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GENERAL AND SPECIFIC COMBINING ABILITY IN SUNFLOWER *(Helianthus annuus* L.)

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SUMMARY

A total of 245 test cross progenies obtained by crossing cytoplasmic male sterile (CMS) lines and restorer (RHA) lines were evaluated in replicated trials in 1995 and 1997. Experiments were carried out in two locations (Osimo, East Central Italy and Budrio, Northern Italy) in 1995, whereas in 1997 trials were conducted only in Osimo. General combining ability (GCA) and specific combining ability (SCA) of the parents was evaluated to identify genotypes suitable to be used as testers for breeding programs and to verify the performance of hybrids. The results obtained in 1995 were used to make test crosses in 1996 to be evaluated in 1997. The GCA and SCA of RHA and CMS lines were nearly always significant for all the studied traits when lines were randomly taken in 1995. When selected testers were used on the basis of the results of the first year, the SCA of new RHA lines and GCA of new CMS lines were not significant for achene yield, but they were for the other traits.

The best GCA estimates for RHA were often higher than those of CMS, indicating that selection for RHA could be more useful than for CMS. As expected, GCA was always lower than SCA. CMS and RHA, with high variance among their test crosses for yield and many other traits, could be used as testers. The lack of a tester with high variance in all traits requires more than one tester in evaluating lines. The GCA of a line can change in function of the germplasm with which it is combined.

Key words: **GCA and SCA effects, line x tester analysis, variance among test crosses**

INTRODUCTION

Sunflower is cultivated at 250,000 ha in Italy, and it is second to olive oil as major oilseed crop. Since *per se* performance of lines is not a good indicator of their combing ability (Ortegon-Morales *et al.*, 1992), the present study was undertaken to estimate the combining ability of cytoplasmic male sterile (CMS) and restorer (RHA) lines using the line x tester analysis. The use of a narrow genetic

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Table 1: Analysis of variance for six characters in sunflower (Osimo and Budrio, 1995)

Source of variation	df	Yield ($q\ ha^{-1}$)	Oil content (%)	Oil yield ($q\ ha^{-1}$)	Thousand seed weight (g)	Plant height (cm)	Days to 50% flowering
Replication	5	2468	358	630	2507	2928	573
Crosses	76	110**	32**	22**	116**	1287**	47**
CMS (L)	6	130**	191**	51**	416**	2340**	207**
RHA (T)	10	523**	93**	95**	344**	6351**	167**
L x T	60	39**	6*	8**	48**	337**	10**
Error	380	21	4	5	30	124	3
GCA		0.29	0.18	0.08	0.42	4.30	0.92
SCA		3.00	0.33	0.67	3.00	35.50	1.17
SCA/GCA		10.31	1.84	8.15	7.20	8.26	1.27

In this and other tables *, ** significant at $P \leq 0.05$ or 0.01

Table 2: General combining ability effects for CMS and RHA for six characters in sunflower (Osimo and Budrio, 1995)

Parent	Yield ($q\ ha^{-1}$)	Oil content (%)	Oil yield ($q\ ha^{-1}$)	Thousand seed weight (g)	Plant height (cm)	Days to 50% flowering
CMS						
265	0.01	-0.99**	-0.22	-1.51*	-6.61**	0.15
287	-1.32*	-1.73**	-1.06**	2.75**	-2.90*	-1.39**
226	-1.56**	0.54*	-0.42	-3.39**	7.63**	3.11**
234	0.88	1.82**	0.83**	3.65**	1.60	-0.89**
284	0.07	2.00**	0.55*	0.30	-8.02**	-2.33**
299	2.54**	0.66**	1.22**	-0.07	3.35*	0.86**
243	-0.63	-2.30**	-0.90**	-1.75**	4.94**	0.50*
RHA						
Pisa	2.89**	-2.14**	0.53*	1.28	-11.96**	-2.98**
Torretta	2.77**	-0.69*	0.91**	4.17**	-1.46	0.21
335/6-9	-6.67**	0.16	-2.69**	-1.33	-10.42**	-1.53**
335/2-3	2.15**	2.41**	1.64**	-1.41	19.89**	3.54**
1234/3	-5.00**	0.59*	-1.89**	-3.45**	-22.03**	-0.41
335/2-8	-0.11	0.70**	0.21	-1.06	5.94**	0.09
274	1.83**	-2.41**	0.02	-0.65	-7.15**	-3.15**
335/2R10	3.79**	1.84**	2.12**	3.28**	14.37**	0.73**
336/3-3	-3.77**	0.68*	-1.36**	-4.87**	-0.13	2.02**
365/1-10	0.87	-0.93**	0.07	0.77	6.89**	1.09**
339/3-2	1.24	-0.20	0.45	3.27**	6.06**	0.40

