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Combining Ability and Heterosis for Yield and Yield Components in Sunflower

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Abstract

Field experiments were carried out during 2005-2007 in order to study the genetic structure of a hybrid sunflower population, to identify the parents and crosses showing superior general and specific combining ability and finally to evaluate F_1 hybrid vigour. Six artificial hybrids were created using 3 CMS and 2 restorer lines in sunflower (*Helianthus annus* L.) According to the results, the ratios of GCA:SCA variance were lower than 1 for plant height and head diameter in the both years; for number of seeds per head and 1000 seed weight in 2007 and for seed yield in 2006. For all these characters, non-additive effects were more effective than the other types of polygenetic effects. The additive gene actions were significant for 1000 seed weight and number of seeds per head in 2006 and for plant height and seed yield in 2007, since the ratios of GCA:SCA variances for these characters were greater than 1. The parental lines CMS 10 and RHA 10 proved to be good combiners having the highest positive GCA effect in yield and certain yield components. The crosses CMS 10 x RHA 03, CMS 01 x RHA 10, CMS 10 x RHA 10 and CMS 23 x RHA 10 might be considered as promising hybrid combinations in terms of seed yield . The values of heterosis and heterobeltiosis values ranged from 109.8 to 218.3% for seed yield. All of the tested hybrids showed positive and significant heterobeltiosis for seed yield.

Keywords: GCA, *Heliantus annuus* L., heterobeltiosis, line x tester, SCA

Introduction

The importance of hybrid cultivars in sunflower has increased recently because of their higher seed yield compared with cross-pollinated varieties in many countries in the world. Hybrids of sunflower are more stable, highly self-fertile, with high yield performance, and more uniform at maturity (Seetharam, 1979; Kaya and Atakisi, 2004). Resistance to diseases and Orobanche has also increased the importance of hybrid varieties. The heterotic performance of a hybrid combination depends upon the combining abilities of its parents (Allard, 1960; Kadkol *et al.,* 1984). Kaya and Atakisi (2004) reported that superior hybrids have been obtained by crossing inbred CMS female and restorer lines with high GCA (General Combining Ability) and SCA (Specific Combining Ability) values. Recently, line x tester analysis has widely been used for combining ability tests, suggested by Singh and Chaudhary (1977). Kempthorne (1957) reported that line x tester analysis is an extension of top cross method in which several testers are used. Virupakshappa *et al.* (1997) stated that two testers were enough to efficiently test GCA of inbred lines. In addition, the use of two testers due to additional costs of using several testers was suggested by Skoric (1992) and Fick and Miller (1997).

High heterosis for yield and its components in sunflower, being cross-pollinated crops has been reported by many previous researchers (Chaudhary and Anand, 1984; Goksoy *et al.,* 2000; Khan *et al.,* 2004; Kaya, 2005). However, heterosis does not appear in all hybrid combinations of the F_1 generation (Hladni *et al.,* 2007). Therefore to achieve the success in hybrid breeding is quite difficult and it takes some time. Hladni *et al.* (2007) reported that the occurrence of heterosis in sunflower hybrids is highly correlated with genetic distance between the parental lines.

The aim of this study was to estimate the amount of heterosis in six hybrids obtained from three CMS and two restorer lines and to select parental lines having good combining abilities and superior high level of heterosis.

Material and methods

Three cytoplasmic male sterile lines, CMS 01, CMS 10 and CMS 23 and two fertility restorer lines, RHA 03 and RHA 10 improved by Uludag University, Faculty of Agriculture, were crossed in all possible combination in 2005 and 2006. All the resultant six experimental hybrids with five parents were planted in randomized complete block desing with four replications under Mustafakemalpasa province, Bursa (Turkey) conditions (40°11'N latitude; 29°04'E longitude; altitude 155 m) in 2006 and 2007. Mustafakemalpasa is located in the southern Marmara Region of Turkey, with average 700 mm annual rainfall and 14.4°C mean monthly temperature. The total rainfall during the growing period of sunflower (March to September) made up of 37% of the annual precipitation. The soil was clayey, and low in fertility. Soil analysis indicated that the phosphorus and potassium levels were medium or high and the organic matter was low (1%). The nitrogen levels in the soils were also low for sunflower. Twenty plants were selected randomly from each of the experimental hybrids and parents in each plot for observations. Data were recorded on plant height (cm), head diameter (cm), number of seeds per head, 1000-seed weight(g), seed yield (kg ha^{-1}), oil content (%) protein content(%) and oil yield (kg ha^{-1}).

