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Combining Ability of Commercial White Pea Bean (Phaseolus Vulgaris L.) Varieties in South Western Ethiopia

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Abstract
The diallel mating design, that produces all possible single crosses among a set of inbred lines has been widely utilized to provide information on the potential of parents involved in hybrid combinations as well as inferences on genetic control of the traits under investigation. It is an important tool, which aids in statistically separating progeny performance in to components relating to general combining ability (GCA), and specific combining ability (SCA). The objective of the study was to determine the type of gene actions involved in the inheritance of the most important quantitative traits in commercial white pea bean cultivars. Forty nine entries (7 parents and 42 F_2 diallel crosses) were grown in a simple lattice design with two replications at Jimma Agricultural Research Center, South Western Ethiopia. The results revealed significant mean squares in all of the characters, except for days to 50 % flowering, days to maturity. There were significant mean squares due to general combining ability, specific combining ability, reciprocal effects, maternal effects, and non-maternal effects in almost all of the characters. The relative contribution of specific combining ability was higher than general combining ability for all of the studied traits, except for days to 50% flowering. This indicating that the non-additive gene actions are influential in the expression of these traits which poses some difficulty as the non-additive gene actions are non-fixable. Thus, selfing should continue for more generation to fix the non-additive gene actions before undertaking selection. Starlight is good general combiner for 100-seed weight and grain yield. The other genotypes may also be good general combiner for other traits because they displayed positive and significant traits.
Keywords: White pea bean, SCA, GCA, reciprocal effects, maternal effects, Non-maternal effects

1. INTRODUCTION

Combining ability, which is the ability to give high yield in hybrid combination, has been shown by various workers to be an inherited character. From the diallel analysis, plant breeders are able to gather information on heterosis and the effects due to reciprocals, maternal, non-maternal, general combining ability (GCA) and the specific combining ability (SCA) of parents in crosses (Yanchuk, 1996; Glover *et al*., 2005). Diallel analysis provides a systematic approach for the detection of appropriate parents and crosses. It also aids plant breeders in choosing the most efficient method for parental selection by allowing them to estimate several genetic parameters (Ramalho et al., 1993). Greater bean grain yield could be obtained by hybridizing superior cultivars.
Increase in yield potential of common bean (*Phaseolus vulgaris*) cultivars has been small, in spite of large variation of most traits, including grain yield. Therefore, the obtention of genetically improved cultivars is the main objective of breeding programs, which have their efficiency increased by a careful choice of parents. One of the most commonly used methodologies for choosing parents is diallel cross, which informs about the parents' potential when in hybrid combinations, and also about gene action involved in determining quantitative traits (Cruz and Vencovsky, 1989; Ramalho *et al.*, 1993). Griffing (1956) diallel analysis procedure is among the most useful ones, especially its method IV, which only considers the hybrid performance, and allows to estimate both exact SCA and GCA. As GCA depends predominantly on additive effects of the genes, it informs about the potential of the segregating populations for selection of high grain yield lines. Diallel mating systems have provided genetic understanding for a chosen set of parents (Murray *et al*., 2003) and have been used to study various traits in many crops.

White pea bean (P. Vulgaris L.) is an important export for Ethiopia. One of the challenges facing white pea bean breeders is the difficulty of incorporating novel traits without breaking up the desire complex of food traits (Myers and Baggett, 1999). In addition, inheritance studies of the seeds per pod and other agronomic traits of common bean are scarce and in some cases are contradictory. For example, De Carvalho *et al.* (1999) found that, dominance effects were involved in the genetic control of number of days to flowering; while Da Silva *et al.* (2004) showed that additive effects were predominant. Basically, such information is important during planning and execution of any breeding programme (Viana et al., 1999). Several methods have been proposed for diallel analysis (Jinks and Hayman, 1953; Hayman, 1954; Dickinson and Jinks, 1956; Griffing, 1956; Gardner and Eberhart, 1966). Among these methodologies, Hayman (1954) has been used to determine gene action on different traits. Apart from additive and dominance gene effects, this method is efficient in detecting epistasis.

It also estimates the genetic component and the limit of selection that may be obtained from assessed parents (Cruz, 2001). Determination of the GCA and SCA effects of a trait is also an important method of estimating additive and non-additive gene action (Griffing, 1956). Examining the GCA of each parent helps in developing superior genotypes, while the SCA effect estimates the performance of hybrids (Cruz and Regazzi, 1994). Therefore, an analysis based on a large number of progenies from diverse parents is essential for formulating an efficient strategy for varietal improvement. Such an analysis enables broad inferences to be drawn about the nature of gene effects and the combining abilities of different varieties.

2. MATERIALS AND METHODS

The experiment was conducted in the experimental field of Jimma Agricultural Research Center. Jimma is located in the South West of Ethiopia at about 355 km from Addis Ababa, and Jimma Agricultural Research Center is 14km away from Jimma town. The area is characterized by one long rainy season (May to October) with mean annual rainfall of 900-1754 mm, and an altitude of 1750 m.a.s.l. The minimum and maximum air temperature for the area is 11^{o}C and 26^{o}C, respectively.