based line to test the GCA of lines instead of a large-based population allows the breeder to work with genotypes usable for commercial hybrids. A line useful as tester should have good GCA and allow a large variability in the test crosses. To identify a similar tester, test cross data were also analyzed for variability among CMS within RHA and among RHA within CMS.

MATERIALS AND METHODS

Seven CMS lines were crossed with 11 restorers in a line x tester combination set in 1994. Test cross progenies were evaluated in two locations (Osimo, East Central Italy, and Budrio, North Italy) in 1995 in a randomized block design in three replicates. Based on the results of general combining ability and variance among test crosses, 3 CMS and 3 RHA were selected. The selected testers were used in 1996 to synthesize 171 test crosses with 21 new CMS lines and 36 new F_5 RHA lines selected for *Plasmopara halstedii* resistance. The resulting hybrids were evaluated in two trials with three replicates in Osimo during 1997. Standard cropping practices were followed for raising a good crop.

Plots consisted of two rows with 13 plants per row in 1995 and 15 plants per row in 1997. Observations were recorded on 5 randomly selected plants from each entry in each replicate; yield was determined on the whole plot excluding the plants at the ends of the rows.

Seed oil content was determined in all replications in 1995 and only on bulked samples in 1997.

The mean values of the observations were subjected to the line x tester analysis (Kempthorne, 1957; Singh and Chaudhary, 1977) to estimate combining ability effects. To check the suitability of lines as tester, mean squares among test crosses within a CMS or within RHA were calculated (Matzinger, 1953; Hallauer and Miranda, 1981).

RESULTS AND DISCUSSION

1995

The variance due to lines and testers was always significant (Table 1) for all traits: yield, oil content, oil yield, thousand seed weight (TSW), plant height and days to 50% flowering. Also, the variances of interaction were significant for all traits. The ratio of SCA:GCA variances showed that SCA variances were greater than GCA variances, indicating the predominance of the non-additive effects for yield and most of the yield components in accordance with Škorić *et al.* (2000).

From the estimates of general combining ability effects for all lines (Table 2), it is evident that no single RHA or CMS line was a good general combiner for all characters studied. Among the CMS lines, 299 showed the best values for yield (2.54), positive and significant estimates for oil content (0.66) and oil yield (1.22), whereas the values for plant height and day to flowering were significant but very small compared with the absolute values of the traits. Line 234 showed the highest estimate for yield, but not significant. It had good estimates for oil content, oil yield and day to flowering. Line 226 had the lowest GCA for yield and consequently for oil yield. It also had the highest plant height and days to flowering GCA, which in this case has been regarded as negative, since shorter and earlier genotypes are preferred.

All three CMS lines had a significant mean square among test crosses with RHA being good testers (Table 3).