Analysis of variance for combining ability was done according to the line x tester method, in which estimates of GCA variances (σ^2_{GCA}) and SCA variances (σ^2_{SCA}) were obtained as suggested by Singh and Chaudhary (1977). Heterosis was calculated as a percentage increase or decrease in the F_1 mean over its better parent and mid-parents. Means and heterotic effects were tested by the least significant differences (LSD) test at the 0.05 and 0.01 levels. The significance of GCA and SCA effects was determined at the 0.05 and 0.01 levels using the t-test.

Results and discussion

Significant F values calculated in the analysis of variance showed that the lines had significant effects for number of seeds per head and 1000 seed weight in 2006 and for plant height in 2007 while the effects of the testers were significant for plant height and seed yield in 2007. Line x tester interactions was highly significant for seed yield in 2006 and for head diameter and 1000 seed weight in 2007 (Tab. 1).

Analysis of variance for combining abilities in each experimental years (2006 and 2007) revealed that the GCA variances were significant at 5% level of probability for number of seeds per head and 1000 seed weight in 2006 and for plant height and seed yield in 2007. On the other hand, the SCA variances were significant for seed yield in 2006 and for head diameter and 1000 seed weight in 2007. Significant SCA variances proved that the variation among hybrid combinations was considerably higher. The ratios of GCA:SCA variance were lower than 1 for plant height and head diameter in the both years; for number of seeds per head and 1000 seed weight in 2007 and for seed yield in 2006 (Tab. 2).

Thus non additive gene actions were more effective for all these characters. As the variances due to SCA were highly significant for seed yield in 2006 and for head diameter in 2007, these characters were influenced by dominant gene actions. On the other hand, neither GCA nor SCA variances were significant for plant height and head diameter in 2006 and for number of seeds per head in 2007. For these characters, most of the total genetic variation was caused by epistatic gene actions, since the SCA variances were higher than the GCA variances. The additive gene actions were significant (P≤0.05) for 1000 seed weight and number of seeds per head in 2006 and for plant height and seed yield in 2007, since the ratios of GCA:SCA variances for these characters were greater than 1. These results revealed that significance of genetic variance components and consequently gene actions varied according to experimental years. Similar results were also obtained in other statudies (Pathak *et al.,* 1985; Goksoy *et al.,* 2000; Goksoy and Turan, 2004; Jan *et al.,* 2005).

Comparative analysis of the GCA effects of the parents is given in Tab. 3a and 3b and Tab. 4a and 4b. In general, significance of the GCA effects was no stable for the parents according to the years. Although the GCA effects of the parents were not significant in terms of plant height and seed yield in 2006; the number of seeds per head and 1000 seed weight in 2007 and head diameter in the both

Tab. 1. Analysis of variance for combining ability (mean squares)

Source	df	Plant height		Head diameter		Seeds per head		1000 seed weight		Seed yield	
		2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
Lines	2	23.8^{ns}	131.6^{ns}	1.94^{ns}	0.31^{ns}	72833.8*	10986.5^{ns}	197.2*	25.5^{ns}	844.3^{ns}	264.8^{ns}
Tester	1	1.1^{ns}	149.5^{ns}	9.12^{ns}	6.72^{ns}	10668.2^{ns}	6000.0^{ns}	152.2^{ns}	11.3^{ns}	902.8^{ns}	5766.0*
Line x tester	2	48.0^{ns}	10.7^{ns}	1.46^{ns}	4.02*	15569.3^{ns}	17658.4^{ns}	26.9^{ns}	48.2*	1655.3*	465.9^{ns}
Error	30	100.4	194.3	2.22	1.18	12201.1	15898.2	35.0	14.1	508.5	363.9

df: degrees of freedom; ns: non significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level