Seven white pea bean varieties (Avanti, OR-04-DH, ARGENE, ER-04-AJ, TA-04-JI, Crest wood and Starlight) were used in this study. These varieties were used for commercial and canning purpose. A complete diallel including reciprocal was obtained giving 49 combinations consisting of seven parents (n), 21F2s [n (n-1)] and 21F2s reciprocals. The selection of parental lines was mainly based on their observed yield potential, some qualitative traits including quality of seed and distinct morphological characteristics. Crossing was made among the seven parents in all possible combinations in a full diallel fashion at Jimma agricultural research center.

Full diallel (including reciprocals) were produced at Jimma Agricultural Research Centre during August to September 2011/12 during the rainy period, and furrow irrigation was provided when the rain stopped, October to November 2011/12. Artificial pollination was conducted in the morning (7:00 AM to 10:00 AM). Plants were hybridized using emasculation with protected rubbing or hook methods where the fertilized stigma of the male parent that carried ample pollen was hooked onto the stigma of the female parent. Sepals were kept intact to protect the bud, and pollination quickly followed (CIAT, 1979).

The experiment was laid out in a simple lattice design with two replications. A spacing of 40 cm between rows was used to facilitate supplemental irrigation, and plants were spaced 20 cm apart within the row. To ascertain full stand in a plot, two seeds per hill were planted and thinned to appropriate stand 10 days after emergence. A plot of four rows each 4 m long (1.6X4m) were used, and 100 kg/ha DAP fertilizer was applied at the time of planting. All necessary agronomic practices were done uniformly as per the recommendations. The correct stand count (80 plants per plot) was maintained after thinning. Stand count at harvest was also done.

Data were collected on days to flowering – the time when 50% of the plants in a row had produced flowers. Days to maturity (DM): The number of days from emergence to the stage when 75% of the plants in a plot reached physiological maturity, i.e., the stage at which pods lose their pigmentation and began to dry.

The height of the plant was determined as the length of the stem from the base of the plant to the topmost flower bud. The average number of pods per plant was computed by dividing the total number of pods by the number of plants. The average number of seeds per plant were also taken. Harvesting was done and 100 seed weight and grain yield per plot were also measured.

Diallel analysis was carried out according to Griffing (1956) Method one, Model one (fixed effects), which involved parents and one-way F2 hybrids (including reciprocals). Griffing portioned the total sum of squares due to the genotypes with p(p-1)/2 –1 degree of freedom into sum of squares due to GCA with p-1 degree of freedom and sum of squares due to SCA with p(p-1)/2 degree of freedom. Here the experimental material itself was the population about which inferences were drawn and hence the estimates obtained from the analysis were applied to those genotypes only. Combining ability analyses was carried out using SAS computer software. Relative importance of GCA, SCA, and the reciprocal cross effects were computed as a proportion of cross effects sum squares. Similarly relative importance of maternal and non-maternal effects was computed as a proportion of reciprocal cross effects sum of squares.

Combining ability was computed using the mathematical model:

$$x_{ij} = \mu + g_i + g_j + s_{ij} + \frac{1}{bc}\sum_k \sum_l e_{ijkl} \begin{cases} i.j = 1,\dots,p, \\ k = 1,\dots,b, \\ l = 1,\dots,c. \end{cases}$$

Where μ is the population mean, gi (gj) is the g.c.a. effect, sij the s.c.a. effect, such that sij = sji, and eijkl is the effect peculiar to the ijklth observation, p,b and c are number of parents, blocks and sampled plants. The restrictions

$$\sum_i g_i = 0, and \sum_j s_{ij} + s_{ii} = 0$$

for each i are imposed

Where Sij is specific combining ability of a cross between the ith and jth parent and Sii is the specific combining ability of a parent selfed. Such linear model for analysis of variance helps to determine whether there is a significant difference among the genotypes tested using the F – ratio as:

$$F = \frac{MSv}{MSe}$$

If the effect of genotypes is significant, the sum of squares due to genotypes will be partitioned in to GCA, SCA and reciprocal effects. Then the additive leaner model for diallel analysis can be written as:

$$\times_{ij} = \mu + g_i + S_{ij} + r_{ij} + \sum \sum e_{ijkl} / bc$$

g = GCA; S = SCA; r = reciprocal effects ; b = no. of blocks ; c = no. of individuals ; e = effects of environmental factors and μ = overall means.

Diallel analysis is limited to the following conditions:

$$S_{ij} = S_{ji} \quad \sum g_i = 0$$

$$r_{ij} = -r_{ij} \quad \sum S_{ij} = 0_i$$

3. RESULTS

Analysis of variance (ANOVA) exhibited highly significant (P<0.001) variation among the 49 genotypes for the traits investigated (table 1). Crosses Avanti X OR-04-DH, Argane X OR-04-DH, and ER-04-AJ X OR-04-DH exhibited the longest days to flowering, while Avanti X Starlight and OR-04-DH X Starlight had the shortest days to flowering of 34 days (Table 1). The crosses ER-04-AJ X TA-04-AJ had the longest maturity date; while TA-04-AJ X Crest wood had the shortest days to maturity. This implies that crosses which displayed early maturity can be further evaluated for their performance in areas of short rainy season and moisture stress areas, where as late maturity is an advantage in areas where relatively long growing period prevails, long maturing materials may still perform well and selected for better adaptability.