In the RHA lines studied, estimates of GCA were larger compared with CMS lines (Table 2). Line 335/2R10 showed high positive estimates for yield, oil content and oil yield but also had high values for plant height and days to flowering, which was regarded as negative. Moreover it did not have a significant mean square among the test crosses with all CMS for yield (Table 3). This shows its suitability for making late productive hybrids, but not for use as tester. Pisa had significant estimates for yield, oil yield, plant height and days to flowering, and was the best combiner and a good tester (Table 3). 365/1-10 and 339/3-2 were intermediate in estimates of GCA for the majority of the traits recorded, but had high and significant variances among test crosses with CMS and were chosen to be used as testers. Except for Pisa, Torretta and 274, which together with positive estimates for yield, also had favorable estimates for plant height and days to flowering. The other RHA lines had good values for plant height and days to flowering, but poor estimates for yield and yield components.

Although the female line, CMS 299 and RHA 335/2R10 had the best GCA for yield; crossing them produced a very low SCA effect for this trait (Table 4). Also, the cross 299 x Pisa did not have significant SCA, but showed the best hybrid combination.

Interestingly, the highest SCA did not always produce the best hybrid combination and this (the better hybrid combination) is often obtained combining a line with high GCA with another intermediate line, sometimes also between lines with intermediate GCA. The best hybrid combinations, however, were obtained between lines with significant GCA, whereas the best heterosis (better SCA) was shown by the crosses between the CMS line with the highest GCA and the RHA line with the poorest GCA (299 x 1234/3), or intermediate CMS line and intermediate RHA line (265 x 335/2-8, 265 x 339/3-2).

1997

In testing new RHA lines (Table 5), the variances of testers (CMS) and RHA were always significant. The contribution of RHA to total variance of test crosses was nearly 40% for yield and oil yield, 57% for plant height, 70% for days to flowering and 26% for TSW. Also the variance due to the interaction between lines and testers was found to be significant for all characters except yield of achenes, suggesting the

Table 3: Mean squares of test-crosses for each parent for six characters in sunflower (Osimo and Budrio, 1995)

Parent	Yield ($q\ ha^{-1}$)	Oil content (%)	Oil yield ($q\ ha^{-1}$)	Thousand seed weight (g)	Plant height (cm)	Days to 50% flowering
CMS						
265	137.3**	24.6**	27.5**	102**	974**	21.7**
287	77.7**	14.7**	11.8**	45	1265**	31.0**
226	105.3**	21.5**	21.3**	111**	1126**	41.3**
234	152.1**	11.7**	28.2**	73**	976**	22.9**
284	44.8*	18.8**	9.0*	56	1268**	35.8**
299	136.0**	14.4**	20.4**	106**	1221**	38.6**
243	103.6**	25.8**	17.7**	140**	1543**	39.9**
RHA						
Pisa	77.0**	38.5**	21.7**	77*	467**	9.0*
Torretta	9.9	15.6**	3.4	42	283*	14.3**
335/6-9	38.6	18.4**	6.0	104**	163	18.8**
335/2-3	34.3	14.3**	9.1	41	473**	21.6**
1234/3	102.2**	22.0**	23.0**	116**	1012**	39.2**
335/2-8	42.9	16.9**	9.5*	128**	651**	38.9**
274	39.5	28.1**	12.1*	61	450**	30.3**
335/2R10	20.1	27.7**	5.7	69*	272*	16.5**
336/3-3	34.6	44.1**	14.8**	137**	261	16.1**
365/1-10	53.9*	22.4**	13.6**	51	613**	41.9**
339/3-2	66.6**	5.9	10.2*	73*	1065**	66.8**

Table 4: Values of traits of the most productive test crosses in the 1995 trials together with the specific combining ability

