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Combining Ability of Sunflower Inbred Lines under Drought Stress

https://doi.org/10.1515/helia-2017-0009
Received May 14, 2017; accepted October 15, 2018

Abstract: Sixteen sunflower hybrids obtained by crossing between four CMS and four restorer lines as tester were evaluated for combining abilities of agronomic traits under optimum and water limited conditions using line × tester mating design. There was considerable variability among genotypes for the traits in both normal and stressed experiments. The results indicated that the lines AGK344 and AGK148 with suitable GCA for early maturity and plant height respectively and AGK52 for oil content and seed and oil yield were desirable combiner under both optimum and stressed condition. In other hand, AGK344 expressed a significant GCA for plant height in suitable direction under stressed condition. Among the testers RGK26 and RGK56 had suitable GCA for days to maturity under both conditions. RGK56 and RGK26 were appropriate combiner for oil content under optimum and water stressed conditions respectively the later had desired GCA for seed and oil yield under water stressed condition too. According to the results, there was differentiate GCA of testers for days to flowering, seed weight and oil content in normal and stressed condition. Differential expressions of GCA in parent inbred lines indicated that selection of restorer lines for the agronomic traits would be more efficient than the selection of CMS lines. It is concluded that heritability of a trait determines the kind of SCA in response to different environments and the SCA effects are more stable for traits with higher heritability.

Keywords: combining ability, graphical radar, heritability, line × tester

Introduction

Although sunflower is considered moderately drought tolerant, however its productivity is greatly affected by drought stress (Erdem *et al.*, 2006; Ghaffari

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et al., 2012; Tahir *et al.*, 2002). Improvement for drought resistance is one of the main objectives in sunflower breeding programs (Fick and Miller, 1997). Efficient selection of parent lines to utilize transgressive segregation and manifestation of heterosis phenomenon is one of the most important challenges in heterosis based breeding programs which in turn serves as a criterion to establish the best selection strategy for developing high yielding hybrid cultivars (Hervé *et al.*, 2001; Škorić, 1992). There are many reports indicating expression of heterosis for sunflower agronomic characteristics (Kaya, 2005; Reddy *et al.*, 1985; Singh *et al.*, 1984). Hladni *et al.* (2007) reported that the occurrence of heterosis in sunflower is highly correlated with genetic distance between the parent lines.

The magnitude of heterosis is determined by the combining ability of the parent lines. General combining ability (GCA) and specific combining ability (SCA) are the main criteria for rapid genetic assaying of test genotypes (Sharma, 1998). Line × Tester mating design is an extension of top cross method (Singh and Chaudhary, 1977) which is used for estimating of general and specific combining ability of parent inbred lines as well as for providing information about the nature of gene action in sunflower (Ghaffari *et al.*, 2011; Hladni *et al.*, 2006; Kaya and Atakisi, 2004; Ortis *et al.*, 2005).

To the best of our knowledge, there is little information about combining ability of sunflower inbred lines under water stressed condition. Rauf *et al.* (2009) used line × tester method for genetic analysis in sunflower under drought stress and observed that female lines contribute more than male line in additive effects controlling leaf hydraulics. In other report combining ability analysis revealed that most of the agronomical traits such as head diameter, number of achene per head, head weight and seed yield are inherited differently and different crosses had the suitable combining ability for seed yield in stressed and non-stressed conditions (Darvishzadeh *et al.*, 2014). The objective of this study was to estimate GCA and SCA effect of sunflower inbred lines to identify the superior combiners for agronomic futures under optimum and water stressed conditions.

Materials and methods

The experiment was carried out in Khoy Agricultural and Natural Resources Research Station in West Azarbaijan, Iran, located in 38° 32’ north latitude and 44° 58’ east altitudes. The genetic materials for combining ability tests were produced by crossing between four CMS and four restorers as lines and testers respectively. The resulted 16 F1 hybrids were evaluated in the following season as RCB design with three replications under optimum and water limited conditions separately. Each experimental plot consisted of 3 rows of 4 m length with 60 × 25 cm spacing between and within rows. Fertilizers were applied at the rate of 100:70:90 kg/ha for N: P: K. Drought stress was imposed by water withholding in R4-R6 growth stages as defined by Schniter and Miller, 1981). Phenological traits as days to flowering and physiological maturity determined during the growth season, while plant height and head diameter were recorded at the end of flowering (R6) and seed and oil yield and the related components were measured after harvest. The mean values of F1 hybrids, inbred and tester lines were used to estimation of the GCA and SCA effects for above mentioned traits using line × tester mating design (Singh and Chaudhary, 1977). Graphical radars were used for manifesting of the association between SCA effects of crosses under optimum and water stressed condition.