Tab. 2. Estimate of variance components

Source	Plant height		Head diameter		Seeds per head		1000 seed weight		Seed yield	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
Lines	-3.031	15.1	0.060	-0.338	6633.8	-833.9	18.8	-2.71	-88.9	-25.1
Testers	-3.917	11.5	0.639	0.308	-408.4	-1471.0	10.5	-2.91	-54.4	441.7
GCA	-1.137	4.5*	0.103	-0.020	1205.1*	-369.0	5.1*	-0.93	-24.7	58.3*
SCA	-13.093	-45.9	-0.190	0.461*	842.0	440.0	-2.0	8.01*	261.7*	25.5
GCA:SCA	0.087	0.1	0.542	0.043	1.4	0.8	2.5	0.12	0.1	2.3

df: degrees of freedom; ns: non significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level; GCA: General combining ability; SCA: Special combining ability years, these effects were significant for the number of seeds per head and 1000 seed weight in 2006 and for plant height and seed yield in 2007.

Significant and negative GCA effects were recorded for CMS 10 and RHA 10 in terms of plant height, while male parent RHA 03 had positive and significant GCA effects for the same character in 2007. Female parent CMS 01 had positive significant GCA effect for the number of seeds per head while CMS 23 showed significant and negative GCA effect in 2006. For 1000 seed weight, only female parent CMS 10 gave highly significant negative GCA effect (-5.404**) in 2006. Significant GCA effects for seed yield were obtained from male parents in 2007. RHA 10 had high positive GCA effect (15.500*) whereas RHA 03 showed negative significant GCA effect (-15.500*). In previous studies, highly negative GCA effects for plant height were found by Mihaljcevic (1988) and Mruthunjaya *et al.* (1995). Our findings were similar to results of researchers given above. Earlier studies revealed that lower GCA effects for head diameter were obtained (Kadkol *et al.,* 1984; Kaya *et al.,* 2004). In addition, Goksoy *et al.* (2000) found that some parent lines had positively or negatively significant GCA effects for 1000 seed weight and seed yield. Our findings were similar to results of researchers given above.

Data on the means and SCA effects of six experimental hybrids for all the traits observed are illustrated in Tab. 5 and Tab. 6. The SCA effects of experimental hybrids for plant height and number of seeds per head were not significant in the both experimental years. However, the

Tab. 3a. Estimates of general combining ability (GCA) effects and mean values (M) of lines and testers for plant height, head diameter and seeds per head characters

Parents	Plant height (cm)				Head diameter (cm)				Seeds per head			
	2006		2007		2006		2007		2006		2007	
	M	GCA	M	GCA	M	GCA	M	GCA	M	GCA	M	GCA
						Lines						
CMS 01	198.3 a^{x}	1.958^{ns}	201.4 a	2.917^{ns}	20.3 ab	0.400^{ns}	14.4 ab	-0.075^{ns}	1211.5 a-c	72.542*	987.0 a	40.583^{ns}
CMS 10	187.0 ab	-0.667^{ns}	177.4 b	-4.633^{ns}	19.7 ab	0.150^{ns}	15.5 a	-0.150^{ns}	1044.8 d	31.792^{ns}	1063.3 a	-32.042^{ns}
CMS 23	183.0 b	-1.292^{ns}	173.9 b	1.717^{ns}	18.7 b	-0.550^{ns}	15.3 a	0.225^{ns}	1087.8 cd	-104.333**	1116.5 a	-8.542^{ns}
ML[1]	189.4		184.2		19.5		15.1		1114.7		1055.6	
						Testers						
RHA 03	150.0 c	-0.208^{ns}	126.1 c	2.496^{ns}	9.2 c	-0.617^{ns}	8.1 c	-0.529^{ns}	225.8 e	-21.083^{ns}	580.3 b	-0.500^{ns}
RHA 10	144.0 c	0.208^{ns}	137.0 c	-2.496^{ns}	6.6 d	0.617^{ns}	7.9 c	0.529^{ns}	113.8 e	21.083^{ns}	390.0 c	0.500^{ns}
MT[2]	147.0		131.6		7.9		8.0		169.8		485.2	
						Standard errors						
Lines	3.543		4.929		0.527		0.384		39.053		44.579	
Testers	2.893		4.024		0.430		0.313		31.887		36.398	

ns: non significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level; x: Means in the same column followed by the same letter were not significantly different at the 0.05 level in the Least Significant Difference (LSD) test; 1) Means of lines; 2) Means of testers