Crosses OR-04-DH X ER-04-AJ, Avanti X TA-04-AJ, OR-04-DH X TA-04-AJ, and Argane X Avanti had the longest plant height, while parents Crestwood and Starlight produced the highest mean values for 100-seed weight. The cross TA-04-AJ X Starlight had the highest grain yield (3621 gm/plot). The next high yielding crosses were OR-04-DH X ER-04-AJ, OR-04-DH X Crest wood, OR-04-DH X Starlight, Argane X Starlight, ER-04-AJ X Avanti, ER-04-AJ X TA-04-AJ, Crestwood X Avanti, and Starlight X Argane. Crosses TA-04-AJ X Crestwood and ER-04-AJ X TA-04-AJ had the highest number of pods/plant of 89.06 and 76.33 respectively; while parents with the highest number of pods per plant were Avanti and ER-04-AJ.

The mean squares (ms) of GCA, SCA, maternal, non maternal and reciprocals exhibited significant (p < 0.001) for the traits studied and this shows the importance of both additive and dominance, reciprocals, and the inter action between cytoplasm and the nuclear gene effects (Table 3). To weigh the relative importance of GCA and SCA in the expression of the different traits, the proportions of GCA and SCA variances were calculated. The SCA variance was higher than the GCA variance component for all the traits other than days to fifty percent flowering.

The highest mean value for hundred seed weight was observed in the cross Avanti X Starlight that is 37.85 gm. This is the forward cross by using Avanti as male and starlight as female. However, the reciprocal cross Starlight X Avanti, the value for this trait is 23.02gm. This indicating that the genotype starlight is best parent when used as female for this trait. Event it has the largest pod length, pod diameter, seed length, seed diameter and seed thickness (mean values not indicated in Table 2). The is because the maternal effect of the crop. Therefore, these genotypes Avanti and Starlight are best parents as male and female for this trait respectively. Moreover, the cross TA-04-AJ X Starlight have the highest yield (90.53qt/ha table2). However, the reciprocal cross Starlight X TA-04-AJ have 41.48qt/ha yield which is less than when used starlight as female and TA-04=AJ as male. In general this genotype starlight is very important used as female parent for almost of the quantitative inherited traits.

The maximum number of pods (89) per plant was observed in the cross TA-04-AJ X Crestwood. However, its reciprocal cross have(39) number of pods per plant which is less than the forward cross. This implies that this genotype TA-04-AJ is important when used as male and Crestwood as female for this trait. The cross Avanti X Starlight has the shortest (34) days to flowering. However, its reciprocal cross Starlight X Avanti has (38) days to flowering. The shortest days maturity (56) was observed in the cross TA-04-AJ X Crestwood. This is the earliest hybrid from all the cross combinations (42 crosses). This hybrid is important for areas having moisture stress. However, the cross ER-04-AJ X TA-04-AJ exhibited the longest days (113) to maturity. Implies that this cross is late maturing and important for areas having long rainy season. The longest plant height (120.7cm) was observed in the cross OR-04-DH X ER-04-AJ. However, the shortest plant height (67.1cm see table2) was exhibited in the cross Crestwood X Argane. The reciprocal effect was also displayed in plant height. For example the hybrid (forward cross) OR-04-DH X ER-04-AJ have the highest plant height as described above. However, the reciprocal cross ER-04-AJ X OR-04-DH exhibited 105cm height which is lower than the forward cross. Thus, ER-04-AJ is best parent when used as female and OR-04-DH is best as female for plant height. This is due to the maternal (reciprocal) and paternal effects of the genotype.

General combining ability (GCA) and specific combining ability (SCA) for bean yield have been studied in the common bean in order to determine the nature of genetic variation and the value of individual parents and/or crosses. Both GCA and SCA Were important in F_2(table 3). Significant ($p<0.05$) reciprocal effects were observed in days to 50% flowering, plant height, hundred seed weight, grain yield, number of pods per plant, number of seed per plant.

Additive and dominance mean squares were significant ($p<0.01$) for all traits in this finding. Maternal reciprocal effects were significant for plant height, grain yield, number of pods per plant, number of seeds per plant and hundred seed weight. Moreover, non-maternal reciprocal effects were significant for plant height, hundred seed weight, and number of pods per plant.

3.1. Combining Abilities

The estimates of GCA effects showed that two varieties had significant values for days to fifty percent flowering. OR-04-DH displayed positive significant gca effects. Indicating that this genotype is good combiner for this trait. However, starlight exhibited significant negative gca effects. This genotype was also showed significant non-maternal reciprocal effects (Table 3).

