Asian Agricultural Research 2017, 9(8): 70 – 74 DOI: 10.19601/j.cnki.issn1943 – 9903.2017.08.017

Line X Tester Analysis of Estimating Heterosis and Combining Ability in F_1 Generation of Sunflower

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Abstract The present research was conducted in Line X tester analysis for estimating combining ability and heterotic effects, restorers male-sterile (CMS) crossed with seven tester lines 3x7 21 F_1 hybrids of sunflower were further used to estimate their general combining ability (GCS), specific combining ability (SCA) and heterosis effects on main traits of sunflower during 2009. For this study, seven lines of sunflower were tested with three testers 7x3 of sunflower to obtain twenty one F_1 genotypes from Line X tester mating design. It was concluded from present study that among the lines, 0505 Cms-6, Peshawer-93 Cms-11, Peshawar-93 Cms-12 were the best general combiners to play the vital role in flowering, maturity, plant height, head diameter, seed index, grain per head and 100-grain yield per plant. While RHP-53, RHP-42, RHP-46 were also the best combiners for all the traits. However, hybrid 54CMS-1 x RHP-42 showed best specific combiners, while Peshawer-93 exhibited good specific combiners for grain yield per plant, the hybrids, plant height, head diameter, seed index, grain per head and grain yield per plant, respectively. Significant differences among the tested sunflower genotypes with regard to mean values of all the investigated traits were determined. The analysis of variance of combining abilities and the analysis of genetic variance components confirmed the non-additive component.

Key words Line X tester, Heterosis, Combining ability, Sunflower

1 Introduction

The sunflower (*Helianthus annuus* L.) belongs to the Compositae family. The genus *Helianthus* is derived from Greek, Helios 'Sun' and anthesis 'Flower' and locally it is known as Surajmukhi. Sixty seven species of this genus are recognized, besides the cultivated species, many are perennials, ornamentals, and weeds. It was also grown as oil seed crop in the late 1800s and early 1900s. Expanded world production of sunflower resulted primarily from development of high-oil varieties by plant scientists and more recently by the development of hybrids. Sunflower is widely grown in the world where the climates are favorable and high quality oil is desired[1]. In Pakistan, sunflower was first introduced as an oilseed crop in the 1960s. Extensive research work on different aspects of this crop has continued since 1964. Two types of sunflower are grown, one for oilseed production and the other as non-oilseed for the home and bird food markets. The oilseed hybrids which may be either linoleic or oleic types generally are black-seeded and have a thin hull that adheres to the kernel. Seed of the oilseed varieties contain from 38 to 50 percent oil and about 20 percent protein. Non-oilseed sunflower also has been referred to as confectionery sunflower and striped or large-seeded varieties and relatively thick hull which remains loosely attached to the kernel, permitting more complete dehulling. Seed of the non-oilseed hybrids generally is larger than that of the oilseed types and has a lower oil percentage and test weight. Sunflower is a major source of vegetable oil in the world. Worldwide production of sunflower has increased steadily[2]. Combining ability is the ability of two parents to transmit favorable or unfavorable traits to their progeny. In biometrical genetics, two types of combining abilities are considered *i. e.* general combining ability (GCA) and specific combining ability (SCA). General combining ability refers to the average performance of parental lines as reflected in its hybrid combinations and specific combining ability refers to the average performance of a particular cross. According to Sprague and Tatum (1942)[3], general combining ability is due to the genes which are largely additive, while specific combining ability is due to genes showing non-additive effects. The importance of combining ability studies lies in the assessment of parental lines and their hybrids showing significant additive and non-additive effect 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[4]. One crucial step in hybrid development is testing of inbred lines for their GCA. The Line X tester analysis is one of the efficient methods of evaluating large number of inbreeds as well as providing information on the relative importance of general combining ability and specific combining ability effects for interpreting the genetic basis of important plant traits. In this context, the present research is designed to investigate the following objectives.

2 Materials and methods

2.1 Seed material The seeds of sunflower and other materials should be collected from Oil Seeds Section, Agriculture Research Institute, TandoJam. And the farm of Sindh Agriculture University

Received: June 25, 2017 Accepted: August 25, 2017
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performed Line X tester analysis and combining ability analysis by using Gen software package (program for quantitative genetic analysis) for the Line X tester method by Singh and Choudary modification by Sharma (2006)[5] when parents were not included in comparative traits.

