number of rows ear^{-1} (77%) and ear length (73%) emphasizing that the additive genetic variance was the major component of genetic variation in the inheritance of these traits and the effectiveness of selection for improving these traits. Zare *et al.* (24) reported that broad-sense heritability in maize ranged between 47.4% and 89.4% for number of rows ear^{-1}. Estimates of broad-sense heritability for number of rows ear^{-1}and grain yield had the highest heritability (0.894 and 0.857, respectively). Moderate estimates of broad-sense heritability were observed for ear length, number of kernels row^{-1}and plant height (0.742, 0.673and 0.641, respectively), also their results concerned over-dominance gene effects for plant height, number of rows ear^{-1} and grain yield. Ear length was controlled by partial dominance, indicating that additive gene effect was more important than non-additive gene effect for controlling the inheritance of this trait. Therefore, improvement of this trait through selection of breeding materials is highly feasible. According to Pshdary (16) results the ratio of $\sigma^2 GCA/\sigma^2 SCA$ was less than one in almost all of the traits at both locations, which indicates the importance of non-additive gene effect in the inheritance of these traits and the average degree of dominance were more than one in those traits with the exception of the traits days to 50% tasseling, days to 50% silking and no.of kernels row^{-1} at both locations, and no. of rows ear^{-1} at Kanipanka location, and no. of ear plant^{-1}, and 300 kernels weight at Qlyasan location. Based on the yield performance in the two maturing groups, high grain yield was recorded in two varieties each among the early and late/intermediate varieties with approximately 4.6 tons ha^{-1} (8). Noor *et al* (15) detected maximum plant height which was 192.5 cm while minimum recorded was 140 cm. Minimum ear height observed was 48 cm while maximum recorded was 97.5 cm. The maximum ear length was 18.5 whereas the minimum ear length was 12 cm. Highest kernel rows ear^{-1} observed was 16 whereas minimum 11 was recorded. Maximum 100-grains weight exhibited was 33.6 g while minimum was 20 g. Highest grain yield 6987 $kg.ha^{-1}$ was recorded while minimum 2269 $kg.ha^{-1}$. The objective of the present study is to estimate genetic parameters like heritability, general and specific combining abilities and average degree of dominance of maize then choose the best parents and crosses in breeding programs.

MATERIALS AND METHODS

This research was carried out during the spring and fall season 2015 at Grdarasha Agricultural Research Station\ College of Agriculture, Erbil. In spring season 2015, four diverse maize inbred line seeds (Table 1) were sown to perform full diallel cross program (all possible crosses including reciprocals). In fall season 2015 the F1 hybrids with their parental lines were evaluated in randomized complete block design (RCBD) with three replications. Data were recorded on five plants for the following traits, days to 50% tasseling, plant height (cm), ear height (cm), no. of ears $plant^{-1}$, ear length (cm), no. of rows ear^{-1}, 150–kernels weight (g) and total yield ($ton.ha^{-1}$). Fertilizer, weed control and other cultural practices were performed according to the plant requirements.The results were analyzed using analysis of variance, when significant differences were genetically analyzed by methods adopted by Singh and Chaudhary.

Table 1. Genetic Materials:

No.	Inbred Lines
1	3007
2	Kr 640
3	5012
4	MSI 4279

Estimation of general and specific combining ability effects:

$$\hat{g}ii= \frac{1}{2p}(Yi.+Y.j) - \frac{1}{p^2}Y..$$

$$\hat{s}ij= \frac{1}{2}(Yij + Yji) - \frac{1}{2p}(Yi.+Y.i + Yj.+Y.j) + \frac{1}{p^2}Y..$$

$$\hat{r}ij=\frac{1}{2}(Yij - Yji)$$

Where: $\hat{g}ii$: effect of expected general combining ability for parent *i* ,

$\hat{s}ij$: effect of expected specific combining ability for single diallel crosses *ij* when *i=j*,

$\hat{r}ij$: effect of expected specific combining ability for single reciprocal crosses *ij* when *i=j*,

Yij: F1's mean as a result of crossing parent *i* with parent *j*,

$Y..$: sum of the means of all parents and F1 s hybrids, and

p: parents number.