Crosses	Yield ($q\ ha^{-1}$)		Oil content (%)		Oil yield ($q\ ha^{-1}$)		Thousand seed weight (g)		Plant height (cm)		Days to 50% flowering	
265 x Torretta	34.2	1.11	44.7	1.90*	13.9	0.99	53.8	1.39	184	1.75	184	1.11
265 x 335/2-3	33.7	1.30	45.5	-0.40	14.1	0.43	46.1	-0.78	195	9.11*	186	-0.22
265 x 335/2-8	35.4	5.27**	45.4	1.23	14.6	2.43**	55.3	8.05**	205	15.35**	182	-0.60
265 x 335/2r10	34.2	0.17	45.0	-0.28	14.1	-0.05	51.8	0.18	192	-6.08	184	0.42
265 x 339/3-2	35.3	3.79*	42.4	-0.85	13.6	1.14	50.6	-0.95	192	2.23	183	-0.75
287 x 335/2r10	36.4	3.64	43.1	-1.51	14.1	0.86	57.5	1.69	208	5.54	182	-0.03
226 x Pisa	33.5	1.88	43.4	0.55	13.1	0.80	46.8	-0.91	191	4.68	182	-1.32
226 x 335/2r10	33.3	0.84	47.8	0.94	14.9	0.94	51.0	1.25	210	-2.32	186	-0.53
234 x Pisa	37.3	3.26	45.5	1.34	15.4	1.78*	56.8	2.08	178	-2.46	179	0.51
234 x Torretta	34.1	0.18	45.3	-0.32	14.0	0.05	58.2	0.54	198	7.04	182	0.32
234 x 335/2-3	36.3	3.00	48.1	-0.60	15.8	1.13	53.7	1.66	208	-3.82	185	-0.34
234 x 274	33.7	0.69	44.6	0.75	13.6	0.50	50.5	-2.29	189	3.90	179	-0.15
234 x 335/2r10	34.3	-0.62	48.7	0.58	15.1	-0.07	55.3	-1.40	205	-1.29	182	-0.70
284 x 335/2-3	34.4	1.91	48.7	-0.15	15.2	0.76	48.5	-0.17	205	2.64	185	0.93
284 x 274	33.4	1.21	43.4	-0.68	13.2	0.39	51.8	2.38	172	-3.48	177	0.12
284 x 3352r10	32.7	-1.40	48.0	-035	14.2	-0.66	51.2	-2.21	200	3.16	182	0.74
299 x Pisa	37.9	2.22	42.8	-0.22	14.7	0.75	52.9	1.89	179	-2.87	181	0.42
299 x Torretta	34.3	-1.27	43.9	-0.54	13.7	-0.63	51.8	-2.07	188	-4.37	183	-0.77
299 x 1234/3	33.7	5.92**	45.5	-0.24	14.1	2.51**	46.1	-0.19	195	22.87**	186	3.02**
299 x 274	36.5	1.84	43.1	0.41	14.3	0.84	51.0	1.87	186	-0.68	181	0.26
299 x 335/2r10	36.1	-0.46	47.3	0.29	15.5	-0.07	56.5	3.50	207	-0.87	185	0.71
299 x 365/1-10	37.2	3.57	45.1	0.93	15.1	1.60	50.2	-0.27	200	-0.39	185	0.52
299 x 339/3-2	35.2	1.11	45.0	0.11	14.5	0.60	53.2	0.17	206	6.27	185	1.37*
243 x Pisa	33.7	1.21	40.8	0.82	12.4	0.58	50.3	0.99	171	-12.13**	178	2.21**
243 x Torretta	33.6	1.18	40.9	-0.61	12.4	0.15	49.9	-2.37	192	-2.46	183	-0.24
243 x 339/3-2	33.4	2.57	44.0	2.09**	13.4	1.62	57.3	5.95**	204	2.68	185	1.40*
LSD	5.2		2.4		2.4		6.3		13		2	

significant contribution of the SCA effects towards the variation among the crosses. The ratio of SCA:GCA variances showed that SCA variances were greater than those of GCA for all characters and consequently non-additive effects were predominant for all traits, confirming previous results obtained in 1995 and also those of Škorić *et al.* (2000).

