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COMBINING ABILITY ANALYSIS OF SOME YIELD CHARACTERS OF SUNFLOWER (*Helianthus annuus* L.)

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SUMMARY

The experiments comprising 25 sunflower hybrids were conducted in three locations in 2000 and 2001. These hybrids were evaluated for combining ability of 6 important yield components. Based on observations in this research, the average flowering duration of the hybrids ranged from 69.6 to 71.8 days, physiological maturity from 98.7 to 104.2 days, hectoliter weight from 355.2 to 408.5 g, 1000-seed weight from 32.5 to 43.5 g, plant height from 98.3 to 134.3 cm and head diameter from 12.6 to 14.0 cm.

Based on all combining ability analyses performed in this research, the cross 2453-A × R-1001 was determined as the best hybrid in the experiment. Among the parental lines, HA89-A and 2644-R were chosen as first female and male testers, respectively; BAH8-A and 2280-R were chosen as second testers for testing combining ability of lines for use in future breeding programs in sunflower.

Key words: sunflower, hybrid breeding, general and specific combining ability

INTRODUCTION

Hybrids are preferred by sunflower growers in many countries in the world due to high yield performance, uniformity, quality, *etc*. Sunflower farmers use hybrids in more than 90% of the sunflower production in Turkey (Kaya, 2003). Superior hybrids have been obtained by crossing inbred *cms* female and restorer lines with high GCA and SCA values.

General (GCA) and specific combining ability (SCA) are important traits in plant breeding. Due to high heterosis occurring generally in hybrids between genetically unrelated inbred lines, all crop breeders that use heterosis have the challenge to find good combiners. Breeding programs can take advantage from such informa-

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tion on combining ability to find best selection strategy for developing high yielding lines and hybrids (Škorić, 1992). Also, evaluating genotypes for combining ability is important in determining appropriate procedures or genotypes to utilize efficiently in breeding programs for main yield characters in sunflower (Miller, 1987). The environmental conditions influence the evaluation of combining ability of sunflower genotypes (Petakov, 1996).

Regarding combining ability analysis, SCA variance higher than GCA variance means that dominant genes have higher effects than recessive ones in determining the studied characters. Conversely, higher GCA variance indicates that additive gene effects play a more important role in determining these traits. If neither variance is significant, it implies the existence of epistatic gene effects (Marinković *et al.*, 2000; Škorić *et al.*, 2000). Combining ability of important sunflower yield characteristics was evaluated by many researchers. Some researchers found that additive gene effects had more important roles in some yield traits such as plant height (Mruthunjaya *et al.*, 1995; Mihaljčević, 1988; Göksoy *et al.*, 1999; Joksimović *et al.*, 2000), 1000-seed weight (Tyagi, 1988; Mruthunjaya *et al.*, 1995; Mihaljčević, 1988; Göksoy *et al.*, 1999; Khan, 2001), flowering time (Mihaljčević, 1988), physiological maturity date (Mihaljčević, 1988; Tyagi, 1988), etc. Others observed that non-additive genes affect dominantly some yield components such as head diameter (Mruthunjaya *et al.*, 1995; Mihaljčević, 1988) and physiological maturity time (Mihaljčević, 1988).

Correct selection of parents of sunflower hybrids is important for achieving high yield performance in breeding programs. Combining ability tests applied to determine best F_1 hybrids and lines with high yield capabilities (Ortegon-Morales *et al.*, 1992; Rao *et al.*, 1992) indicated that GCA could be used as criterion for parent selection. Besides, Laureti and Gatto (2001) observed that restorer lines had higher GCA values than *cms* lines for some important yield characters such as plant height, 1000-seed weight, and flowering time, so the selection of restorer lines for these traits would be more efficient than the selection of *cms* lines.

Testing combining ability of lines in sunflower breeding programs starts generally in the S_3 or S_4 generations. Sunflower breeders usually prefer 2-3 tester lines to evaluate with crossing inbred lines. Virupakshappa *et al.* (1997) indicated that 2 testers were enough to efficiently test GCA of inbred lines. Due to additional costs of using more testers, the use of 2 testers was suggested and applied by many researchers around the world (Miller, 1987; Škorić, 1992; Fick and Miller, 1997).