Results and discussion

According to the analysis of variance there was considerable variability for all the traits among genotypes under optimum irrigation which is expressed in both parents and hybrids (Table 1). There was also a significant difference among female and male inbred lines for studied traits which could be resulted from maternal effect. Significant differences among hybrids for all traits indicated varying performance of cross-combinations and allow further analysis via line × -tester method. The variance due to the lines and testers which is an indicator of GCA was significant for all the studied traits. The variances due to the SCA of line × tester were significant for all the traits except for days to maturity and seed yield. The significance of the line × tester interaction suggests that testers were able to discriminate within the set of inbred lines. The values of variance due to GCA of lines and testers were higher than SCA for days to flowering and maturity, head diameter, seed weight, oil content and seed and oil yield indicates the prevalence of additive gene action in inheritance of these traits as indicated by Gangappa *et al.* (1997) too. There was also considerable maternal effect for plant height and seed weight. Significant variance of parents vs. hybrids for days to flowering, plant height, head diameter, seed weight and seed yield indicated expression of heterosis for these traits.

Under water limited condition there was significant differences among genotypes for all the studied traits (Table 2). There was more variability among restorers than CMS lines for most of the traits as seed and oil yield, indicated that restorers were highly divergent from CMS lines which confirms the choice of restorers as testers. Highly significant differences among parents vs. hybrids

Table 1: Analysis of variance for agronomic traits under optimum irrigation.

Sources of variation	DF	Days to Flowering	Days to Maturity	Plant Height	Head Diameter	1000 Seeds Weight	Oil Content	Seed Yield	Oil Yield
Replication	2	1.9	3.5	797.5**	2.0	140.5	12.4*	290,166.0	118,973.7
Genotype	23	12.9**	13.9**	1652.7**	14.5**	197.2**	13.2**	6,240,565.1**	1,106,537.9**
Parents	7	3.8**	29.7**	494.6**	19.5**	227.9**	24.0**	1,230,745.5**	268,328.5**
Female	3	5.4**	27.0**	280.1**	6.9	235.9**	24.5**	756,072.3	268,328.5*
Male	3	3.4*	32.3**	426.7**	14.6**	108.5	24.2**	617,187.3	203,659.2*
Female × Male	1	0.0	30.4**	1341.9**	71.7**	562.4**	25.8**	4,495,433.6**	106,089.1
Hybrid	15	10.2*	7.1**	502.2*	6.6*	156.4*	8.8**	2,518,769.4*	949,054.5**
Line	3	29.1**	15.4**	658.0**	20.2**	457.6**	19.5**	1,964,413.1**	507,987.9**
Tester	3	18.3**	21.4**	149.3**	24.3**	189.3**	19.7**	1,137,252.0*	665,470.5**
Line × Tester	9	7.1**	3.6	152.2**	7.8*	97.2*	4.0	946,918.4*	187,903.1**
Parent × Hybrid	1	121.0*	5.8	27,097.6**	45.2**	592.7**	1.3	971,362,251.6**	252,113.4
Error	46	1.1	2.4	49.3	3.0	44.5	3.4	370,112.6	64,916.0
cv		1.65	1.38	3.65	8.82	11.27	4.53	15.91	16.34

*and ** denote to the statistical significance in probability of 5 and 1% respectively.

Table 2: Analysis of variance for agronomic traits under water limited condition.