2.2 Experiment design The seeds of parents (lines and testers) were sown for mating crosses during 2009. The seeds of F_1 hybrids along with parental lines were sown in a Randomized Complete Block Design (RCBD) with three replications at Oilseeds Section, Agriculture Research Institute, Tandojam. At maturity, heads were threshed separately (parents + crosses) for next season. In the next season, F1 along with parents was sown in Randomized Complete Block Design (RCBD) with three replications. The analysis of variance was carried out according to statistical methods developed by Gomez and Gomez (1984)[6], whereas heterotic effects were determined by adopting the formula of Fehr (1987)[7]. The general and specific combining ability and their estimates were calculated according to methods developed by Kempthorne (1957)[8], followed by Singh and Choudhry (1979)[9]. All the agronomic practices were done at proper time and inputs were given in recommended doses. At the time of maturity, the observations were recorded on plant height (cm), fertilizer at the rate of 125 N and 75 kg ha-1 P was applied in the form of urea and diammonium phosphate (DAP). Full dose of phosphorus with 1/3rd of nitrogen was applied at the time of land preparation while remaining nitrogen was applied in three equal split doses with first irrigation, other inputs like irrigation were applied at proper times and when required. All the cultural practices including weeding *etc.* were adopted uniformly in the whole experiment throughout the growing period. Ten plants were randomly tagged from each replication per genotype. Each plot consisted of four rows 5.5 m long and 60 cm apart. The distance between plants on each row was 20 cm. Fertilizers were applied at the rate of requirements respectively. Harvesting and threshing were done manually. The traits including plant height, head diameter, lifecycle duration, grain yield, 1000-seed weight, oil content and oil yield were determined with the method as explained by Schneiter and Miller (1981). A sample of 1000-filled seeds (at 8% moisture content) was drawn at random from the bulked seed of 10 random plants and weighed with an electronic balance. Oil content was estimated with the help of nuclear magnetic resonance spectrometry (NMR). Data for hybrids were subjected to "Line X Tester" analysis to estimate general combining ability (GCA), specific combining ability (SCA), and their respective variance components. The estimates of general combining ability and specific combining effects of parents and hybrids were obtained as follows. 1. RHP-42; 2. RHP-53; 3. RHP-46, (male) lines & 1.54, CMS-2, 2. Peshawar-93 3. 81, CMS-10, 4. T 4 0319, 5.0505 CMS-6 6.54 CMS-1 7. Peshawar-93 (female) lines. The following characters were studied. Days to flowering, days to maturity, plant height (cm), stem girth (mm), head diameter (cm), number of grains per head, seed index (g), and grain yield per plant (g).

Table 1 Lines X tester crosses

54 CMS-2 X RHP-42	Peshawar-93 X RHP-46
CMS-10 X RHP-42	T4 0319 X RHP-42
0505-CMS-6 X RHP-42	54 CMS -1 X RHP-42
Peshawar-93 X RHP-42	54-CMS-2 X RHP-53
Peshawar-93 X RHP-53	81 CMS-10 X RHP-53
T4 0319 X RHP-53	0505 CMS-6 X RHP-53
CMS-1 X RHP-53	Peshawar-93 X RHP-53
54 CMS-2 X RHP-46	Peshawar-93 X RHP-46
81CMS-10 X RHP-46	T4 0319 X RHP-46
10505 CMS-6 X RHP-46	54 CMS -1 X RHP-46
Peshawar -93 X RHP-46	

2.3 Data analysis Combining ability is the ability of two parents to transmit favorable or unfavorable traits to their progeny. In biometrical genetics, two types of combining abilities are considered i.e. general combining ability (GCA) and specific combining ability (SCA). General combining ability refers to the average performance of parental lines as reflected in its hybrid combinations and specific combining ability refers to the average performance of a particular cross. According to Sprague and Tatum (1942)[3], general combining ability is due to the genes which are largely additive, while specific combining ability is due to non-additive effects. The importance of combining ability studies lies in the assessment of parental lines and their hybrids showed significant additive and non-additive effects 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[4]. One crucial step in hybrid development is testing of inbreed lines for their GCA. The Line X tester analysis is one of the efficient methods of evaluating large number of inbreeds as well as providing information on the relative importance of general combining ability and specific combining ability. When we see that an inbred line combines well in any cross, it is due to specific combining ability. Estimated by full sib mating has relationship with heterosis.