Estimation of components of variance for both General and Specific combining abilities:

$$\sigma^2\hat{g}ii= (gii)^2-\frac{MS\bar{e}}{p^2}$$

$$\sigma^2\hat{s}ij= \frac{1}{p^{-2}}\sum \hat{s}ij^2-\frac{MS\bar{e}\,(p^2-2p+2)}{2p^2}$$

$$\sigma^2\hat{r}ij = \frac{1}{p^{-2}}\sum \hat{r}ij^2- \frac{MS\bar{e}}{2}$$

Where: $\sigma^2\hat{g}ii$: variance of expected effect of general combining ability for parent *i*,

$\sigma^2\hat{s}ij$: variance of expected effect of specific combining ability for diallel crosses of parent *i*, and

$\sigma^2\hat{r}ij$: variance of expected effect of specific combining ability for reciprocal crosses of parent *i*.

Estimation of standard error for the differences between the effects of the general combining ability of two parents, two diallel crosses and reciprocal crosses, respectively:

$$S.E._{(gi - gj)} = \sqrt{\frac{MS\bar{e}}{p}}, \quad S.E._{(sij- sik)} = \sqrt{\frac{(p-1)MS\bar{e}}{p}},$$

$$S.E._{(Rij- Rik)} = \sqrt{MS\bar{e}}$$

Heritability:

$$h^2b.s =\frac{\sigma^2\ G}{\sigma^2\ p} = \frac{\sigma^2\ A+\sigma^2 D}{\sigma^2 A+\sigma^2 D+\sigma^2 e}=\frac{2\sigma^2 gca+ \sigma^2 sca}{2\sigma^2 gca+\sigma^2 sca+\sigma^2 e}$$

$$h^2n.s =\frac{\sigma^2 A}{\sigma^2 p} = \frac{\sigma^2\ A}{\sigma^2\ A+\sigma^2 D+\sigma^2 e}=\frac{2\sigma^2 gca}{2\sigma^2 gca+\sigma^2 sca+\sigma^2 e}$$

Estimation of average degree of dominance:

$$\bar{a}=\sqrt{\frac{2\sigma^2 D}{\sigma^2\ A}} = \sqrt{\frac{2\sigma^2 sca}{2\sigma^2\ gca}} = \sqrt{\frac{\sigma^2 sca}{\sigma^2\ gca}}$$

If: $\bar{a}$= zero denotes no dominance,

$\bar{a} < 1$ denotes partial dominance,

$\bar{a}$= 1 denotes complete dominance,

$\bar{a}$ > 1 denotes over dominance.

RESULTS AND DISCUSSION

Days to 50% tasseling:

Analysis of variance indicated that there were highly significant differences between genotypes for this character. Parent 2 and 3 were the earliest with average 49.0 days required to 50% tasseling respectively, while parent 1 was the latest with 53.3 days. The differences in parent's days to 50% tasseling caused also the differences in their hybrids. Regarding the diallel hybrids, the hybrid 1×2 with 47.0 days was the earliest and it was earlier than the parents, but the diallel hybrid 3×4 with 52.0 days was the latest. Both the reciprocal hybrids 2×1 and 3×2 with 47.67 days had the shortest period to 50% tasseling, while 4×1 with 50.0 days had the longest period, (5, 12, 16 and 21) found significant differences between genotypes in this trait. The combining ability analysis showed highly significant GCA and SCA mean squares (Table 2). Table 3 represented that the highest positive value of $\hat{g}ii$ was 0.938 in parent 4, this value indicates the high contribution of this parent in increasing the number of days to 50% tasseling in its hybrids, while parent 2 exhibited the highest negative value of $\hat{g}ii$ reaching -1.104, explaining the contribution of this parent in decreasing the number of days to 50% tasseling in its hybrids. Pertaining the SCA effect of the hybrids, the maximum SCA effect value was 0.479 in the diallel hybrid 3×4, while the highest negative SCA effect value was -1.438 showed by the diallel cross 1×2. The positive effect of SCA indicating the increase days to 50% tasseling in the hybrids compared with their parents. The maximum $\acute{r}ij$ value detected of RCA was 1.167 in the reciprocal hybrid 4×3. The highest variance of GCA and RCA effect, performed by parent 2 which was 1.219 and 1.380 respectively, but SCA effect highest value was 1.649 observed in parent 1 demonstrating the large contribution of this parent in transferring this trait to its hybrids. Estimation of some genetic parameters for the trait number of days to 50% tasseling also existed in Table 2, the variance component relating to GCA was less than the variance component due to SCA, making the ratio of $\sigma^2gca\ /\sigma^2sca$ value less than one (0.282) implying the large contribution of non-additive gene action in the inheritance of this trait. It was reflected on the average degree of dominance value for diallel cross by giving more than one (3.552), and it was 0.183 for reciprocal cross. Previously (19) reported similar results. The heritability measured in both broad and narrow sense for diallel cross seen to be 0.858 and 0.309 respectively, while the heritability in broad and in narrow sense for reciprocal cross was 0.689 and 0.677 respectively. The results suggested the hybridization and selection method to improve this trait. Similar values have been showed by (16).