The SCA estimates show that Avanti x OR-04-DH was good cross to reduce days to maturity. The cross CRESTWOOD X STARLIGHT was good hybrid for number of seeds per plant. Avanti x Argene, OR-04-DH X ER-04-AJ, and ER-04-AJ X TA-04-AJ were displayed positive significant SCA effects for plant height. The cross ER-04-AJ X STARLIGHT was displayed positive significant SCA effects for hundred seed weight. However, Argene X ER-04-AJ and Argene X CRESTWOOD exhibited negative significant SCA effects for this trait.

Avanti x ER-04-AJ, TA-04-AJ X STARLIGHT, and CRESTWOOD X STARLIGHT were displayed positive significant SCA effects for grain yield. However, Argene X TA-04-AJ displayed negative significant SCA effects for this trait. OR-04-DH X CRESTWOOD, ER-04-AJ X TA-04-AJ, TA-04-AJ X CRESTWOOD, and TA-04-AJ X STARLIGHT were displayed significant positive SCA effects number of pods per plant. However, Avanti x TA-04-AJ,OR-04-DH X TA-04-AJ, ER-04-AJ X CRESTWOOD and CRESTWOOD X STARLIGHT were exhibited negative significant SCA effects for this trait. Avanti x OR-04-DH, OR-04-DH X Argene, ER-04-AJ X TA-04-AJ, and TA-04-AJ X STARLIGHT were displayed positive significant SCA effects for number of seeds per plant. However, the cross OR-04-DH X TA-04-AJ was displayed negative significant SCA effects for this trait.

ER-04-AJ X OR-04-DH was displayed negative significant reciprocal effects for days to flowering. However, crestwood X TA-04-AJ had displayed highly negative significant ($P<0.001$) reciprocal effects for days to maturity. TA-04-AJ X Avanti and Crestwood X ER-04-AJ were displayed significant positive reciprocal effects for plant height. Starlight X Avanti and Starlight X TA-04-AJ were exhibited positive significant reciprocal effects for hundred seed weight. However, TA-04-AJ X ARGENE was exhibited negative significant reciprocal effects.

Starlight X TA-04-AJ and Starlight X crestwood were displayed positive significant reciprocal effects for grain yield. Starlight X OR-04-DH, TA-04-AJ X ER-04-AJ, and Crestwood X TA-04-AJ were displayed positive significant reciprocal effects for number of pods per plant. However, OR-04-DH X Avanti, Argene X Avanti, TA-04-AJ X ARGENE were displayed negative significant reciprocal effects for this trait. Argene X OR-04-DH and 70.96* were exhibited positive significant reciprocal effects. However, the cross ER-04-AJ X Avanti was displayed negative significant reciprocal effects.

4. DISCUSSION

This experiment showed that there were significant variation among the seven white pea bean varieties. Significant GCA, SCA, Reciprocal, Maternal and Non-maternal effects were exhibited in this study. Significant GCA and SCA mean squares indicated that both additive and non-additive gene effects are important for white pea bean breeding even though the relative contribution of both GCA and SCA differ for each traits. Moreover, significant reciprocal, maternal and non-maternal effects displayed for each in most of the traits. The significant reciprocal and maternal effects implies that the cytoplasmic genes of the reciprocal crosses and maternal effects have an important influence in hybrid combination for white pea bean crosses. This implies that selection of female parent for any breeding program in common bean is important. Seeds of forward crosses can't be mixed with seeds of reciprocal crosses. It indicates earliness, lateness, larger and smaller seed size, pod size, higher or lower number of seeds per plant per pod etc. Arunga *et al* (2010) reported significant GCA and SCA for days to flowering, plant height, number of pods per plant, pod weight, pod length and pod diameter.

Machado *et al*.(2002) who reported the predominance of an additive effect on grain yield in F_2 segregant populations, derived from diallel hybrids of common bean. Barelli *et al.*(2000c) verified large additive gene effect for seed weight.Ceyhal et al.,2014 reported significant mean squares in plant height, pod per plant, seeds per pod, seeds per plant, seed yield and 100-seed weight. Moreover, significant means squres were reported for plant height, number of pods per plant, number of seeds per pod, number of seeds per plant, 50-seedweight and grain yield (Concalves-Vidigal *et al*.,2008). He also reported significant GCA and SCA mean squares for these traits. significant GCA and SCA mean squares were also reported for these traits (Barelli *et al*.,2000). This indicating that both additive and non-additive gene actions are important for the inheritance of these traits in white pea bean breeding program.

The results of this study are both similar to and contradict previous studies of white pea bean. For example, significant GCA effects for number of days to flowering has been reported (Barelli *et al*., 1999; Da Silva *et al.,* 2004) which is similar to these findings. Significant GCA and SCA mean squares for plant height, number of branches per plant, first fertile node, number of pods per plant, number of seeds per plant, 100-seed weight, seed yield per plant in Faba bean breeding was reported(Zeinab *et al*.,2014). The role of non-additive gene effects for plant height was reported by Rodrigues *et al*. (1998) while this study indicates that additive gene effects play a major role. For number of pods per plant, the results of Barelli *et al*. (1999) and are similar to this study while Da Silva *et al.* (2004) contradicts the findings. Moreover, Arunga *et al*. (2010) reported additive gene effect play a major role for plant height. Such variations in the results may arise from differences in the genetic backgrounds of the varieties used in the various studies.

white pea bean is a self-pollinating crop, and autogamous plants are homozygous and thus they do not make use of the dominance effects of genes at individual loci (Moreno-Gonzalez and Cubero, 1993). Usually, varieties of autogamous plants are pure lines or multi-lines whose seed are commercially produced by self-pollination, even though a few exceptions, like wheat, tobacco, cotton and tomato can produce commercial hybrids. Therefore,crosses involving genotypes with greater estimates of general combining ability should be potentially superior for the selection of lines in advanced generations (Franco *et al*., 2001).