Many researchers generally preferred Griffing's statistical method (Dua and Yadava. 1983; Rao *et al.*, 1992) or line × tester analysis (Kadkol *et al.*, 1984; Mihaljčević, 1988; Tyagi, 1988; Ortegon-Morales *et al.*, 1992; Marinković, 1993; Tan, 1993; Mruthunjaya *et al.*, 1995; Alone *et al.*, 1996; Gangappa *et al.*, 1997; Virupakshappa *et al,.* 1997; Göksoy *et al.*, 1999; Joksimović *et al.*, 2000; Marinković *et al.*, 2000; Rojas *et al.*, 2000; Škorić *et al.*, 2000) to evaluate combining ability of sunflower inbred lines for some significant yield characters. However, neither

method evaluates efficiently the combining ability of sunflower inbred lines because branched restorers and *cms* female lines are not used in commercial sunflower production. Due to economic importance of F_1 hybrids only, North Carolina Design II or factorial mating design are the best methods for measuring combining ability in cross-pollinated crops (Beil and Atkins, 1967; Cukadar-Olmedo *et al*., 1997).

The main objectives of this study were to evaluate sunflower lines and hybrids for combining ability in different environments and to determine GCA and SCA of different female and male inbred lines and to find the best testers for testing F_1 hybrid combinations for important yield traits.

MATERIAL AND METHODS

Twenty-five hybrids developed by crossing 5 cytoplasmic male sterile (*cms*) female lines (BAH4-A, BAH8-A, HA-89-A, 0704-A and 2453-A) to five male restorer lines (2644-R, 2284-R, 2280-R, 25711-R and R-01001) were used in this study conducted in National Sunflower Research Project. These hybrids were made from 1999 plantings in the fields of Trakya Agricultural Research Institute-Edirne and evaluated in North Carolina Design II. The 25 hybrids obtained in 1999 were planted at three locations (experiment fields in Edirne, Kýrklareli and Saray-Tekirdag) in 2000 and 2001. The experimental design was randomized complete block design with three replications.

The experiments were conducted in three-row plots, 6 m long, with 70 × 35 cm planting density. The middle row only was harvested for experimental purposes and plot size was 3.78 m^2 at harvest. Flowering and physiological maturity time (day), 1000-seed weight (g), hectoliter weight (g), head diameter (cm) and plant height (cm) were observed and measured in this experiment. Combining ability analysis for each character was calculated according to Beil and Atkins (1967). According to this method, i female (**gi**) and j restorer male inbred lines (**gj**) general and specific combining ability (**gij**) denote, respectively:

gi = (yi. – y..)

gj= (yj. – y..)

gij=(yij - yi. - yj. + y..)

RESULTS AND DISCUSSION

GCA of inbred lines, SCA of hybrids and their interactions were significant for all yield components in the summarized ANOVA at three environments in two years (Table 1). The observed significance of GCA and SCA in all traits measured in this study indicated that both additive and the non-additive (dominance and/or epistasis) gene effects played important roles in determining these traits. Both mean squares of GCA of female and restorer lines were extremely higher than SCA of

hybrids. The large and significant mean squares for locations and numerous interactions with locations were indicative of large difference in growing conditions and management. The GCA of inbred lines by both location and year interactions were significant in all traits except head diameter.