Table 2. Mean Squares of variance analysis for genotypes, general and specific combining ability for the parents, F1 diallel crosses, and reciprocal crosses of the studied characters

S. O. V	*Replication*	*Genotypes*	*GCA*	*SCA*	*RCA*	$\sigma^2 e$	*GCA/ SCA*	*GCA/RCA*	*MSé*
d.f / *Traits*	2	15	3	6	6	30			
Days to 50% tasseling	12.000	9.143**	5.912**	3.821**	0.843 n.s	2.356	1.547	7.016	0.785
Plant height	57.286	331.235**	33.726**	164.769**	94.398**	53.303	0.205	0.357	17.768
Ear height	37.679	278.664**	102.308**	110.911**	70.155**	62.015	0.922	1.458	20.672
No. of ears $plant^{-1}$	0.003	0.030n.s	0.009 n.s	0.012 n.s	0.008 n.s	0.020	0.757	1.208	0.007
Ear length	0.169	7.642**	0.229 n.s	4.745**	1.509 n.s	0.435	0.048	0.151	0.145
No. of rows ear^{-1}	0.057	10.060**	12.082**	1.597 n.s	0.745 n.s	1.703	7.568	16.212	0.568
150-kernels weight	21.807	61.615**	46.286**	20.924**	7.279**	15.479	2.212	6.359	5.160
Total yield	2.440	8.645**	0.883 n.s	5.381**	1.382 n.s	1.571	0.164	0.638	0.524

$F_{0.05}$ (3, 30) = 2.922, $F_{0.05}$ (6, 30) = 2.421, $F_{0.05}$ (15, 30) = 2.015

$F_{0.01}$ (3, 30) =4.510, $F_{0.01}$ (6, 30) = 3.473, $F_{0.01}$ (15, 30) = 2.700

Table 3. Estimation of general and specific combining abilities effect, their variances and some genetic parameters for character Days to 50% tasseling:

ĝii	1	2	3	4	σ^2 ĝii	σ^2ŝij	σ^2ŕij
1	0.313	-1.438	0.021	-1.312	0.049	1.649	-0.156
2	-0.333	-1.104	0.187	-0.396	1.219	-0.094	1.380
3	-0.333	0.833	-0.146	0.479	0.021	0.272	0.698
4	-0.500	0.000	1.167	0.938	0.879	0.560	1.054
	ĝii	ŝij	ŕij				
S.E	0.443	0.767	0.886				
Mse´	σ^2gca	σ^2sca =σ^2D	σ^2gca /σ^2sca	σ^2A	σ^2D_r	σ^2D	
0.785	0.854	3.035	0.282	1.709	0.029	3.035	
ā	$h^2_{b.s}$	$h^2_{n.s}$	$\bar{a}_r$	h^2_{bsr}	h^2_{nsr}	σ^2G	
3.552	0.858	0.309	0.183	0.689	0.677	4.744	

Plant height (cm):