Table 5: Analysis of variance for five characters in 36 new RHAs and their testers

Source of variation	df	Yield content ($q\ ha^{-1}$)	Oil yield ($q\ ha^{-1}$)	Thousand seed weight (g)	Plant height (cm)	Days to 50% flowering
Replication	2	140	27.2	6.35	13428	34.5
Crosses	107	53**	12.4**	3.31**	387**	12.5**
CMS (T)	2	273**	74.1**	58.21**	3075**	109.5**
RHA (L)	35	65**	15.6*	2.67**	675**	26.9**
L x T	70	40	9.0*	2.06**	166*	2.4**
Error	214	32	6.2	1.08	114	1.5
GCA		0.07	0.02	0.01	1.20	0.06
SCA		2.67	0.93	0.33	17.00	0.30
SCA/GCA		38.02	50.77	48.15	14.13	5.50

The estimates of GCA of testers (Table 6) were opposite to those observed in 1995. CMS 226 had significant positive GCA for all traits, whereas in 1995 seed yield, oil yield and TSW were negative, indicating that GCA of a line is dependent on the genetic material with which it is combined. This was also confirmed by the other lines. In fact 299, which was the best combiner for yield and yield components in 1995, with the exception of plant height, had the poorest GCA. Also 234 had different GCA than in 1995.

Among RHA lines some showed very high estimates of GCA for achene yield and consequently for oil yield. RHA 8/8-9 was a good combiner for yield and days to flowering followed by 8/8-53, which did not have significant estimates for days to flowering. The best estimates for yield were shown by 25/80-2 with the values of 5.29 for yield and 2.69 for oil yield, but it had very high values for plant height and days to flowering.

For the ability of lines to be used as tester (Table 7), 226 was confirmed for its suitability for yield and TSW, and for morphological or phenological traits, whereas 234 and 299 were confirmed for all traits except for achene yield. Among RHA lines, none combined good estimates for GCA and suitability to be used as tester. Instead, those with better GCA could be used to make superior hybrids. In fact, they are those showing good estimates for SCA (Table 8).

For the new CMS lines, the analysis of variance for combining ability and estimates of variance due to GCA and SCA are presented in Table 9. The variance due to CMS was not significant for the two main traits, yield and oil yield, but it was significant for TSW, plant height and days to flowering. Similar results were observed for testers (RHA), which had a non-significant variance estimate for seed yield. The variance of the interaction between CMS and RHA was significant for yield, oil yield

Table 6: General combining ability effects for new RHAs and their testers (CMS) for five characters