Sources of variation	DF	Days to Flowering	Days to Maturity	Plant Height	Head Diameter	1000 Seeds Weight	Oil Content	Seed Yield	Oil Yield
Replication	2	0.8	10.9*	923.1**	0.5	11.6	65.2**	117,475.2	134,322.2**
Genotype	23	8.4**	20.9**	1903.3**	15.1**	135.3**	16.7**	3,463,057.0**	627,274.2**
Parents	7	2.1	45.1**	564.0**	10.8**	74.5*	26.0**	921,748.2**	196,978.4**
CMS	3	1.4	55.1**	211.6*	0.4	67.7	41.6**	498,403.1**	129,934.5**
Restorer	3	3.2	29.0*	94.4	6.8**	106.1*	17.3*	403,318.3*	96,121.7**
CMS × Restorer	1	0.7	63.3**	3029.6**	54.1**	0.0	5.1	3,747,073.0**	700,675.0**
Hybrid	15	4.0*	9.3	216.9**	2.7*	136.5**	13.5*	1,555,432.0**	336,179.9**
Line	3	31.5*	10.3**	557.4**	2.8	540.0**	20.3*	507,951.5**	169,263.8**
Tester	3	8.5**	11.5**	55.2	3.3	21.9	21.5*	267,539.6*	91,638.2**
Line × Tester	9	3.7	2.8	171.2**	1.6	69.3*	8.5	248,967.5*	99,620.2**
Parent × hybrid	1	119.1**	25.0**	36,576.2**	230.8**	542.6**	0.0	49,866,606.5**	8,005,759.0**
Error	46	2.0	2.3	59.5	1.3	28.0	5.6	96,348.4	19,472.5
C.V.	2	0.8	10.9*	923.1**	0.5	11.6	65.2**	117,475.2	134,322.2**

*and ** denote to the statistical significance in probability of 5 and 1% respectively.

indicated expression of heterosis for all the traits except oil content. This could be resulted from the fact that only the parent lines with higher oil content have been selected for crossing in breeding program. Significant heterosis for early flowering and maturity, seed weight, seeds head $^{-1}$ and seed yield (Gill and Punia, 1996; Hladni *et al.*, 2007; Yilmaz and Emiroglu., 1994) has been reported in sunflower.

The line AGK344 with negative significant GCA was desirable combiner for early maturity under both optimum and stressed conditions (Table 3). This implies to the fact that this line possesses genes responsible for earliness and can be used for improvement of early mature sunflower hybrids. For days to flowering, only AGK148, had significant GCA in desired direction, however its GCA was positive for days to maturity. This could be resulted from long seed filling duration in this line. AGK148 also depicted a significant negative GCA for plant height in both conditions indicating that it possesses genes responsible for reduced height and could be used for improvement of dwarf sunflower hybrids. AGK344 showed a differentiate response and had desired GCA for plant height under stressed condition. AGK52 with positive GCA for oil content and seed and oil yield was the suitable combiner for improvement of oil yield in both conditions. Goksoy *et al.* (2000) reported significant GCA effects for seed weight and seed yield in sunflower inbred lines.

Table 3: General combining ability of lines under optimum and water stressed condition.

Lines	Days to flowering		Days to maturity		Plant height		Head diameter	
	NS	S	NS	S	NS	S	NS	S
AGK52	2.3**	2.4**	0.6	−0.1	7.4**	9.6**	0.5	0.1
AGK 148	−0.8**	−0.8*	1.0**	1.2**	−10.1**	−5.5**	−0.7	−0.7*
AGK 222	−0.4	−0.6	−0.1	0.0	2.7	−0.2	−0.6	0.1
AGK 344	−1.1**	−1.0**	−1.6**	−1.0**	−0.1	−4.0*	0.8	0.4
S.E.gi	0.3	0.4	0.4	0.4	1.8	1.9	0.4	0.3
Lines	**Seed weight**		**Oil content**		**Seed yield**		**Oil yield**	
	NS	S	NS	S	NS	S	NS	S
AGK52	−0.6	−5.1**	1.0*	1.8**	851.7**	222.7**	394.6**	156.0**
AGK 148	−3.0	−1.3	0.7	−1.0	−195.0	114.8	−60.6	15.5
AGK 222	−5.2**	−3.3	0.1	0.2	33.7	−108.7	8.9	−47.0
AGK 344	8.8**	9.8**	−1.8**	−1.0	−690.4**	−228.8**	−342.9**	−124.6**
S.E.	1.7	1.3	0.5	0.6	152.1	77.6	63.7	34.9

*and ** denote to the statistical significance in probability of 5 and 1% respectively.

Among the testers RGK19 had a desired GCA for days to flowering under both optimum and water limited conditions (Table 4), however this line was not suitable combiner for days to maturity. There were two restorers; RGK26 and RGK56 with suitable GCA for days to maturity under both conditions. RGK 56 and RGK26 were appropriate combiners for oil content under optimum and water stressed conditions respectively, the later had desired GCA for seed and oil yield under water stressed condition too. Under optimum irrigation only RGK46 had a positive GCA for oil yield. Higher GCA effects indicate a greater role of additive while higher SCA values refer to dominant gene action for a given characteristic (Fehr, 1987). According to the results there was similar GCA of lines for the studied traits in optimum and stressed conditions, however the response of testers was different for days to flowering, seed weight and oil content. There are reports which confirm differential expression of GCA in parent inbred lines. Laureti and Del Gatto (2001) and

Table 4: GCA effects of sunflower testers under optimum (NS) and water stressed(S) conditions.