The predominance of SCA variance on pod weight per plant denotes that selection for pod yield may not be made in early breeding generations (Wu *et al*., 2000). This contradicts with the present studies because at F1 and F2 generations we can get larger or smaller seed size, large number of seeds which gives highest grain or seed yield by using forward and reciprocal crosses in common bean breeding(Data not shown). Studies reveal that the additive gene effects were important for grain yield in maize (Betran *et al*., 2003; Derera *et al*., 2008) and the dominance gene effects were predominant for root yield in cassava (Jaramillo *et al*., 2005). If dominance effects are important for a trait, the most appropriate selection methods are those that take advantage of heterosis and the general and specific combining abilities (Moreno-Gonzalez and Cubero, 1993). Significant GCA effects were observed in days to fifty percent flowering, hundred seed weight, grain yield, and number of pods per plant. Significant SCA effects were observed in hundred seed weight, grain yield, number of pods per plant and number of seeds per plant(Table4). Moreover, significant reciprocal, maternal and non-maternal effects were observed in plant height, hundred seed weight, grain yield, number of pods per plant and number of seeds per plant. Reciprocal differences for days to flowering and silking dates have been reported in other crops (Jinks, 1954; Khehra and Bhalla, 1976).

Generally, the choice of female parent is critical in a breeding programme. Moreover, it recommended that crosses portraying reciprocal effects should not be mixed with direct crosses (Khan *et al*., 1991; Pavasia *et al*., 1999). Snap bean breeders prefer to reduce the number of days to flowering and thus increase the number of harvests per growth cycle. Starlight exhibited the largest and significant gca effects for hundred seed weight and grain yield but the smallest and significant gca for number of pods per plant. Arunga *et al*. (2010) has reported the largest gca values for days to flowering and grain yield. SCA values provide important information about the performance of the hybrid relative to its parents. The SCA effect alone has limited value in the choice of parents in breeding programmes for self-pollinated crops like bean (Cruz and Regazzi, 1994). The SCA effect should be used in combination with other parameters, such as the hybrid mean value of a trait and the GCA of the respective parents. Thus, hybrid combinations with high means, favorable SCA estimates and involving at least one of the parents with high GCA, would tend to increase the concentration of favorable alleles. Moreover, it was observed that parents having low GCA might show good potential in varietal combinations.

Early maturing cross TA-04-AJ X Crestwood was obtained from the 7X7 full diallel cross including reciprocals. It displayed 56 days to maturity. However, its reciprocal cross exhibited 96 days to maturity. The longest days to maturity (113 days) was obtained in the cross ER-04-AJ X TA-04-AJ. This implies that these hybrids displayed earliness are important for drought stress areas and these crosses displayed late maturity are important for areas having long rainy season. similar findings reported that 58 to 68 days for early, 75 t0 80 medium and 80-120 days for late maturing varieties were obtained (Van Schoonhoven and Voysest, 1991).

5.CONCLUSION

Generally both additive and no-additive gene actions are important in the inheritance of desirable traits in common bean. Moreover, the cytoplasm reciprocal crosses and the interaction between the cytoplasm and nuclear gene have an important contribution in white pea bean breeding. thus selection of female parent for any breeding program in common bean is important and seeds of forward cross can't be mixed with seeds of reciprocal crosses since there is a maternity effect in common bean breeding.

Significant GCA effects was displayed in days to fifty percent flowering, hundred seed weight and number of pods per plant. This implies that the additive gene effect is important for the inheritance of these traits. However, significant SCA effects was observed in hundred seed weight, grain yield, number of pods per plant and number of seeds per plant. This implies that the dominance gene action is important for the inheritance of these traits. Significant reciprocal effects was also observed in days to fifty percent flowering, plant height, hundred seed weight, grain yield, number of pods per plant and number of seeds per plant. Indicating that the maternal reciprocal effects are important for the inheritance of these traits. The best general combiner was observed in Starlight for grain yield and hundred seed weight, OR-04-DH for days to fifty percent flowering and plant height, TA-04-AJ and Crestwood for number of pods per plant. These varieties can be incorporated into white pea bean breeding program.

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Table 1: Means squares showing genotypic differences for days to 50% percent flowering, days to maturity, plant height(cm), 100-seed weight, grain yield, number of pods per plant, number of seeds per plant.