Table 1: The combined ANOVA of some yield components in 2000 and 2001

Sources of variation	Df	Mean squares					
		Flowering T	PM Time	Plant Height	Head Dia	1000-SW	Hectol W
Year (Y)	1	2757.8**	310.8**	54628.3**	179.2**	1454.4**	66758.6**
Location (L)	2	968.2**	1027.3**	32493.4**	458.4**	1701.4**	18715.2**
Y × L	2	1269.7**	1518.1**	15375.6**	151.8**	1419.9**	22483.0**
Reps (L × Y)	12	13.1**	24.9**	109.5 **	2.1*	58.6**	990.3**
Female (F) +	**4**	**21.4****	**143.4****	**2964.0****	**3.1***	**582.9****	**4474.3****
Y × F	4	4.7**	24.4**	215.1**	2.0 ns	38.1*	2100.1**
L × F	8	3.6**	43.1**	124.4**	1.3 ns	63.3**	414.2**
L × Y × F	8	2.3*	44.7**	120.1*	3.9**	20.5 ns	714.0**
Male (M) +	**4**	**8.5****	**9.8***	**3000.6****	**4.3****	**254.8****	**8120.1****
Y × M	4	1.8 ns	11.2*	69.1 ns	2.8 ns	7.2 ns	721.1**
L × M	8	3.1**	5.7 ns	55.2 ns	1.1 ns	10.5 ns	423.8**
L × Y × M	8	1.9*	11.5 **	63.9 ns	2.4 ns	35.6**	589.5**
F × M +	**16**	**2.9****	**12.7****	**228.4****	**2.4***	**82.6****	**1301.7****
Y × F × M	16	2.6**	7.6 *	17.5 ns	1.6 ns	9.3 ns	265.3*
L × F × M	32	1.5*	5.2 ns	74.2 *	2.1*	11.8 ns	205.2 ns
Y × L × F × M	32	1.1 ns	5.5 ns	67.3 ns	1.9*	8.9 ns	282.7**
Error	288	0.9	3.9	47.0	1.2	11.3	140.8

** Significant at the %1 and * at the % 5 probability level; ns = nonsignificant
+ Female (F) Male (M) and the F × M interaction represent GCAF, GCAM, and SCA, respectively.

Of the GCA effects for parents, only that for HA-89-A *cms* was positive. The female line BAH-8-A and the male line R-1001 had the highest negative values among the lines (Table 2). Earliness is one of the desired characters in sunflower breeding, to be combined with high yield performance. Therefore, negative GCA values of both flowering and physiological maturity times were preferred in this research. The female line BAH-8-A and the restorer line R-1001 were selected as the best combiners for flowering time in this experiment.

Table 2: GCA and SCA rates of lines and crosses for flowering time

Restorer	Female / Flowering Time (day) / SCA										Restorer Avg/ GCA	
	BAH4-A		BAH8-A		2453-A		0704-A		HA89-A			
2644-R	70.8	**0.4**	70.2	**-0.2**	70.3	**0.2**	70.3	**-0.6**	71.8	**0.4**	70.7	**0.0**
2284-R	69.9	**-0.6**	70.0	**-0.2**	70.9	**0.2**	70.6	**0.4**	71.4	**0.4**	70.6	**0.0**
2280-R	70.5	**0.0**	70.6	**0.4**	70.7	**0.0**	70.4	**-0.3**	71.5	**0.0**	70.8	**0.2**
25711-R	70.5	**0.2**	69.8	**-0.4**	71.2	**0.0**	71.5	**1.2**	70.9	**-0.8**	70.8	**0.2**
R-1001	69.9	**0.0**	69.6	**0.4**	69.7	**-0.2**	70.0	**0.0**	71.0	**0.0**	70.0	**-0.6**
Female Avg/GCA	70.3	**-0.2**	70.0	**-0.6**	70.5	**0.0**	70.6	**-0.2**	71.3	**0.8**	70.6	

The average flowering time of hybrids ranged from 69.6 to 71.8 days. The cross HA-89-A × R-1001 had the lowest SCA value, but the earliest time were observed in the hybrid BAH8-A × R-1001. The majority of the hybrids (18) exhibited positive SCA effects and only a few of them (7) revealed the desired negative SCA effect. Low values of both GCA and SCA were also obtained by Kadkol *et al.* (1984), Mihaljčević (1988), Tyagi (1988) Mruthunjaya *et al.* (1995), Alone *et al.* (1996) and Gangappa *et al.* (1997).

The average physiological maturity time (PM) of hybrids was 101.9 days and the hybrid PMs ranged between 98.7 and 104.2 days from planting (Table 3). Like for flowering time, the female line BAH8-A had the lowest value and GCA effect for PM. Among the male lines, 2644-R had the lowest values, so these two lines were selected as the best combiners for PM in this study. The cross BAH8-A × R-1001 had the lowest value and SCA rate for PM. Eleven negative and 14 positive SCA values were observed in the hybrids tested in this study.