As predicted in Table 2 there were highly significant differences between genotypes for this trait. The maximum plant height produced by parent 2 with 165.800 cm, while the minimum value was 151.367 cm for parent 4. With relevant to the diallel crosses revealed that the values restricted between 163.233 cm to 179.667 cm for both crosses 3×4 and 1×2 respectively, but for reciprocal crosses limited between 165.533 cm to 187.900 cm for reciprocal crosses 2×1 and 3×1 respectively. Similar results were reported previously by other researchers (3, 4, 8 and 21). Regarding the combining ability analysis showed highly significant GCA, SCA and RCA mean squares (Table 2). But several researchers estimated no significant differences for GCA and SCA. The data in Table 4 reveals the estimations of both general and specific combining ability effects, maximum positive GCA effect exhibited by parent 3 with 2.117, predicting the high contribution of this parent in the inheritance of this trait to its hybrids. The only negative general combining ability was -2.812 gave by parent 4, indicating the ability of this parent in decreasing plant height in its crosses, maximum positive SCA effect value recorded by the cross 1×3 was 10.325, whereas the solely negative effect was -1.192 exhibited by the diallel cross 1×2. Involving RCA effect for reciprocal crosses as shown in the same table, the maximum positive effect recorded by the reciprocal cross 2×1 which was 7.067, but the maximum negative effect was -12.167 recorded by the cross 4×3.

The highest variance of GCA and SCA effect exhibited by parent 4 with 7.910 and 74.520 respectively, showing the large contribution of this parent in its hybrids in the inheritance of this trait. Highest variance due to RCA was 131.680 recorded by parent 3. Previously Zare *et al.* (24) found significant effects. Some genetic parameters for plant height were also explained in Table 4. The variance components due to SCA were higher than variance components due to GCA, causing the ratio $\sigma^2 gca / \sigma^2 sca$ to be less than one (0.018), clarifying the great role of non-additive gene effect in the inheritance of this trait. The average degree of dominance were 55.271 and 3.796 for both diallel and reciprocal crosses respectively. Heritability in both broad and narrow sense estimated, in broad sense was 0.896 and 0.711 for both diallel and reciprocal crosses, whereas were 0.031 and 0.087 in narrow sense for both diallel and reciprocal crosses respectively, predicting the importance of hybridization method to improve this trait. Results of other researchers as (16, 19, 20 and 24) were in agreement to the present results.

Table 4. Effects and variances of general and specific combining abilities for parents, F1 diallel crosses and reciprocal crosses with some genetic parameters for plant height:

ĝii	1	2	3	4	σ^2 ĝii	σ^2ŝij	σ^2ŕij
1	0.262	-1.192	10.325	6.704	-1.042	70.933	30.038
2	7.067	0.433	2.954	6.400	0.188	44.260	29.372
3	-5.050	-6.900	2.117	3.000	4.480	35.504	131.680
4	1.550	-3.117	-12.167	-2.812	7.910	74.520	47.453
S.E	ĝii	ŝij	ŕij				
	2.108	3.650	4.215				
Mse´	σ^2gca	σ^2sca =σ^2D	σ^2gca /σ^2sca	σ^2A	σ^2D_r	σ^2D	
17.768	2.660	147.001	0.018	5.319	38.315	147.001	
ā	$h^2_{b.s}$	$h^2_{n.s}$	$\bar{a}_r$	h^2_{bsr}	h^2_{nsr}	σ^2G	
55.271	0.896	0.031	3.796	0.711	0.087	152.320	

Ear height (cm):

Table 2 revealed highly significant differences between genotypes for ear height. Maximum ear height exhibited by parent 2 which was 91.065 cm and minimum value was 65.867 cm recorded by parent 4. Regarding the diallel hybrids, the maximum ear height gave by the cross 1×2 with 100.200 cm and the minimum value was 81.000 cm exhibited by diallel cross 3×4, but reciprocal crosses were extended between 83.333 cm to 103.400 cm for both reciprocal crosses 2×1 and 3×2 respectively. Previously researchers were reported similar results (3, 4 and 15). Considering general and specific combining abilities effect and their variances for this trait signified in Table 5. Genetic analysis showed highly significant mean squares related to GCA, SCA and RCA, Table 2. Parent 2 obtained highest positive $\hat{g}ii$ value which was 2.094, while parent 4 performed the merely negative GCA effect (-5.348). The maximum positive SCA effect due to diallel crosses was 8.631 showed by the cross 1×4, whereas the only negative $\hat{s}ij$ gave by the cross 1×2 was -1.194. Highest positive RCA effect detected in the cross 2×1 was 8.433, while the reciprocal cross 4×3 produced maximum negative value for $\acute{r}ij$ which was -8.967. Concerning the $\sigma^2\hat{g}ii$, $\sigma^2\hat{s}ij$ and $\sigma^2\acute{r}ij$, the maximum variance regarding the GCA effects was obtained by parent 4 with 28.600 and for SCA was 46.661 by parent 1, whereas maximum variance due to $\acute{r}ij$ parent 3 showed maximum variance with 61.624. Also Zare *et al.* (24) found significant mean squares for both GCA and SCA, while Andrés-Meza *et al.* (8) observed no significant differences for both GCA and SCA. For trait ear height some genetic parameters were shown in the previous Table, the variance component due to SCA was greater than GCA, making the ratio of variance for GCA to SCA to be less than one (0.151). The average degree of dominance for diallel and reciprocal crosses were 6.632 and 1.348 respectively, implying the role of over dominance gene effect as controlled the inheritance of this trait. Heritability estimated in broad sense for both diallel and reciprocal crosses were 0.850 and 0.715 respectively. But in narrow sense were 0.197 and 0.375 for both diallel and reciprocal crosses respectively, signifying the importance of hybridization method to improve this trait. Many researchers expressed similar results. But researchers such (5 and 16) denoted different results.