3 Results

3.1 Mean performance and analysis of variance The present study was carried out in Line X tester analysis of estimating combining ability and heterotic effects in F_1 genotypes of sunflower during 2009. Seven lines were tested with three testers to obtain twenty one F_1 hybrids for days to flowering, days to maturity; plant height; head diameter; seed index; number of grains per head and grain yield per plant (g). The results were obtained and described. The mean square from analysis of variance was shown in genotypes, cross parent; lines and testers were highly significant ($p < 0.01$) for all the characters of days to flowering , days to maturity, plant height, head diameter, seed index, grains per head and grains yield per plant (Table 2), where as plant height was non-significant among the parents. (i) Mean performance. The mean performance of lines, testers and F_1 hybrids (Table 2) showed that parent 0505 CMS-6 took fewer (71.00) days to complete flowering followed by 54 CMS-1, while hybrid Peshawar-93 CMS-2 x RHP-53 (77.00) for the character days to maturity, parent of 54 CMS-1 took higher (82.00) days for maturity and hybrid 0505 CMS-6 x RHP-46 took maximum (88.00) days to maturity followed by Peshawar 93 CMS-11 x RHP-53 and t4-0319 x RHP-46 which showed (84.00) days to maturity. T4-0319 produced taller (195.41 cm) plant height among the hybrids. While parent peshawer-93 CMS-12 gave higher (24.19 cm) head diameter followed by RHP-46 (23.36 cm) among the hybrids 81 CMS-10 x RHP-46 gave maximum (29.40 cm) head diameter among the hybrids. (ii) Analysis of variance. As shown from Table 1, the mean square from analysis of variance was shown in genotypes, cross, parents, lines and testers were highly significant, and showed that parent RHP-46 gave higher (8.34 g) seed index and peshawer-93 CMS-12 was ranked next maximum (8.30 g) seed index while cross 54 CMS-2 x RHP-46 set maximum (11.33g) seed index. For the character number of grain/head 0505 CMS-6 x 81CMS-10 showed the highest seed/head for the character grain yield/plant (959.95) in cross RHP-46 which showed highest (1444.72) grain per plant followed by 0505 CMS-6 (49.00g) yield per plant among the parents. Hybrids 81 CMS-10 x RHP-46 gave maximum (69.00g) grains yield per plant among the hybrids.

Table 2 Mean square (analysis of variances) for yield and yield components of sunflower

Source of variation	D. F.	Days to 75% flowering	Days to 75% maturity	Plant height cm	Head diameter cm	Seed index	Number of grain	Grain yield plant $^{-1}$
Replication	2	6.4946	5.0645	9904.4300	4.1962	0.81248	1112.0	12.290
Genotype	30	20.0208 **	61.3871 **	1695.8000 **	36.4337 **	7.07535 **	146604.0 **	432.158 **
Cross	20	59.7439 **	54.1429 **	1086.4900	33.8991 **	6.12972 **	140032.0 **	427.319 **
Parents	9	27.2037 **	46.7000 *	632.545ns	29.8246 **	4.22827 **	104224.0 **	229.633 **
Lines (GCA)	6	45.3400 **	55.6000 **	500.9300ns	16.6300 **	4.3000 **	120524.0 **	320.430 **
Testers (GCA)	2	41.6600 **	50.6300 **	490.6000ns	15.1900	3.4500 **	115687.0 **	350.910 **
Line X tester (SCA)	12	55.1400 **	71.1300 **	42.2500ns	18.4800 **	25.2900.0 **	80545 **	424.100 **
Error	60	1.0391	0.8645	698.54	0.9016	1.01107	11462.0	4.079

Note: **, * = significant at 1% and 5%, respectively; NS = non-significant.

3.2 General combining ability analysis (GCA) General combining ability refers to the average performance of parental lines as reflected in its hybrid combinations and specific combining ability refers to the average performance of a particular cross. According to Sprague and Tatum (1942)[3], the general combining ability is due to the genes which are largely additive, while specific combining ability is due to non-additive effects. The importance of combining ability studies lies in the assessment of parental lines and their hybrids show significant additive and non-additive effects 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[4]. One crucial step in hybrid development is testing of inbreed lines for their GCA. The Line X tester analysis is one of the efficient methods of evaluating large number of inbreeds as well as providing information on the relative importance of general combining ability and specific combining ability.