Table 3: GCA and SCA rates of lines and crosses for physiological maturity

Restorer	Female / Physiological maturity time (day) / SCA										Restorer Avg/ GCA	
	BAH4-A		BAH8-A		2453-A		0704-A		HA89-A			
2644-R	101.3	**0.4**	101.1	**0.8**	102.3	**-0.8**	102.1	**-0.2**	102.8	**-0.2**	101.9	**-0.2**
2284-R	100.9	**0.2**	100.4	**-0.4**	102.4	**0.0**	102.1	**-0.4**	103.4	**0.6**	101.8	**0.0**
2280-R	101.4	**0.4**	101.8	**0.8**	102.5	**-0.8**	103.0	**-0.2**	103.6	**-0.2**	102.5	**0.8**
25711-R	100.0	**-0.4**	99.7	**0.0**	104.2	**1.4**	102.3	**0.0**	101.7	**-1.0**	101.6	**-0.4**
R-1001	100.2	**-0.6**	98.9	**-1.2**	102.9	**0.2**	102.7	**0.8**	104.1	**0.8**	101.8	**-0.2**
Female Avg/GCA	100.7	**-1.2**	100.4	**-1.6**	102.9	**1.0**	102.4	**0.4**	103.1	**1.4**	101.9	

The distribution of SCA rates for hectoliter weight (from -10.4 to 18.6) was larger than the distributions of the other traits evaluated in the study (Table 4). Similar values were also obtained for GCA (from-13.0 to 12.4). The greatest positive GCA effects for hectoliter weight were observed for the male parent 2280-R and for the female parent HA-89-A.

Table 4: GCA and SCA rates of lines and crosses for hectoliter weight

Restorer	Female / Hectoliter weight (g) / SCA										Restorer Avg/ GCA	
	BAH4-A		BAH8-A		2453-A		0704-A		HA89-A			
2644-R	384.2	**4.0**	372.4	**2.8**	375.3	**-6.2**	375.3	**0.2**	379.2	**-0.8**	388.6	**-4.2**
2284-R	396.1	**8.0**	379.3	**1.8**	382.1	**-7.2**	385.2	**-1.8**	397.3	**-0.8**	388.0	**3.8**
2280-R	392.1	**-4.6**	399.1	**12.2**	386.5	**-11.8**	398.0	**2.6**	408.5	**1.6**	396.8	**12.4**
25711-R	374.5	**2.8**	355.2	**-6.4**	379.0	**6.6**	365.5	**-4.0**	381.8	**1.0**	371.2	**-13.0**
R-1001	374.8	**-10.2**	365.4	**-10.4**	404.6	**18.6**	387.4	**3.0**	394.0	**-1.0**	385.3	**1.0**
Female Avg/GCA	384.3	**0.0**	374.3	**-9.8**	385.5	**1.2**	383.1	**-1.2**	394.0	**9.8**	384.2	

These lines could be considered as best combiners for hectoliter weight, an important yield trait in the sunflower breeding. However, the male line 25711-R and the female line BAH8-A had the highest negative GCA values for all traits examined in the experiment. Additionally, the highest positive SCA value (18.6) in the cross

2453-A × R-1001 and the highest negative SCA value (-11.8) of all traits in the cross 2453-A × 2280-R were obtained for hectoliter weight. The general mean of the hybrids in this study was 384 g, with the actual hectoliter weights ranging between 355.2 and 408.5 g.

Table 5: GCA and SCA rates of lines and crosses for 1000-seed weight

Restorer	Female / 1000 Seed weight (g) / SCA										Restorer Avg/ GCA	
	BAH4-A		BAH8-A		2453-A		0704-A		HA89-A			
2644-R	37.1	**0.5**	39.1	**-0.2**	41.9	**1.3**	43.5	**1.6**	32.8	**-3.2**	38.9	**2.5**
2284-R	32.5	**-0.5**	35.8	**0.2**	36.5	**-0.4**	38.6	**0.4**	32.5	**0.3**	35.2	**-1.2**
2280-R	33.1	**-0.7**	36.4	**-0.2**	34.8	**-3.1**	42.8	**3.6**	33.7	**0.4**	36.1	**-0.3**
25711-R	33.5	**1.3**	35.8	**0.8**	35.5	**-0.8**	34.3	**-3.2**	33.6	**1.9**	34.6	**-1.9**
R-1001	34.4	**-0.6**	37.2	**-0.6**	42.1	**3.0**	38.1	**-2.3**	34.9	**0.5**	37.3	**0.9**
Female Avg/GCA	34.1	**-2.3**	36.8	**0.4**	38.2	**1.7**	39.5	**3.1**	33.5	**-2.9**	36.4	