Parent	Yield (q ha^{-1})	Oil yield (q ha^{-1})	Thousand seed weight (g)	Plant height (cm)	Days to 50% flowering
CMS					
226	1.82**	0.96**	0.55**	4.78**	0.98**
234	-1.13*	-0.50*	0.29*	0.98	-1.03**
299	-0.69	-0.46*	-0.83**	-5.76**	0.06
RHA					
8/8-1	3.22	1.32	-0.48	3.36	0.79*
8/8-8	1.81	0.92	0.44	1.70	-0.43
8/8-9	4.90**	2.08*	0.23	0.59	-2.10**
8/8-11	0.40	-0.19	-0.15	-5.19	-2.43**
8/8-12	0.23	0.06	-0.21	-15.64**	-1.88**
8/8-14	1.41	0.76	-0.12	-2.30	0.23
8/8-18	-2.73	-1.45	0.02	-2.75	-1.77**
8/8-36	-0.61	-0.26	-0.48	-2.41	-2.21**
8/8-37	3.85*	1.51	0.62	-8.30	-1.54**
8/8-38	-3.09	-1.79*	-0.33	-11.75**	-0.88*
8/8-41	-0.47	-0.26	-0.21	-9.19*	-1.43**
8/8-42	2.99	1.54	0.11	-3.64	-0.10
8/8-46	-2.28	-1.09	-0.23	0.92	-0.65
8/8-53	3.95*	1.72*	1.11**	1.59	-0.10
8/8-59	1.13	0.59	-0.50	-11.86**	-1.32**
8/8-68	-0.29	-0.39	-0.20	3.03	-0.32
8/8-81	0.02	-0.06	-0.53	-0.41	0.68
8/8-83	0.66	0.32	-0.67*	-0.08	0.57
25/80-1	-2.96	-1.12	-0.04	10.25*	2.35**
25/80-2	5.29**	2.69**	0.50	13.03**	1.35**
25/80-5	3.89*	2.23**	-0.42	17.59**	3.90**
25/80-8	2.32	1.27	0.35	13.92**	2.46**
25/80-9	-1.02	-0.07	-0.98**	14.14**	3.35**
25/80-10	-1.72	-0.48	0.54	6.59	2.57**
25/80-11	-0.21	0.03	-0.05	8.25	2.46**
41/48-2	0.60	0.18	1.56**	2.36	-0.10
41/48-3	-0.79	-0.10	0.71*	3.36	-0.21
41/48-4	1.59	0.83	-0.30	-17.64**	-1.88**
41/48-6	-3.57	-1.86*	-0.69*	-7.75	-0.88*
41/48-7	-1.15	-0.32	-0.11	13.03**	2.12**
41/48-9	-2.20	-1.01	0.41	-2.52	-0.65
41/48-15	-0.53	0.06	0.52	4.14	1.12**
41/48-16	-6.05**	-3.06**	0.35	-5.52	-0.54
4/68-3	-4.77**	-2.39**	-0.22	5.25	-1.10**
4/48-9	-1.78	-1.12	0.30	-9.30*	-2.77**
2/8-18	-2.03	-1.13	-0.85*	-6.86	1.35**

Table 7: Mean squares of test-crosses for each parent for five characters in sunflower in 1997

Parent	Yield (q ha^{-1})	Oil yield (q ha^{-1})	Thousand seed weight (g)	Plant height (cm)	Days to 50% flowering
CMS					
226	58.9**	13.5**	2.17**	236**	9.4**
234	41.4	9.3*	2.51**	383**	10.3**
299	44.9	10.8*	2.11**	388**	12.4**
RHA					
8/8-1	20.9	5.8	0.90	322	5.5*
8/8-8	13.9	3.0	5.57**	97	5.4*
8/8-9	11.1	1.7	1.67	192	3.1
8/8-11	59.9	13.0	3.05	115	4.8*
8/8-12	41.7	13.4	2.81	817**	3.4
8/8-14	91.0	21.2*	3.26*	206	4.8*
8/8-18	12.6	2.5	0.02	806**	5.5*
8/8-36	12.6	4.6	2.84	349*	8.5**
8/8-37	22.0	6.2	2.18	559**	4.1
8/8-38	5.1	1.7	4.86*	299	4.1
8/8-41	96.4*	24.7*	3.41*	262	3.4
8/8-42	160.3**	36.4**	2.07	526*	4.1
8/8-46	80.7	17.2	6.48**	246	2.3
8/8-53	24.1	6.1	8.22**	544**	4.8*
8/8-59	14.8	1.7	3.19	112	1.3
8/8-68	83.9	16.9	6.30**	31	2.3
8/8-81	44.5	9.7	7.25**	91	7.0**
8/8-83	41.8	9.4	2.71	211	5.8*
25/80-1	27.1	8.7	6.66**	272	4.0
25/80-2	14.6	4.6	2.45	57	2.3
25/80-5	6.4	1.4	3.33*	75	1.8
25/80-8	15.4	2.6	5.23**	36	1.4
25/80-9	104.4*	28.1*	8.98**	108	6.3*
25/80-10	107.5*	24.4*	3.01	137	2.8
25/80-11	43.8	8.3	3.76*	222	3.4
41/48-2	76.7	15.5	0.08	494*	0.4
41/48-3	37.5	10.1	0.51	439*	5.8*
41/48-4	12.5	3.0	1.68	4	10.1**
41/48-6	97.5*	17.2	2.00	96	2.8
41/48-7	17.9	5.8	2.24	10	14.8**
41/48-9	29.4	5.0	2.35	163	2.3
41/48-15	5.6	3.5	2.19	341	20.1**
41/48-16	5.0	2.1	4.19*	96	19.1**
4/68-3	169.0**	37.0**	6.29**	268	4.1
4/48-9	24.3	5.2	3.83*	1	6.8*
2/8-18	38.5	11.6	4.70*	280	9.3**