3.3 Specific combining ability (SCA) Specific combining ability is a performance of a parent under consideration, in a specific cross. The specific combining ability represents deviation from GCA. It is due to dominance genetic variance and all the three types of gene interaction helping into identification and hence selection of best cross combinations i.e. those with the desired output. When we see that a inbred line combines well in any cross, it is due to specific combining ability. Estimated by full sib mating has relationship with heterosis.

3.4 Seed index The data regarding GCA effects for seed index showed that among the lines, line peshawer-93 CMS-12 showed the highest (6.65) GCA effect followed by line 0505 CMS-6 (3.35) GCA effects for seed index and tester RHP-46 gave maximum (3.00) GCA variance for seed index among the testers. Peshawer-93 CMS-12 and RHP-46 gave maximum additive gene effects for seed index and should be utilized for further breeding programs through hybridization and selection to improvizing seed index, while hybrid 54 CMS-1 x RHP-52 gave maximum (21.15) SCA effects for seed index while other hybrids show a fair amount of SCA variance for some traits. However, cross 91 CMS-10 x RHP-53 gave maximum (63.63) relative heterosis and peshawer-93 CMS-11 x RHP-42 gave highest (50.03) heterobeltiosis among the hybrids. Similar findings were obtained by Habibullah *et al.* (2006)[10], Shankar *et al.* (2007)[11] who observed that additive type of genes action controlled the character seed index. The hybrids, 81 CMS-10 x RHP-53 and peshawer-93 CMS-11 x RHP-42 have more non-additive gene effects seed index and are utilized for hybrid crop development.

3.5 Days to flowering Among the parents, maximum (5.50) GCA effect was given by line 0505 CMS-6 and tester RHP-53 (4.89) effects for days to flowering, however, hybrid 54 CMS-1 x RHP-42 gave maximum (15.07) SCA effects, followed by Peshawer-93CMS-1 RHP-46 (14.35) SCA variance for days to flowering among the hybrids.

3.6 Days to maturity The GCA variance for days to maturity showed four lines out of seven gave positive GCA variances and one tester out of three recorded positive GCA effects for above traits. However lines 54CMS-1, 81CMS-10 and 54 CMS-2 gave positive 4.84, 3.86, 3.35 and 2.25 GCA effects for days to maturity while tester RHP-42 recorded higher (6.63) GCA effects among the testers for days to maturity. The SCA effects for days to maturity showed that fourteen hybrids had positive SCA effects while the rest had negative SGA variance for days to maturity. The cross 54CMS-1 x RHP-42 (10.15) showed the highest SCA effects followed by peshawer-93

CMS-11 x RHP-42 and t4-0319 x RHP-46 with (4.45) for days to maturity among the hybrids.

3.7 Plant height Among the parents, three lines gave positive GCA effects for plant height while the rest had negative GCA effects for plant height, however, maximum (10.41) GCA variance was given by line Peshawar CMS-11 followed by Peshawar-93 CMS-12 (6.60) and tester RHP-46 gave higher (7.75) GCA effects for plant height among the testers for plant height.

3.8 Head diameter The calculation of GCA effects for head diameter showed that three lines had positive GCA effects while the rest showed negative effects and one tester out of three gave positive GCA effects, the line Peshawar-93 CMS-12 gave maximum (3.35) GCA effects followed by peshawer-93 CMS-11 (2.30) and RHP-46 gave higher (6.10) GCA effects for head diameter among the testers. However fourteen F1 hybrids recorded positive SCA effects for head diameter and the remaining gave negative SCA effects. The hybrids 54 CMS-1 x RHP-42 gave the highest (9.15) SCA effects followed by t4-0319 x RHP-46 (4.46) for head diameter. The data regarding the GCA effects for seed index presented showed that the line peshawer-93 CMS-12 gave maximum (6.65) effect followed by 0505 CMS-6 (3.35) GCA effects for seed index and tester RHP-46 gave higher (3.00) GCA effects than tester for seed index. However, hybrid 54 CMS-1 x RHP-42 gave maximum (21.15) SCA effects followed by 54 CMS-1 x RHP-53 (15.15) SCA effects for seed index among the hybrids.