Table 5. Effects and variances of general and specific combining abilities for parents, F1 diallel crosses and reciprocal crosses with some genetic parameters for ear height:

$\hat{g}ii$	1	2	3	4	$\sigma^2\ \hat{g}ii$	$\sigma^2\hat{s}ij$	$\sigma^2\acute{r}ij$
1	1.419	-1.194	5.506	8.631	0.721	46.661	30.513
2	8.433	2.094	3.540	0.223	4.384	35.390	24.896
3	0.117	-6.483	1.835	4.031	3.369	22.689	61.624
4	3.250	-2.517	-8.967	-5.348	28.600	42.189	45.400
S.E	$\hat{g}ii$	$\hat{s}ij$	$\acute{r}ij$				
	2.273	3.937	4.546				
Mse´	σ^2gca	σ^2sca =σ^2D	σ^2gca /σ^2sca	σ^2A	σ^2D_r	σ^2D	
20.672	13.606	90.239	0.151	27.212	24.742	90.239	
ā	$h^2_{b.s}$	$h^2_{n.s}$	$\bar{a}_r$	h^2_{bsr}	h^2_{nsr}	σ^2G	
6.632	0.850	0.197	1.348	0.715	0.375	117.451	

No. of ears plant^{-1}:

Table 2 elucidated that mean squares for all of the GCA, SCA and RCA were not significant. Table 6 informs the estimation of genetic analysis for general and specific combining ability effects and their variances, parent 1 obtained highest GCA effect values with 0.031. Whereas parent 4 with -0.044 exhibited maximum negative GCA effect. Highest positive effect value due to SCA was 0.119 showed by diallel cross 1×4, while the highest negative value was -0.106 recorded by the cross 2×4. Dealing with the reciprocal crosses, maximum positive RCA effect was obtained by the crosses 3×1 and 4×1 with 0.067, whereas the maximum negative value performed by the reciprocal cross 3×2 which was -0.100. Parent 4 recorded highest GCA and RCA effect variances with 0.002 and 0.013 respectively. Regarding the variance effect for SCA both parents 1 and 3 produced maximum $\sigma^2\hat{s}ij$ with 0.006. In the pre mentioned table, some genetic parameters on this trait were also observed, the variance component for SCA was larger than GCA variance component, making the ratio of σ^2gca /σ^2sca to be less than one (0.080) indicating the importance of non-additive gene effect in controlling the inheritance of this trait. Considering the estimation of heritability, showed to be 0.505 and 0.186 in broad sense for both diallel and reciprocal crosses respectively, while in narrow sense found to be 0.070 and 0.144 respectively, suggesting hybridization method for improving this trait. The results of Pshdary (16) were in accordance to these results.

Table 6. Effects and variances of general and specific combining abilities for parents, F1 diallel crosses and reciprocal crosses with some genetic parameters for No. of ears plant^{-1}:

ĝii	1	2	3	4	σ^2 ĝii	σ^2ŝij	σ^2ŕij
1	0.031	-0.015	-0.040	0.119	0.001	0.006	0.001
2	0.000	0.023	0.060	-0.106	0.001	0.005	0.007
3	0.067	-0.100	-0.010	-0.040	0.000	0.006	0.003
4	0.067	-0.067	0.000	-0.044	0.002	0.002	0.013
S.E	ĝii	ŝij	ŕij				
	0.041	0.070	0.081				
Mse´	σ^2gca	σ^2sca =σ^2D	σ^2gca /σ^2sca	σ^2A	σ^2D_r	σ^2D	
0.007	0.000	0.006	0.080	0.001	0.001	0.006	
ā	$h^2_{b.s}$	$h^2_{n.s}$	$\bar{a}_r$	h^2_{bsr}	h^2_{nsr}	σ^2G	
12.503	0.505	0.070	1.121	0.186	0.114	0.007	