Testers	Days to flowering		Days to maturity		Plant height		Head diameter	
	NS	S	NS	S	NS	S	NS	S
RGK19	−1.1**	−1.2**	0.9*	1.0**	0.4	−1.0	−0.5	−0.4
RGK 26	0.5*	0.8*	−1.1**	−0.8*	0.1	−0.7	0.6	0.3
RGK 46	−0.1	0.1	1.3**	0.6	−2.7	−1.5	−0.1	−0.4
RGK 56	0.7**	0.3	−1.2**	−0.9*	2.2	3.2	0.0	0.6
S.E.	0.3	0.4	0.4	0.4	1.8	1.9	0.4	0.3
Testers	**Seed weight**		**Oil content**		**Seed yield**		**Oil yield**	
	NS	S	NS	S	NS	S	NS	S
RGK19	2.3	1.4	−1.8**	−1.9**	−136.8	−21.3	−126.7	−62.6
RGK 26	0.0	0.7	0.0	1.2*	86.8	211.6**	41.9	129.1**
RGK 46	1.5	−0.5	0.8	0.8	227.3	−137.2	128.9*	−40.7
RGK 56	−3.9*	−1.6	1.0*	−0.1	−177.3	−53.2	−44.1	−25.8
S.E.	1.7	1.3	0.5	0.6	152.1	77.6	63.7	34.9

*and ** denote to the statistical significance in probability of 5 and 1% respectively.

Ortis *et al.* (2005) reported higher GCA of restorers than maternal lines for plant height, 1000-seed weight and flowering time which indicated that selection of restorers would be more efficient than selection of CMS lines regarding these traits.

Considering SCA effects; AGK52 × RGK19 and AGK148 × RGK56 were suitable combiners for early flowering in both optimum and stressed conditions, the first one had also desirable SCA for days to maturity under optimum irrigation (Table 5). Two crosses; AGK222 × RGK46 and AGK344 × RGK26 had a desirable SCA for early flowering under non-stressed condition. The hybrid AGK52 × RGK46 was determined as a good combination for plant height under stressed condition, however the hybrids AGK222 × RGK19 and AGK344 × RGK26 were better in optimum irrigation. For seed weight AGK222 × RGK19 and AGK344 × RGK56 were desirable combinations in both irrigation treatments. AGK222 × RGK56 and AGK344 × RGK19 had significant positive SCA for oil content in optimum and stressed conditions while the first one was better in stressed condition too. Two crosses; AGK148 × RGK56 and AGK222 × RGK19 were determined as preferable combiners for seed and oil yield and AGK52 × RGK26 for oil yield under stressed condition. Under optimum irrigation AGK344 × RGK56 had the highest positive SCA for seed yield. Goksoy *et al.* (2000) and Goksoy and Turan (2004) have indicated positive and significant SCA effects for seed yield and its components in some hybrid combinations. Generally, the higher expression of heterosis is highly correlated with genetic distance between the parental lines (Hladni *et al.*, 2007).

Comparison of SCA effects in optimum and drought stressed condition

Graphical radars were used in order to determine the relationship between SCA's under optimum and water stressed conditions (Figure 1). There was a similar response for SCA effects for days to maturity under both irrigation treatments. Despite of this concordant response, only

AGK52 × RGK19 had a significant SCA in desired direction under optimum irrigation. The similar response of SCA effects for days to maturity in different irrigation treatments could be because of higher heritability of this trait as confirmed by Tabrizi *et al.* (2012). Expressing differentiated SCA effects for plant height, AGK344 × RGK19 had the highest positive SCA in optimum while lower SCA in drought stressed conditions. AGK344 × RGK26 and AGK222 × RGK19 had desired SCA for plant height in optimum while AGK52 × RGK46 in stressed conditions. There is contradictory results bout the nature of gene action controlling plant height (Bajaj *et al.*, 1997; Ghaffari *et al.*, 2011) However, the results of this study support the idea that plant height is more sensitive to environmental condition. For oil content there was a similarity response of SCA effects to irrigation treatments. There are reports indicate involving of additive gene action

Table 5: Specific combining ability of restorers and CMS inbred lines of sunflower under optimum and water stressed condition.