3.9 Number of grains per head The GCA effects for grains per head showed that line T4-0319 gave the highest (15.22) GCA effects followed by 81 CMS-10 (14.15) and Peshawar-93 CMS-12 (10.25) GCA effects for grains per head and tester RHP-53 gave higher (8.43) GCA effects for grains per head among testers. The SCA effects for grains per head showed that 54 CMS-1 x RHP-42 gave higher (14.49) SCA effects for grains per head followed by 0505 CMS-6 x RHP-53 (14.44) SCA effects for number of grains per head.

3.10 Grain yield per plant Among lines, four lines recorded positive GCA effects while giving negative effects for grain yield per plant. Line Peshawar-93 CMS-12 gave the highest (7.22) GCA effects followed by 0505 CMS-6 (4.40) GCA effects for grain yield per plant. while one tester out of three gave positive GCA effects and the remaining two gave negative GCA effects, tester RHP-42 gave the maximum (7.70) GCA effects for grains yield per plant. The thirteen hybrid recorded positive SCA effects out of twenty one crosses for grain yield per plant. The hybrid 54-CMS-1 x RHP-46 scored first (26.40), 54CMS-2 x RHP-46 scored second (25.30) and peshawer-93 CMS-12 x RHP-46 scored third (18.35) SCA variances for grains per plant among the hybrids.

Table 3 General combining ability (GCA) effects of lines and testers for various characters of sunflower in F_1 generation

Parents	Days to 75% flowering	Days to 75% maturity	Plant height cm	Head diameter cm	Seed index	Number of grain	Grain yield plant^{-1}
Female lines							
54 CMS-2	2.25	2.25	-3.35	-3.35	-6.68	-13.45	-2.00
Peshawer-93 CMS-11	-3.37	-7.64	10.41	-1.14	-0.61	-14.07	-8.03
81 CMS-10	-3.35	3.86	-6.65	2.30	2.15	14.15	2.25
T4-0319	-1.15	3.35	-4.45	-1.16	2.28	15.22	-9.69
0505 CMS-6	5.50	-3.35	-7.45	-2.25	3.35	2.25	4.40
54 CMS-1	2.32	4.83	4.89	2.25	-7.14	-14.35	3.35
Peshawer-93 CMS-12	-2.20	-3.30	6.60	3.35	6.65	10.25	7.72
S.E. (G_i)	0.21	0.03	0.85	0.09	1.11	2.00	1.40
Testers (pollinators/male)							
RHP-42	4.45	6.63	-4.45	-2.21	-4.89	-3.14	7.70
RHP-53	4.89	-3.35	-3.35	-3.89	1.89	8.43	-3.30
RHP-46	-9.34	-3.30	7.75	6.10	3.00	5.29	-4.42
S.E. (G_i)	1.89	1.35	0.74	1.40	1.59	0.95	1.00

3.11 Heterosis In proposing the term heterosis to replace the older term heterozygosis, G. H. Shull aimed to avoid limiting the term to the effects that can be explained by heterozygosity in Mendelian inheritance. The physiological vigor of an organism as manifested in its rapidity of growth, its height and general robustness, is positively correlated with the degree of dissimilarity in the gametes by whose union the organism was formed. The more numerous the differences between the uniting gametes at least within certain limits, the greater on the whole the amount of stimulation is. These differences need not be Mendelian in their inheritance to avoid the implication that all the genotypic differences stimulate cell-division, growth and other physiological activities of an organism Mendelian in their inheritance and also to gain brevity of expression suggesting that the word 'heterosis' should be adopted. Heterosis is often discussed as the opposite of inbreeding depression although differences in these two concepts can be seen in evolutionary considerations such as the role of genetic variation or the effects of genetic drift in small populations on these concepts. Inbreeding depression occurs when the related parents have children with traits that negatively influence their fitness largely due to homozygosity. In such instances, outcrossing should result in heterosis. Not all outcrosses result in heterosis. For example, when a hybrid inherits traits from its parents that are not fully compatible, fitness can be reduced. This is a form of outbreeding depression.