The average 1000-seed weight of the hybrids ranged from 32.5 g to 43.5 g, with the general average of 36.4 g (Table 5). The highest mean values and GCA rates were observed in 0704-A for females and 2644-R for restorers. Therefore, these two lines were selected as best combiners for 1000-seed weight. The restorer lines 2453-A *cms* and R-1001 also had high positive GCA values and these lines could be considered as the second testers for this trait. The highest 1000-seed weight was measured in the cross 0704-A × 2644R, but the highest SCA rate in this experiment was observed in the hybrid 0704-A × 2280-R. These results showed that at least one of the parents should have a high GCA value to obtain a high SCA value in the hybrid.

The general mean of the hybrids for plant height was 121.2 cm, the values ranging between 98.3 cm and 134.3 cm (Table 6). 2284-R and 2644-R from males and 2453-A, BAH8-A and BAH4-A from females had higher positive GCA values than the others. The highest SCA value was measured in the 14th cross (HA89-A × 2280-R) and more negative SCAs (13) were observed in the experiment. The similar high negative both GCA and SCA values were obtained by Kadkol *et al.* (1984), Mihaljčević (1988), Mruthunjaya *et al.* (1995) Gangappa *et al.* (1997) and Škorić *et al.* (2000).

Table 6: GCA and SCA rates of lines and crosses in plant height

Restorer	Female / Plant height (cm) / SCA										Restore Avg./ GCA	
	BAH4-A		BAH8-A		2453-A		0704-A		HA89-A			
2644-R	125.4	**-2.3**	127.6	**-0.5**	133.0	**2.7**	125.7	**0.7**	115.4	**-0.7**	125.4	**4.3**
2284-R	130.6	**0.5**	131.5	**1.3**	134.3	**1.5**	127.1	**-0.5**	115.0	**-2.9**	127.7	**6.5**
2280-R	125.0	**2.3**	123.2	**0.1**	116.0	**-8.7**	121.0	**1.3**	115.4	**4.9**	120.1	**-1.3**
25711-R	115.0	**-0.5**	116.8	**1.3**	122.2	**4.5**	111.7	**-0.5**	98.3	**-4.9**	112.8	**-8.5**
R-1001	122.6	**-0.1**	120.6	**-2.3**	124.7	**-0.1**	118.5	**-1.1**	113.4	**3.5**	120.0	**-0.9**
Female avg/GCA	123.7	**2.7**	123.9	**2.9**	126.0	**4.7**	120.8	**-0.3**	111.5	**-9.9**	121.2	

The higher head diameter is one of the desired characteristics in sunflower breeding. The lower values were obtained generally in both GCA and SCA rates for this trait due to drought conditions in two years conducted the experiment. The

general mean of hybrids over two years was 13.3 cm and head diameters of them changed from 12.6 cm to 14.0 cm. The similar both lower GCA and SCA values were obtained by Kadkol *et al*. (1984), Alone *et al*. (1996), Gangappa *et al*. (1997).

Table 7: GCA and SCA rates of lines and crosses for head diameter

Restorer	Female / Head diameter (cm) / SCA										Restorer Avg/ GCA	
	BAH4-A		BAH8-A		2453-A		0704-A		HA89-A			
2644-R	13.8	**-0.1**	14.0	**0.5**	13.3	**-0.2**	13.8	**0.3**	13.2	**-0.6**	13.6	**0.3**
2284-R	13.5	**0.0**	13.5	**0.3**	12.9	**-0.2**	13.1	**0.0**	13.3	**-0.1**	13.3	**-0.1**
2280-R	14.0	**0.3**	12.6	**-0.7**	13.2	**-0.1**	13.6	**0.4**	13.6	**0.1**	13.4	**0.1**
25711-R	13.2	**0.0**	12.9	**-0.1**	13.1	**0.2**	12.7	**-0.3**	13.3	**0.1**	13.0	**-0.3**
R-1001	13.4	**-0.2**	13.1	**-0.1**	13.4	**0.2**	12.9	**-0.3**	13.9	**0.4**	13.3	**0.0**
Female avg/GCA	13.6	**0.2**	13.2	**-0.1**	13.2	**-0.2**	13.2	**-0.1**	13.5	**0.2**	13.3	