Crosses	Days to flowering		Days to Maturity		Plant Height		Head Diameter	
	NS	S	NS	S	NS	S	NS	S
AGK52 × RGK19	−1.9**	−1.8*	−1.5*	−0.5	0.2	5.9	0.6	0.9
AGK52 × RGK26	0.1	0.8	1.5*	1.4*	3.4	−1.9	1.4	−1.2*
AGK52 × RGK46	1.5**	0.3	−0.6	−1.0	−5.6	−8.2*	−0.4	0.7
AGK52 × RGK56	0.3	0.8	0.7	0.1	1.9	4.3	−1.6*	−0.4
AGK148 × RGK19	0.5	1.1	1.1	0.9	−4.0	1.9	1.4	−0.6
AGK148 × RGK26	1.2**	0.1	0.4	−0.3	0.9	−1.4	−0.7	0.8
AGK148 × RGK46	0.2	0.2	−0.7	0.0	4.5	3.1	−0.5	0.0
AGK148 × RGK56	−2.0**	−1.3**	−0.8	−0.5	−1.4	−3.5	−0.3	−0.1
AGK222 × RGK19	−0.2	−0.2	0.5	0.8	−8.6**	−3.4	−0.1	0.0
AGK222 × RGK26	−0.2	0.2	−0.8	−0.7	5.4	2.3	−0.5	0.0
AGK222 × RGK46	−1.5**	−0.7	0.7	0.2	3.8	3.9	−0.2	−0.1
AGK222 × RGK56	2.0**	0.8	−0.3	−0.3	−0.6	−2.7	0.7	0.1
AGK344 × RGK19	1.5**	0.9	0.0	−1.2	12.3**	−4.2	−1.9*	−0.3
AGK344 × RGK26	−1.1*	−1.1	−1.0	−0.4	−9.7**	1.1	−0.2	0.4
AGK344 × RGK46	−0.1	0.3	0.6	0.9	−2.8	1.3	1.0	−0.6
AGK344 × RGK56	−0.3	−0.2	0.5	0.7	0.1	1.9	1.1	0.4
SE	0.5	0.6	0.7	0.7	3.0	3.3	0.8	0.5
Crosses	**1000 Seeds Weight**		**Oil Content**		**Oil Yield**		**Seed Yield**	
	NS	**S**	**NS**	**S**	**NS**	**S**	**NS**	**S**
AGK52 × RGK19	−3.3	−2.3	−0.9	−1.7	135.8	−637.0**	12.2	−307.0**
AGK52 × RGK26	3.6	−0.8	0.8	0.9	451.9	245.9	221.5	142.0*
AGK52 × RGK46	−0.4	2.1	0.5	0.9	−387.0	197.9	−143.9	92.7
AGK52 × RGK56	0.1	1.0	−0.5	−0.1	−200.7	193.3	−89.8	72.2
AGK148 × RGK19	1.8	1.8	0.1	1.0	15.7	94.7	4.8	61.2
AGK148 × RGK26	−3.5	−4.7**	0.2	−0.7	−318.9	−479.5**	−124.0	−223.8**
AGK148 × RGK46	1.1	1.8	0.3	−0.7	40.6	83.6	24.3	17.7
AGK148 × RGK56	0.7	1.1	−0.6	0.3	262.6	301.2*	94.9	144.9*
AGK222 × RGK19	8.3**	5.6**	−1.2	−1.1	−55.5	413.5**	−54.1	139.9*
AGK222 × RGK26	−1.7	1.0	−0.3	−0.2	119.1	212.3	30.7	81.4
AGK222 × RGK46	1.6	0.3	−0.3	−1.1	788.1**	21.4	321.6**	−4.8
AGK222 × RGK56	−8.1**	−6.9**	1.7*	2.4*	−851.7**	−647.2**	−298.2**	−216.6**
AGK344 × RGK19	−6.8	−5.0*	1.9*	1.8	−96.0	128.8	37.2	105.8
AGK344 × RGK26	1.7	4.5	−0.8	0.0	−252.0	21.3	−128.2	0.4
AGK344 × RGK46	−2.2	−4.2	−0.5	0.9	−441.7	−302.9*	−202.0	−105.6
AGK344 × RGK56	7.5*	4.8**	−0.7	−2.6*	789.8**	152.8	293.1*	−0.6
SE	2.9	2.3	0.8	1.0	263.4	134.4	110.3	60.4

*and ** denote to the statistical significance in probability of 5 and 1% respectively.