Tab. 3b. Estimates of general combining ability (GCA) effects and mean values (M) of lines and testers for 1000 seed weight and seed yield characters

Parents	1000 seed weight (g)				Seed yield (kg ha^{-1})			
	2006		2007		2006		2007	
	M	GCA	M	GCA	M	GCA	M	GCA
				Lines				
CMS 01	41.5 c	2.208^{ns}	34.3 c	-1.079^{ns}	1733 c	25.92^{ns}	1467 d	-15.83^{ns}
CMS 10	35.3 c	-5.404**	33.8 c	2.021^{ns}	1620 c	87.29^{ns}	1427 d	-47.96^{ns}
CMS 23	41.5 c	3.196^{ns}	34.5 c	-0.942^{ns}	1468 c	113.21^{ns}	1321 d	63.79^{ns}
ML[1]	39.4		34.2		1607		1405	
				Testers				
RHA 03	15.4 d	-2.521^{ns}	15.9 d	-0.688^{ns}	158 d	61.33^{ns}	365 e	-155.00*
RHA 10	11.2 d	2.521^{ns}	17.6 d	0.688^{ns}	170 d	-61.33^{ns}	288 e	155.00*
MT[2]	13.3		16.8		164		327	
				Standard errors				
Lines	2.093		1.330		79.73		67.45	
Testers	1.709		1.086		65.10		55.07	

ns: non significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level; x: Means in the same column followed by the same letter were not significantly different at the 0.05 level in the Least Significant Difference (LSD) test; 1) Means of lines; 2) Means of testers

Tab. 4a. Estimates of special combining ability (SCA) effects and mean values (M) of the hybrids for plant height, head diameter and seeds per head characters

Crosses	Plant height (cm)				Head diameter (cm)				Seeds per head			
	2006		2007		2006		2007		2006		2007	
	M	SCA	M	SCA	M	SCA	M	SCA	M	SCA	M	SCA
CMS 01 x RHA 03	195.0 ab	-0.292^{ns}	188.2 ab	-1.083^{ns}	19.3 ab	-0.208^{ns}	14.4 ab	0.392^{ns}	1317.5 ab	5.958^{ns}	1016.0 a	-40.250^{ns}
CMS 10 x RHA 03	195.3 ab	2.583^{ns}	181.6 ab	-0.133^{ns}	19.0 ab	-0.283^{ns}	13.3 b	-0.708*	1224.0 a-c	-46.792^{ns}	1035.3 a	51.625^{ns}
CMS 23 x RHA 03	189.8 ab	-2.292^{ns}	189.3 ab	1.217^{ns}	19.1 ab	0.492^{ns}	14.7 ab	0.317^{ns}	1175.5 b-d	40.833^{ns}	995.8 a	-11.375^{ns}
CMS 01 x RHA 10	196.0 a	0.292^{ns}	185.4 ab	1.083^{ns}	21.0 a	0.208^{ns}	14.7 ab	-0.392^{ns}	1347.8 a	-5.958^{ns}	1097.5 a	40.250^{ns}
CMS 10 x RHA 10	190.5 ab	-2.583^{ns}	176.9 b	0.133^{ns}	20.8 ab	0.283^{ns}	15.7 a	0.708*	1359.8 a	46.792^{ns}	933.0 a	-51.625^{ns}
CMS 23 x RHA10	194.8 ab	2.292^{ns}	181.9 ab	-1.217^{ns}	19.3 ab	-0.492^{ns}	15.1 a	-0317^{ns}	1136.0 cd	40.833^{ns}	1019.5 a	11.375^{ns}
Mean of crosses	193.5		183.9		19.7		14.6		1260.1		1016.2	
Standard error	5.010		6.970		0.745		0.543		55.229		63.044	

ns: non significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level; ^{x}: Means in the same column followed by the same letter were not significantly different at the 0.05 level in the Least Significant Difference (LSD) test