4 Discussions

Combining ability is the ability of two parents to transmit favorable or unfavorable traits to their progeny. In biometrical genetics, the combining ability includes two types, general combining ability (GCA) and specific combining ability (SCA). Combining ability refers to the average performance of the parent in a hybrid combination, whereas specific combining ability refers to average performance of particular cross. Present study also aimed to determine combining ability and heterotic effects in a sunflower from Line X tester analysis for some quantitative traits. The maximum (5.50) GCA effect was produced by line 0505 CMS-6 and tester RHP-53 (4.89) GCA effects for days to flowering. These parents should be selected for further breeding program, and higher (15.07) SCA effect was recorded from the cross 54 CMS-1 x RHP-42 followed by peshawer-93 CMS-1 x RHP-46 SCA effects for days to flowering among the hybrids. However, hybrids peshawer-93 CMS-12 x RHP-53 gave maximum (21.54 and 16.18) mid parent and better parent heterosis respectively while 54 CMS-2 x RPH-53 gave next maximum (16.92) relative heterosis and T40319 x RHP-46 produced (15.38) heterobeltiosis for flowering. These hybrids having more additive type of gene action are selected for hybrid crop development of sunflower. Similar results were obtained by Bhat *et al.*, (2000)[12], Nehru *et al.* (2000)[13]. The GCA effects for yield and other characters of 7 inbred female lines, were presented in the results revealing that the parents T4-0319 and0505 CMS-1 were good combiners for yield and oil content. The highest GCA effect for yield was observed for line Peshawer-93, followed by lines RHP-53, whereas the lowest GCA value was observed for line 54 CMS-2, followed by line RHP-42. Significant additive genetic variance for seed yield exists in sunflower, suggesting that selecting lines on the basis of yield should be useful in developing lines with good combining ability. The lines 0505 CMS-6 showed the highest GCA RHP-53 for oil content followed by line 81, whereas the lowest GCA value was observed for line 54. The highest GCA effects for head diameter were observed for line CMS-11, followed by lines T4-0319. Previous research[14] also reported positive GCA for yield, head diameter and oil content. In addition, the line CMS-12 appeared to be good combiners for seed weight (1.01). The preponderance of additive gene action observed for yield, head diameter and oil content indicates that there will be progress in selection form crosses involving inbred. The usefulness of a particular cross in exploiting heterosis is judged by the SCA effect of component lines. According to Sprague and Tatum (1942)[3], the SCA is controlled by non-additive gene action. The SCA effect is an important criterion for the evaluation of hybrids. Mean square for SCA was highly significant for 1000-seed weight and plant height. The results indicated that non-additive effects were important for these traits. The SCA effects for 100-seed weight, plant height, yield and other characters of crosses are presented. The cross of 54 CMS-2 showed the highest SCA effect for 100-seed weight (2.67), followed by the crosses of 54CMS-2 x RHP-42 (1.31). In this research, increasing plant height was considered to be undesirable but increasing yield, oil content, 100-seed weight and head diameter were desirable. Also, the highest negative SCA effect for plant height was observed for the cross. The importance in SCA effect was not found for yield, head diameter and oil content. However, the highest specific combination for seed yield was 14 followed by Peshawer-93. Among the crosses, T4-0319 showed the greatest positive SCA effect for head diameter (1.22). The best specific combinations for oil content were 0505 CMS-6 x RHP-53.

5 Conclusions

It was concluded from present study that all the traits were significant flowering, days to maturity, plant height, and head diameter, seed index grain per head and grain yield per plant. Among the lines 0505 CMS-6, Peshawer-93 CMS-11, Peshawer-93 CMS-12 , and 81 CMS-10 were best general combiners for days to flowering, days to maturity, plant height (cm), head diameter (cm) seed index, grain per head and grain yield per plant. While testers RHP-53, RHP-42, and RHP-46 were also the best combiners for all the trait studies. However, hybrid 54 CMS-1 x RHP-42 showed best specific combiners for days to flowering , days to maturity, plant height (cm), head diameter (cm), seed index and grains per head, while Peshawar-93 CMS-12 x RHP-46 exhibited good specific combiners for grain yield per plant. The hybrid peshawer-93 CMS-12 x RHP-53, Peshawar-93 CMS-11 x RHP-81 CMS-10 x RHP-53, Peshawer-93 CMS-11 x RHP-46, Peshawer-93 CMS-11 x RHP-42 and 81 CMS x RHP-46 recorded higher heterotic effect of days to flowering, days to maturity, plant height, head diameter, seed index, grains per head and grains yield per plant among the hybrids respectively.

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