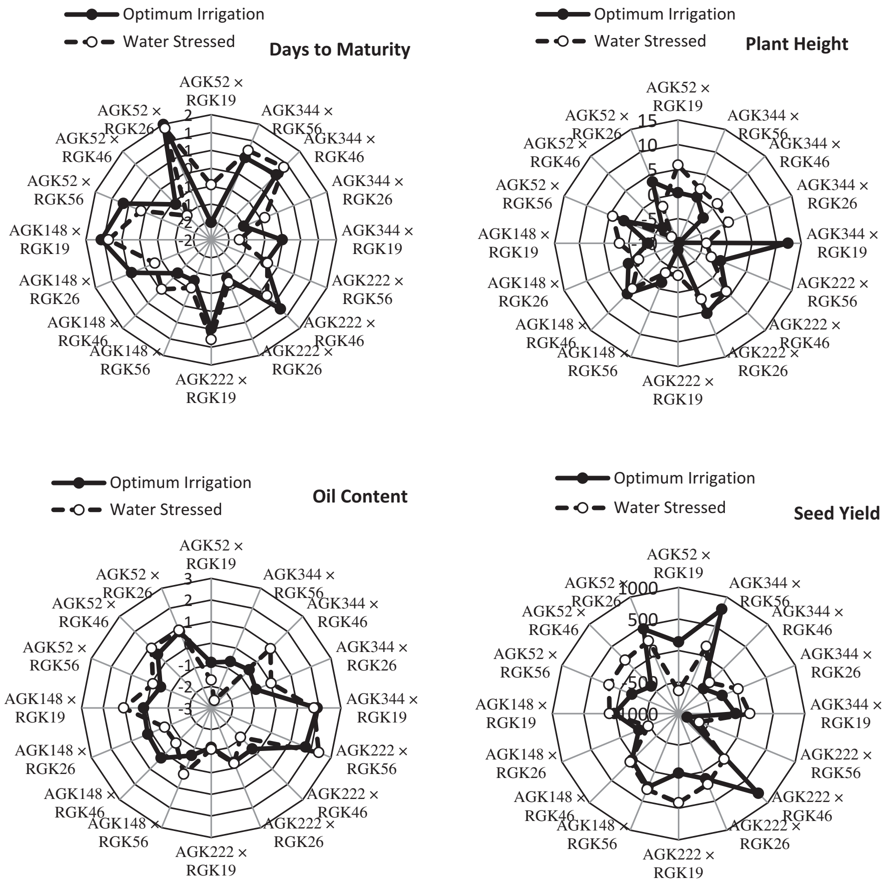

Figure 1: Graphical radar for exploiting SCA effects of sunflower hybrids under optimum and water stressed conditions.

on controlling of oil content in sunflower (Bajaj *et al.*, 1997; Sharma *et al.*, 2003, Ghaffari *et al.*, 2011). It is concluded that this harmonic response could be as a result of higher heritability of oil content. There was a major inconstancy in SCA effects for seed yield in two irrigation treatments, which expressed in Figure 1. Under optimum irrigation hybrids as AGK344 × RGK56 and AGK222 × RGK46 in outer circle of diagram were determined as suitable crosses regarding seed yield, however two other hybrids; AGK222 × RGK19 and AGK148 × RGK56 were appropriate combiners under stressed condition. Hybrids as AGK52 × RGK19, AGK52 × RGK46, AGK52 × RGK56 and AGK344 × RGK26 had differentiate SCA for seed yield under irrigation condition. Seed yield as a quantitative trait is affected by non-genetic effects and this minimize the heritability of the trait under different environments, which is indicated in many reports. We concluded that as other plant characteristics, heritability of a trait determines the kind of SCA in response to different environments. The results of this study indicated that SCA effects are more stable for traits with higher heritability are inconstant for low heritable traits as seed yield.

Conclusions

There was differentiate GCA of testers for days to flowering, seed weight and oil content in normal and stressed condition. Differential expressions of GCA in parent inbred lines indicated that selection of restorer lines for these traits would be more efficient than the selection of CMS lines. It is concluded that heritability of a trait determines the kind of SCA in response to different environments and the SCA effects are more stable for the traits with higher heritability.

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