Tab. 4b. Estimates of special combining ability (SCA) effects and mean values (M) of the hybrids for 1000 seed weight and seed yield characters

Crosses	1000 seed weight (g)				Seed yield (kg ha^{-1})			
	2006		2007		2006		2007	
	M	SCA	M	SCA	M	SCA	M	SCA
CMS 01 x RHA 03	64.5 b	1.783^{ns}	50.5 ab	2.588*	2502 ab	-125.6*	2054 bc	872.5^{ns}
CMS 10 x RHA 03	61.0 b	0.096^{ns}	48.9 ab	-2.162^{ns}	2839 a	150.0*	1880 c	-543.8^{ns}
CMS 23 x RHA 03	67.2 b	-1.879^{ns}	47.7 b	-0.425^{ns}	2464 b	-24.4^{ns}	2014 bc	-328.7^{ns}
CMS 01 x RHA 10	66.7 b	-1.783^{ns}	46.7 b	-2.588*	2630 ab	125.6*	2190 ab	-872.5^{ns}
CMS 10 x RHA 10	63.5 b	-0.096^{ns}	54.6 a	2.162^{ns}	2416 b	-150.0*	2299 ab	543.8^{ns}
CMS 23 x RHA10	76.5 a	1.879^{ns}	49.9 ab	0.425^{ns}	2390 b	24.4^{ns}	2389 a	328.7^{ns}
Mean of crosses	66.5		49.7		2540		2137	
Standard error	2.960		1.281		112.760		124.090	

ns: non significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level; ^{x}: Means in the same column followed by the same letter were not significantly different at the 0.05 level in the Least Significant Difference (LSD) test.

hybrid CMS 10 x RHA 10 showed positively significant SCA effect (0.708*) while the hybrid CMS 10 x RHA 03 had negatively significant (-0.708*) SCA effect in 2007.

The average 1000 seed weight ranged between 61.0 g and 76.5 g in 2006 and 46.7 g to 54.6 g in 2007 for experimental hybrids. The SCA effects of the experimental hybrids were not significant for 1000 seed weight in 2006. The significant and positive SCA effect was obtained in the hybrid CMS 01 x RHA 03 while the hybrid CMS 01 x RHA 10 showed the significant and negative SCA effect (-2.588*) in 2007.

The average seed yields of the experimental hybrids ranged from 1880 kg ha^{-1} in 2007 to 2839 kg ha^{-1} in 2006. The SCA effects were positively significant for the hybrids CMS 10 x RHA 03 and CMS 01 x RHA 10 and negatively for the hybrids CMS 01 x RHA 03 (-125.6*) and CMS 10 x RHA 10 (-150.04*). In previous studies, positive and significant SCA effects for some yield components and seed yield were obtained by Pathak *et al.* (1985), Goksoy *et al.* (2000), Goksoy and Turan (2004).

Significant heterosis and heterobeltiosis values were observed for all experimental hybrids in terms of 1000 seed weight and seed yield. In general, heterosis values were significant in all experimental hybrids for plant height, head diameter and number of seeds per head, whereas heterobeltiosis values were not significant for the some characters (Tab. 5 and Tab. 6). The range of variation of significant heterosis among experimental hybrids varied from 12.1 to 26.2% for plant height, 25.6 to 58.3% for head diameter, 25.9 to 134.7% for number of seeds per head, 79.9 to 173.1% for 1000 seed weight and 109.8 to 218.3% for seed yield in the both experimental years. All the hybrids had heterosis values of over 100% for 1000 seed weight and seed yield.

All of the experimental hybrids showed positive and significant heterobeltiosis for 1000 seed weight and seed yield (Tab. 6). The hybrids CMS 23 x RHA 03, CMS 01 x RHA 10, CMS 10 x RHA 10, and CMS 23 x RHA 10 showed more than 50% heterosis over the better parent in the hybrid combination for seed yield. Similarly, heterosis values over the better parent for 1000 seed weight ranged between 36.1 and 84.3% in the both experimental years. Singh *et al.* (1984) reported high heterosis for seed yield, ranging from 47 to 206%, with values of 5 to 55% for other yield components. Similar results have been reported earlier by Giriraj *et al.* (1986), Goksoy *et al.* (2000), Khan *et al.* (2004) and Kaya (2005).