Ear length (cm):

Data recorded on ear length were shown in Table 2, predicted that there were highly significant differences between genotypes and SCA mean squares, also Mostafavi *et al.* (14) reached highly significant differences. But Zare *et al.* (24) only recorded significant mean square for GCA. Contents of Table 7 refers to the effects of GCA, SCA and RCA, showed that biggest GCA effect value was 0.133 for parent 3, and the highest SCA effect of diallel hybrids was 1.428 observed in the cross 1×4, while the maximum RCA effect value produced by the reciprocal cross 3×2 with 0.633, indicating the increase of this trait in these hybrids compared to their parents. The variance of general and specific combining ability effects for both diallel and reciprocal crosses also possesses in Table 7, noticed that highest GCA and SCA effect variances exhibited by parent 4 with 0.057 and 1.896 respectively, while the maximum variance due to $\sigma^2ŕij$ produced by parent 3 was 2.174. The results showed the ability of this parent to transfer this trait to some of its hybrids without others. In the previously explained table also clarified the analysis of some genetic parameters, SCA variance component was greater than GCA effect, causing the ratio of σ^2gca /σ^2sca to be less than one (0.003), but the values of both $\bar{a}$ and $\bar{a}_r$ were 330.600 and 7.002 respectively. Heritability estimated in broad sense for both diallel and reciprocal crosses were 0.970 and 0.830 respectively, and in narrow sense were 0.006 and 0.033, denoting hybridization method to improve the trait ear length. Same results were showed in (5, 16, 18 and 19)'s researches, however, different values for heritability were corroborated by other researchers (20 and 24).

Table 7. Effects and variances of general and specific combining abilities for parents, F1 diallel crosses and reciprocal crosses with some genetic parameters for ear length:

ĝii	1	2	3	4	σ^2 ĝii	σ^2ŝij	σ^2ŕij
1	0.107	0.443	0.277	1.428	0.002	1.110	0.089
2	-0.267	-0.001	0.684	0.888	0.000	0.619	0.299
3	0.417	0.633	0.133	0.305	0.018	0.289	2.174
4	0.280	-0.033	-1.950	-0.238	0.057	1.896	1.460
S.E	ĝii	ŝij	ŕij				
	0.190	0.329	0.380				
Mse´	σ^2gca	σ^2sca =σ^2D	σ^2gca /σ^2sca	σ^2A	σ^2D_r	σ^2D	
0.145	0.014	4.600	0.003	0.028	0.682	4.600	
ā	$h^2_{b.s}$	$h^2_{n.s}$	$\bar{a}_r$	h^2_{bsr}	h^2_{nsr}	σ^2G	
330.600	0.970	0.006	7.002	0.830	0.033	4.627	

No. of rows ear $^{-1}$:

Values in Table 2 explains that there were highly significant differences among genotypes and GCA mean squares for this trait. Also other researchers (9, 14, 21 and 24) found similar results. Table 8 demonstrates genetic analysis for no. of rows ear $^{-1}$, Maximum positive *ĝii* found in parent 2 with 1.377 which was the evidence for the large contribution of this parent to increase this trait in its hybrids, whereas maximum negative GCA effect was -1.169 performed by parent 4 showing the great contribution of this parent to decrease the trait no. of rows ear $^{-1}$ in its hybrids. Considering the SCA effect, 1.106 was the highest positive value produced by diallel cross 1×4, whereas maximum negative value was -1.106 exhibited by the cross 3×4. The reciprocal cross 3×1 obtained maximum positive value which was 1.050, On the other hand the merely negative value was -0.567 appeared in the reciprocal cross 3×2. With relevant to the GCA variance maximum effect value was 1.896 occurred in parent 2 and for SCA was 1.146 detected in parent 3. But the RCA variance effects were restricted between 0.200 to 1.519 for both parents 3 and 4 respectively. Furthermore, the same table also reveals estimation of some genetic parameters for this trait, it was obvious that the variance component regarding the $\sigma^2 gca$ was greater than $\sigma^2 sca$, making the $\sigma^2 gca/\sigma^2 sca$ ratio to be more than one (1.865), which affected on the value of average degree of dominance, to be less than one (0.536) for diallel crosses. Previously researchers as (16 and 17) gave similar results. Heritability in broad sense for both diallel and reciprocal crosses were 0.896 and 0.874, while in narrow sense were 0.706 and 0.854 for both diallel and reciprocal crosses respectively. These results suggested the selection and hybridization methods to improve this trait. These results were in agreement with the results of other researchers (22 and 24).