Parameters	Replication	Genotype	Error
MD	39.22ns	101.77ns	88.73
DFPF	13.96*	4.39ns	2.51
PH	81.00ns	323.60***	119.6
HSWT	45.53ns	56.87***	15.41
GY	338590	396711***	104399
NPPT	21.14ns	316.91***	49.13
NSPPT	3516	3969***	1303
DF	1	48	48

where, MD=days to maturity, DFDF=days to fifty percent flowering, PH=plant height, HSWT=hundred seed weight, GY=grain yield, NPPT=number of pods per plant and DF= degree of freedom.

Table 2. Genotype means of days to 50% flowering, days to maturity, plant height(cm), 100-seed weight, grain yield, number of pods per plant and number of seeds per plant.

Crosses	Hundred seed weight (gm)	Grain yield (qt/ha)	Number of pods per plant	Number of seeds per plant	Maturity date	Days to fifty Percent Flowering	Plant height (cm)
1x2	20.87	32.48	25.40	157.8	97.03	41.94	83.6
1 × 3	22.41	39.5	36.00	167.3	105.05	40.12	78.9
1 × 4	18.29	44.53	47.86	145.4	92.83	37.52	86.3
1 × 5	15.19	42.5	39.00	196.4	96.21	39.21	118.3
1 × 6	18.35	33.38	37.40	138.8	110.02	36.91	81.3
1 × 7	37.85	35.13	19.10	78.0	106.35	33.69	102.3
2 × 1	18.39	42.15	45.90	241.5	94.44	37.73	89.2
2 × 2	19.29	32.13	29.80	126.3	104.20	39.76	93.6
2 × 3	15.48	33.53	41.10	289.6	83.30	39.44	96.6
2 × 4	20.08	52.75	34.30	145.8	96.39	36.25	120.7
2 × 5	18.63	36.13	36.80	127.3	97.65	40.37	114.7
2 × 6	20.71	47.15	51.33	197.7	99.17	40.08	103.1
2 × 7	27.56	51.1	34.20	133.2	95.68	33.87	90.5
3 × 1	23.99	33	52.73	147.2	98.38	38.65	113.3
3 × 2	21.76	32.5	31.10	107.0	102.70	41.52	71.3
3 × 3	20.47	43.7	34.60	158.5	105.44	37.02	73.1
3 × 4	15.91	31.25	34.70	129.4	92.54	37.90	82.4
3 × 5	14.33	21.88	24.70	136.2	92.02	39.79	89.3
3 × 6	15.55	34.28	34.10	158.6	100.91	36.22	83.5
3 × 7	26.01	61.03	30.60	139.1	106.14	39.21	93.4
4 × 1	17.48	45	34.50	240.2	93.10	36.73	89.5
4 × 2	15.12	34.38	34.70	155.3	95.44	41.16	105.1
4 × 3	16.30	30	37.20	148.1	96.66	38.80	78.0
4 × 4	16.67	26.95	39.70	163.4	108.09	39.95	91.3
4 × 5	25.93	45.23	76.33	314.2	112.54	39.02	69.2
4 × 6	13.65	30	29.30	125.8	94.90	38.26	109.1
4 × 7	36.24	38	21.80	96.4	83.94	35.20	93.9
5 × 1	18.07	36.03	34.40	130.9	82.51	34.39	70.3
5 × 2	16.56	31.43	25.00	105.4	96.24	38.55	100.7
5 × 3	24.84	32.5	49.66	136.5	95.92	35.76	97.6
5 × 4	16.20	37.63	38.20	172.3	103.41	37.89	82.0
5 × 5	14.34	37.78	28.70	115.0	89.37	39.32	80.2
5 × 6	18.34	29.38	89.06	163.0	55.5	38.13	87.7
5 × 7	29.43	90.53	38.00	170.3	107.12	34.40	93.2
6 ×1	18.49	44.73	44.00	199.7	101.79	38.62	81.7
6 × 2	18.74	34.13	41.30	140.4	95.06	37.17	80.0
6 ×3	15.62	43.98	47.93	186.4	91.02	38.82	67.1
6 ×4	20.38	29.2	34.70	158.6	99.47	37.83	78.2
6 × 5	20.82	35.53	39.10	170.9	95.51	35.37	81.8
6 ×7	16.21	42.85	35.80	150.0	94.99	36.58	77.7
7 × 1	23.02	28.95	32.30	144.4	105.39	37.65	76.5
7 × 2	27.16	37.8	20.00	88.8	109.25	37.02	83.0
7 × 3	30.60	51.13	27.80	127.4	103.60	36.43	90.5
7 × 4	31.32	40	25.90	125.3	92.31	37.59	77.5
7 × 5	23.31	41.48	44.60	175.3	97.36	37.10	96.3
7 × 6	24.63	17.63	31.20	165.6	98.11	38.38	93.6
S.E	5.218	17.63	7.009	23.2	12.52	2.106	10.94
L.S.D	10.77	658.2	14.155	36.10	25.84	4.347	22.20
CV	18.16	21.1	18.9	73.14	9.69	4.17	12.3

1=Avanti,2=OR-04-DH, 3=Argane, 4=ER-04-AJ,5=TA-04-AJ, 6=Crestwood, 7=Starlight, HSWT=handred seed weight, GY=grain yield, NPPT=number of pod per plant,NSPPT=number of seed per plant, NSPD=number of seed per pod, DM=days to maturity, DFPF=days to 50% flowering

Table 3. GCA, SCA, reciprocals, maternal and non-maternal mean squares for days to 50% flowering, days to maturity, hundred seed weight, plant height, grain yield, number of seed per plant and number of pods per plant.