Tab. 5. Heterosis (H_t) and Heterobeltiosis (H_b) values of the hybrids for plant height, head diameter and seeds per head characters

Crosses	Plant height (cm)				Head diameter (cm)				Seeds per head			
	2006		2007		2006		2007		2006		2007	
	H_t	H_b	H_t	H_b	H_t	H_b	H_t	H_b	H_t	H_b	H_t	H_b
CMS 01 x RHA 03	12.13**	-1.66^{ns}	14.93**	-6.55^{ns}	30.85**	-4.93^{ns}	28.00**	0.00^{ns}	83.34**	8.75^{ns}	29.65*	2.94^{ns}
CMS 10 x RHA 03	15.90**	4.44^{ns}	19.67**	2.37^{ns}	31.49**	-3.55^{ns}	12.72^{ns}	-14.19*	92.66**	17.15*	25.94*	-2.82^{ns}
CMS 23 x RHA 03	14.75**	4.69^{ns}	26.20**	8.86^{ns}	36.92**	2.14^{ns}	25.64**	-3.92^{ns}	78.90**	8.06^{ns}	17.41^{ns}	10.84^{ns}
CMS 01 x RHA 10	14.42**	-1.16^{ns}	9.57^{ns}	-7.94^{ns}	56.13**	3.45^{ns}	30.67**	2.08^{ns}	103.40**	11.25^{ns}	59.33**	11.19^{ns}
CMS 10 x RHA 10	15.00**	1.87^{ns}	12.50^{ns}	-0.28^{ns}	58.33**	5.58^{ns}	34.19**	1.29^{ns}	134.73**	30.15**	28.39*	-12.25^{ns}
CMS 23 x RHA10	19.66**	7.45*	17.02*	4.60^{ns}	52.57**	3.21^{ns}	30.17**	-1.31^{ns}	89.08**	4.43^{ns}	35.35**	-8.69^{ns}
Average	15.31		16.65		44.38		26.90		97.02		32.68	

ns: non significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level;

Tab. 6. Heterosis (H_t) and Heterobeltiosis (H_b) values of the hybrids for1000 seed weight and seed yield characters

Crosses	1000 seed weight (g)				Seed yield (kg ha^{-1})			
	2006		2007		2006		2007	
	H_t	H_b	H_t	H_b	H_t	H_b	H_t	H_b
CMS 01 x RHA 03	124.96**	55.42**	101.19**	47.23**	164.41**	44.37**	124.17**	40.30**
CMS 10 x RHA 03	140.63**	72.80**	96.78**	44.67**	218.33**	75.20**	109.80**	31.75**
CMS 23 x RHA 03	136.55**	61.93**	89.29**	38.26**	203.08**	67.85**	138.91**	52.46**
CMS 01 x RHA 10	153.13**	60.72**	79.96**	36.15**	176.41**	51.76**	139.48**	49.59**
CMS 10 x RHA 10	173.12**	79.89**	112.45**	61.54**	169.94**	49.14**	168.10**	61.11**
CMS 23 x RHA10	190.32**	84.34**	88.10**	44.64**	191.82**	62.80**	196.95**	80.85**
Average	153.12		94.63		187.33		146.23	

ns: non significant; *: significant at p=0.05 probability level; **: significant at p=0.01 probability level;

Conclusions

Considering to combining ability analysis, when the GCA:SCA variance ratio is greater than 1 it means that additive genes have higher effect than non-additive genes on inheritance of character observed whereas, when the GCA:SCA variance ratio is lower than it 1 indicates that non-additive effects (dominant or epistatic) are more effective in the inheritance of studied characters.

As a result, although the significance of the GCA effects was not stable for the parents in the two experimental years, parents CMS 10 and RHA 10 were good combiners with the highest positive GCA effect involved in the best-yielding crosses. In addition, the crosses CMS 10 x RHA 03, CMS 01 x RHA 10, CMS 10 x RHA 10 and CMS 23 x RHA 10 might be considered as promising hybrid combinations for higher seed yield based on their yield, heterosis and heterobeltiosis values and SCA effects.

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