Table 8. Effects and variances of general and specific combining abilities for parents, F1 diallel crosses and reciprocal crosses with some genetic parameters for no. of rows ear $^{-1}$:

ĝii	1	2	3	4	σ^2 ĝii	σ^2ŝij	σ^2ŕij
1	-0.894	-0.740	0.202	1.106	0.763	0.728	0.555
2	0.250	1.377	0.431	0.769	1.896	0.242	0.465
3	1.050	-0.567	0.685	-1.106	0.470	1.146	0.200
4	0.717	0.250	0.417	-1.169	1.366	0.197	1.519
S.E	ĝii	ŝij	ŕij				
	0.377	0.652	0.753				
Mse´	σ^2gca	σ^2sca =σ^2D	σ^2gca /σ^2sca	σ^2A	$\sigma^2 D_r$	σ^2D	
0.568	1.919	1.029	1.865	3.838	0.089	1.029	
ā	$h^2_{b.s}$	$h^2_{n.s}$	$\bar{a}_r$	h^2_{bsr}	h^2_{nsr}	σ^2G	
0.536	0.896	0.706	0.215	0.874	0.854	4.867	

150-kernels weight (g):

Table 2 reveals that there were highly significant differences among genotypes and the mean squares related to the GCA, SCA and RCA were highly significant for trait 150-kernels weight. Also (9, 21 and 24) found significant mean squares for both GCA and SCA. In Table 9 clarified the effects and variances of each of GCA, SCA and RCA for parents, F1 diallel crosses and reciprocal crosses respectively, with some genetic parameters for this trait. Considering the *ĝii*, parent 4 showed the highest positive value with 3.084, while the highest negative value observed in parent 3 which was -2.725. Maximum positive SCA effect value was 2.399 recorded by diallel cross 1×2, whereas the only negative value exhibited by the cross 1×3 was -1.936. The reciprocal cross 3×2 showed the highest positive *ŕij* value with 2.922, while the highest negative RCA effect value was -2.342 produced by the cross 2×1. The maximum values due to σ^2*ĝii*, σ^2*ŕij* and σ^2*ŝij* was 9.513, 5.715 and 7.243 for parents 4, 3 and 2 respectively. Concerning the genetic parameters, The SCA variance component was greater than the GCA variance caused the ratio of σ^2*ĝii* to σ^2*ŝij* to be less than one (0.435), also Shams *et al.* (18) gave less than one for σ^2*ĝii* /σ^2*ŝij* ratio. The average degree of dominance for diallel crosses was more than one (2.300), ascertaining the over dominance gene effect as controlled the inheritance of trait 150-kernels weight.

Heritability for diallel crosses in both broad and narrow sense found to be 0.851 and 0.396, while for reciprocal crosses were 0.741 and 0.688 orderly. The results suggesting the selection and hybridization method to improve this trait. (16, 17, 19 and 20) found nearly results.

Table 9. Effects and variances of general and specific combining abilities for parents, F1 diallel crosses and reciprocal crosses with some genetic parameters for 150-kernels weight:

ĝii	1	2	3	4	σ^2 ĝii	σ^2ŝij	σ^2ŕij
1	-0.599	2.399	-1.936	1.894	0.037	4.932	1.497
2	-2.342	0.240	0.241	2.113	0.058	3.391	7.243
3	-1.538	2.922	-2.725	1.937	7.427	5.715	4.378
4	0.552	-0.443	-2.225	3.084	9.513	1.113	5.903
S.E	ĝii	ŝij	ŕij				
	1.136	1.967	2.271				
Mse´	σ^2gca	σ^2sca =σ^2D	σ^2gca /σ^2sca		σ^2A	σ^2D_r	σ^2D
5.160	6.854	15.764	0.435		13.709	1.060	15.764
ā	$h^2_{b.s}$	$h^2_{n.s}$	$ā_r$		h^2_{bsr}	h^2_{nsr}	σ^2G
2.300	0.851	0.396	0.393		0.741	0.688	29.473