PARAMTERS	MEAN SQUARES				
	GCA	SCA	REC	MAT	NMAT
MD	84.15ns	86.59ns	99.99ns	96.62ns	101.37ns
DFPF	8.60**	1.93ns	5.00*	5.57ns	4.80ns
PH	220.52ns	05.42ns	262.28**	363.82**	243.98*
HSWT	164.11***	54.58***	33.31**	31.21*	34.28**
GY	343718.96*	318384.47**	223852.66*	436162.71**	157661.64ns
NPPT	386.20***	219.72***	227.90***	173.94**	254.40***
NSPPT	2148.86ns	2983.01**	3170.60**	6675.02***	2252.49ns

* Significant at $p < 0.05$; *** Significant at $p < 0.001$.,HSWT=hundred seed weight, GY=grain yield, NPPT=number of pod per plant, NSPPT=number of seed per plant, DM=days to maturity, DFPF=days to 50% flowering, =number of pod per plant.

Table 4. Estimates of GCA,SCA and reciprocal effects for days to fifty percent flowering, days to maturity, plant height, hundred seed weight, grain yield, number of pods per plant and number of seeds per plant obtained 7 X 7 diallel cross including reciprocals.

Genotypes	Traits						
	DFPF	DM	PH	HSWT	GY	NPPT	NSPPT
GCA effects							
Avanti	0.02ns	1.98ns	-0.83ns	-0.82ns	-85.86 ns	1.40ns	8.53 ns
OR-04-DH	0.59*	0.84ns	5.96**	-1.45*	-21.89 ns	-2.77*	-2.26ns
Argene	0.41ns	-0.27ns	-3.87ns	-0.92ns	-16.92 ns	-0.19ns	1.13ns
ER-04-AJ	0.34ns	1.99ns	0.87ns	-0.73ns	-81.35 ns	0.60ns	7.83ns
TA-04-AJ	0.23ns	1.84ns	1.38ns	-1.87**	51.74 ns	5.19***	3.91ns
CRESTWOOD	-0.52ns	-2.41ns	-3.02ns	-0.15ns	-124.98 ns	3.21*	2.11ns
STARLIGHT	-1.07**	-0.30ns	-0.49ns	5.94***	279.26 ***	-7.45***	-21.24*
SCA effects							
Avanti x OR-04-DH	1.16 ns	-1.34 ns	-7.46 ns	-0.55	71.07 ns	-0.10 ns	38.10 *
Avanti x Argene	-0.41 ns	-0.48 ns	12.06*	0.97	18.74 ns	6.08 ns	-7.70 ns
Avanti x ER-04-AJ	-0.59 ns	0.75 ns	-0.88 ns	-2.22	418.80*	2.02 ns	21.16 ns
Avanti x TA-04-AJ	0.27 ns	0.09 ns	5.03 ns	-0.73	65.72 ns	-7.00*	-4.07 ns
Avanti x CRESTWOOD	0.02 ns	4.41 ns	-3.38 ns	-2.05	238.80 ns	-1.02 ns	3.32 ns
Avanti x STARLIGHT	-1.41 ns	1.03 ns	9.35 ns	1.29	-88.48 ns	-10.75 ns	-11.92 ns
OR-04-DH X Argene	0.77 ns	-1.09 ns	-6.87 ns	0.43	-179.58 ns	1.95 ns	44.14*
OR-04-DH X ER-04-AJ	-0.15 ns	-1.85 ns	17.34**	0.76	306.84 ns	-0.45 ns	-10.31 ns
OR-04-DH X TA-04-AJ	-0.30 ns	0.48 ns	11.63 ns	0.87	-212.88 ns	-8.63**	-40.58*
OR-04-DH X CRESTWOOD	-0.30 ns	2.05 ns	-0.13 ns	-0.67	238.09 ns	8.80**	13.91 ns
OR-04-DH X STARLIGHT	-0.84 ns	-2.36 ns	-0.40 ns	0.56	186.99 ns	1.978 ns	3.68 ns
Argene X ER-04-AJ	-0.73 ns	-3.99 ns	-5.54 ns	-3.77*	-210.52 ns	-1.58 ns	-25.49 ns
Argene X TA-04-AJ	-0.63 ns	3.08 ns	7.21 ns	2.29	-481.35*	-4.96 ns	-23.96 ns
Argene X CRESTWOOD	0.62 ns	0.16 ns	-6.55 ns	-4.09*	172.87 ns	0.92 ns	13.98 ns
Argene X STARLIGHT	-1.02 ns	4.21ns	15.47 ns	0.26	203.67 ns	1.86 ns	-2.88 ns
ER-04-AJ X TA-04-AJ	-0.05 ns	2.82 ns	15.38**	0.83	157.43 ns	14.40***	76.24***