The highest average values and GCA rates was obtained at 2644-R for males, BAH4-A and HA89-A for females. These lines were selected as the best combiners for head diameters to test combining ability for the future breeding works. However, the highest SCA rate (0.5) and value (14 cm) was measured at 6^{th} cross (BAH8-A × 2644-R) for head diameter. This result showed that one of parents having high GCA would be enough to get high SCA too.

CONCLUSION

Based on the combining ability analysis for 6 traits, BAH-8-A female and R-1001 restorer lines for flowering time, BAH8-A female and 2644-R male for physiological maturity time, 2280-R and HA-89-A for hectoliter weight, 0704-A and 2644-R for 1000 seed weight, 2284-R and BAH8-A for plant height, 2644-R male and BAH4-A and HA89-A females for head diameter were selected as best combiners for testing combining ability of lines in the experiment. 2644-R was determined the first tester for male lines due to the being at the higher level in majority of desired traits in this research. Although BAH8-A line usually showed earliness, HA89-A line attracted for higher seed quality. Therefore, HA89-A was nominated as the first tester due to exist at higher level in more important traits in sunflower. Additionally, BAH8-A for *cms* lines and 2280-R for restorers were selected as second testers when needed. The 15^{th} cross (2453-A × R-1001) was selected as the best hybrid for showing generally higher performance in many desired traits examined in the experiment.

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ANÁLISIS DE APTITUD COMBINATORIA DE ALGUNAS CARACTERÍSTICAS DE RENDIMIENTO DE GIRASOL (*Helianthus annuus* L.)

RESUMEN

Los ensayos con 25 híbridos de girasol, se realizaron en tres ubicaciones, en los anos 2000 y 2001. Esos híbridos fueron evaluados a la aptitud de combinación para 6 componentes de rendimiento importantes. Sobre la base de las observaciones realizadas, fue determinado que la duración de floración promedia era desde 69,6 hasta 71,8 días, la madurez fisiológica desde 98,7 hasta 104,2 días, el peso hectolítrico desde 355,2 hasta 408,5 g, el peso de 1000 granos desde 32,5 hasta 43,5 g, la altura de la planta desde 98,3 hasta 134,3 cm y el diámetro del capítulo desde 12,6 hasta 14,0 cm.

Sobre la base del análisis de aptitud de combinación realizado, el cruzamiento 2453-A × R-1001 fue evaluado como el mejor híbrido en el ensayo. Entre las líneas parentales, HA89-A y 2644-R fueron elegidos como los primeros testers femeninos y masculinos, mientras que BAH8-A y 2280-R como segundos testers para la prueba de la aptitud de combinación en los futuros programas de selección de girasol.

ANALYSE DES APTITUDES COMBINATOIRES DE QUELQUES CARACTÉRISTIQUES DE RENDEMENT DU TOURNESOL (*Helianthus annuus* L.)

RÉSUMÉ

Des expériences comprenant 25 hybrides de tournesol ont été effectuées dans trois localités en 2000 et 2001. L'aptitude combinatoire de ces hybrides a été évaluée pour six composants de rendement importants. Les observations effectuées ont établi que la durée moyenne de la floraison était de 69,6 à 71,8 jours, la maturité physiologique de 98,7 à 104,2 jours, le poids d'hectolitre de 355,2 à 408,5 g, le poids de 1000 graines de 32,5 à 43,5 g, la hauteur de la plante de 98,3 à 134,3 cm et le diamètre de la tête de 12,6 à 14,0 cm.

L'analyse des aptitudes combinatoires a évalué le croisement 2453-A x R-1001 comme étant le meilleur hybride de l'expérience. Parmi les lignes parentales, HA89-A et 2644-R ont été choisis comme premiers testeurs mâle et femelle et BAH8-A et 2280-R comme deuxièmes testeurs pour l'analyse des aptitudes combinatoires dans les futurs programmes de sélection du tournesol.