Total yield (ton ha^{-1}):

Data in Table 2 stated that there were highly significant differences among genotypes and mean squares for the SCA, but other researchers only found highly significant general combining ability effect. As shown in Table 10 general and specific combining abilities effects and their variances, the value 0.337 was the maximum positive GCA effect value confirmed by parent 2, while the maximum negative value was -0.448 gave by parent 4. Regarding the diallel crosses, in the cross 1×4 with 2.239 noticed the maximum positive SCA mean squares effect, whereas the maximum negative *ŝij* value was -0.615 for the cross 3×4. The reciprocal combining ability positive values were ranged between 0.000 to 1.543 for both reciprocal crosses 4×1 and 4×2, and the negative values were -1.033 and -0.567 for both crosses 4×3 and 3×2 respectively. Dealing with the variances due to general and reciprocal combining ability effects, 0.201 and 3.003 were the highest value showed by parent 4, while the maximum *σ^2ŝij* was 2.370 performed by parent 1. Table 10 also comprise estimations of some genetic parameters for the trait total yield, *σ^2sca* was larger than the *σ^2gca* making the ratio of variance component due to GCA to the variance component due to SCA to be less than one (0.012) confirming the great role of non-additive gene effect in the inheritance of this trait, and the average degree of dominance were (81.179 and 2.679) for both diallel and reciprocal crosses respectively, signifying the over dominance gene effect in controlling the inheritance in trait total yield . Researchers as (10, 17 and 18) submitted similar results. Heritability in broad sense for both diallel and reciprocal crosses preferred to be 0.905 and 0.512, but in narrow sense were 0.022 and 0.112 respectively. These results associated with the results of some researchers (20 and 19), and high heritability in broad sense reported 0.85 by Zare *et al.* (24).

Table 10. Effects and variances of general and specific combining abilities for parents, F1 diallel crosses and reciprocal crosses with some genetic parameters for total yield:

ĝii	1	2	3	4	σ^2 ĝii	σ^2ŝij	σ^2ŕij
1	-0.015	-0.230	0.038	2.239	-0.032	2.370	-0.074
2	0.017	0.337	1.066	0.783	0.114	0.711	1.378
3	0.613	-0.567	0.126	-0.615	0.016	0.374	1.103
4	0.000	1.543	-1.033	-0.448	0.201	1.561	3.003
S.E	ĝii	ŝij	ŕij				
	0.362	0.626	0.723				
Mse´	σ^2gca	σ^2sca =σ^2D	σ^2gca /σ^2sca		σ^2A	σ^2D_r	σ^2D
0.524	0.060	4.857	0.012		0.120	0.429	4.857
ā	$h^2_{b.s}$	$h^2_{n.s}$	$ā_r$		h^2_{bsr}	h^2_{nsr}	σ^2G
81.179	0.905	0.022	2.679		0.512	0.112	4.977

LIST OF ABBREVIATIONS

σ^2P	Phenotypic variance.
σ^2G	Genotypic variance.
σ^2e	Mean squares of experimental error or (environmental variance).
σ^2A	Additive variance.
σ^2D	Dominance variance.
σ^2D_r	Dominance variance for reciprocal crosses.
GCA	General combining ability.
SCA	Specific combining ability for diallel crosses.
RCA	Specific combining ability for reciprocal crosses.
σ^2GCA	The variance of general combining ability.
σ^2SCA	The variance of Specific combining ability for diallel crosses.
σ^2RCA	The variance of Specific combining ability for reciprocal crosses.
ĝii	General combining ability effect.
ŝij	Specific combining ability effect.
ŕij	Reciprocal combining ability effect.
ā	Average degree of dominance.
$\bar{a}_r$	Average degree of dominance for reciprocals.
$h^2_{b.s}$	Heritability in broad sense.
$h^2_{n.s}$	Heritability in narrow sense.
MSé	Revised mean squares of experimental error.

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