ER-04-AJ X CRESTWOOD	0.45 ns	4.65 ns	7.07 ns	-2.29	-143.96 ns	-8.93*	-23.02 ns
ER-04-AJ X STARLIGHT	-1.61 ns	-7.85	-4.23 ns	7.57*	59.11 ns	-8.20 ns	-23.48 ns
TA-04-AJ X CRESTWOOD	0.55 ns	-16.52ns	-2.34 ns	0.20	-167.65 ns	18.54***	5.64 ns
TA-04-AJ X STARLIGHT	0.06 ns	-0.7ns	16.42 ns	0.87	911.19**	25.23***	82.95 *
CRESTWOOD X STARLIGHT	-0.44 ns	21.14*	7.47 ns	-1.49	942.61**	-12.09*	29.21 ns
Reciprocal effects							
OR-04-DH X Avanti	0.75 ns	-0.75 ns	-2.80 ns	2.17	-188.64 ns	-10.25*	-41.84 ns
Argene X Avanti	1.00 ns	3.50 ns	-17.19 ns	-0.88	130.00 ns	-8.41*	10.05 ns
ER-04-AJ X Avanti	0.75 ns	0.00 ns	-1.59 ns	0.18	-14.36 ns	6.64ns	-47.41*
TA-04-AJ X Avanti	1.50 ns	2.50 ns	24.01***	-0.13	134.36 ns	2.30 ns	32.75 ns
Crestwood X Avanti	-0.50 ns	-0.75 ns	-0.20 ns	0.43	-227.00 ns	-3.30 ns	-30.45 ns
Starlight X Avanti	-1.50 ns	1.75 ns	12.89 ns	7.95***	128.36 ns	-6.60 ns	-33.21 ns
Argene X OR-04-DH	-0.75 ns	-1.25 ns	12.64 ns	-0.05	15.64 ns	5.00 ns	91.29***
ER-04-AJ X OR-04-DH	-2.25*	0.75 ns	7.80 ns	2.63	362.64 ns	-0.20 ns	-4.75 ns
TA-04-AJ X OR-04-DH	-0.50 ns	2.25 ns	7.01 ns	2.20	94.00 ns	5.90 ns	10.95 ns
Crestwood X OR-04-DH	0.25 ns	-0.25 ns	11.54 ns	-0.83	260.25 ns	5.06 ns	28.65 ns
Starlight X OR-04-DH	-1.50 ns	0.50 ns	3.75 ns	1.35	270.86 ns	7.10 *	22.20 ns
ER-04-AJ X ARGENE	-1.00 ns	-4.00 ns	2.20 ns	-0.93	24.75 ns	-1.25 ns	-9.35 ns
TA-04-AJ X ARGENE	1.00 ns	0.25 ns	-4.15 ns	-6.35**	-212.50 ns	-12.44*	-0.14 ns
Crestwood X ARGENE	0.00 ns	5.75 ns	8.21 ns	1.38	-203.72 ns	-6.96 ns	-13.91 ns
Starlight X ARGENE	1.50 ns	1.75 ns	1.45 ns	-0.63	193.14 ns	1.40 ns	5.85 ns
TA-04-AJ X ER-04-AJ	-1.00 ns	-0.75 ns	-6.40 ns	2.93	156.86 ns	19.11***	70.96*
Crestwood X ER-04-AJ	-0.25 ns	-0.50 ns	15.46*	-0.83	16.25 ns	-2.70ns	-16.40 ns
Starlight X ER-04-AJ	0.48 ns	0.35 ns	8.20 ns	1.24	-102.79 ns	-2.45ns	-14.45 ns
Crestwood X TA-04-AJ	1.25 ns	-21.00***	2.95 ns	-1.48	-118.14 ns	24.90***	-3.96 ns
Starlight X TA-04-AJ	-1.75 ns	-0.75 ns	-1.55 ns	5.28**	971.28***	-3.30 **ns**	-2.50 ns
Starlight X crestwood	-1.00 ns	-0.25 ns	-7.95 ns	-2.68	504.25*	2.30 **ns**	-7.81 ns
MAT effects							
Avanti	0.29	0.89	2.16 ns	1.39*	-5.33 ns	-2.80*	-15.73*
OR-04-DH	-0.79*	0.39ns	6.51**	0.45	170.29*	4.73***	27.17***
Argene	0.17 ns	0.21ns	1.75 ns	-0.80	-49.14 ns	-2.26 ns	-16.98*
ER-04-AJ	0.24 ns	0.34ns	1.26 ns	0.20	-43.24 ns	1.25 ns	14.52*
TA-04-AJ	-0.21 ns	-3.71*	-2.72 ns	0.74	97.20 ns	0.97 ns	-17.28*
CRESTWOOD	-0.25 ns	2.36ns	-6.56**	-0.19	110.94 ns	-2.11 ns	4.04 ns
STARLIGHT	0.53 ns	-0.48ns	-2.40 ns	-1.79**	-280.73***	0.22 ns	4.27 ns

Where, MAT=maternal effects, NMAT=non-maternal effects, GCA, general combining ability, SCA=specific combining ability, ns=non significant.