Table 8: Values of traits of the most productive test crosses between 3 CMS and 37 RHAs and estimates of their specific combining ability

Crosses	Yield ($q\ ha^{-1}$)		Oil yield ($q\ ha^{-1}$)		Thousand seed weight (g)		Plant height (cm)		Days to 50% flowering	
226 x 8/8-1	32.3	-2.55	14.2	-1.20	51.5	0.45	230	4.22	175	-1.75*
226 x 8/8-8	34.1	0.64	15.2	0.20	60.0	4.75	224	-0.11	175	-0.20
226 x 8/8-9	33.4	-3.19	14.6	-1.57	49.0	-5.50	226	3.33	174	0.14
226 x 8/8-11	35.4	3.34	15.3	1.44	55.5	3.10	218	1.11	174	0.47
226 x 8/8-12	33.3	1.46	14.9	0.72	54.5	2.20	215	8.89	174	0.25
226 x 8/8-14	37.6	4.54	16.9	2.10	55.5	2.90	217	-3.11	177	0.47
226 x 8/8-37	36.6	1.06	16.0	0.44	58.5	1.95	221	7.55	175	0.25
226 x 8/8-42	40.9	6.28*	18.5	2.88**	55.5	1.90	226	7.55	175	-0.86
226 x 8/8-46	33.3	3.95	14.7	1.68	58.0	5.75	229	5.66	175	0.02
226 x 8/8-53	37.0	1.45	16.5	0.65	64.5	5.90*	233	9.66	175	0.47
226 x 8/8-68	34.4	3.01	14.9	1.20	58.0	5.60	223	-2.45	175	-0.31
226 x 8/8-81	34.3	2.63	15.1	1.12	57.0	6.15*	215	-6.34	177	0.69
226 x 8/8-83	32.7	0.38	14.7	0.26	52.5	2.50	225	3.00	177	0.14
226 x 25/80-2	35.9	-1.05	16.2	-0.58	53.5	-2.35	228	-6.78	177	-0.64
226 x 25/80-5	34.2	-1.36	15.6	-0.70	48.5	-2.60	236	-3.34	179	-0.53
226 x 25/80-8	34.8	0.79	15.5	0.11	51.5	-3.55	234	-2.00	178	-0.75
226 x 25/80-9	35.6	4.96	16.6	2.56	52.0	3.65	232	-4.56	179	0.02
226 x 25/80-10	34.5	4.51	15.7	2.07	56.5	0.35	219	-9.34	177	-1.53*
226 x 41/48-2	32.9	0.63	14.8	0.52	58.0	-3.15	232	7.89	175	0.53
234 x 8/8-1	36.0	4.06	15.9	2.00	46.5	-3.05	223	1.36	177	2.59
234 x 8/8-9	33.9	0.31	15.0	0.25	50.0	-2.90	210	-8.86	172	0.15
234 x 8/8-37	33.3	0.75	14.7	0.58	52.5	-2.50	211	1.36	172	-0.08
234 x 8/8-41	35.8	7.62*	16.1	3.78**	50.5	-0.20	211	1.91	174	1.48*
234 x 8/8-53	32.3	-0.38	14.4	0.01	55.5	-2.15	217	-3.20	174	0.15
234 x 25/80-2	32.6	-1.36	14.4	-0.89	57.5	2.85	227	-3.98	175	0.03
234 x 25/80-5	32.1	-0.51	14.6	-0.27	53.5	3.75	239	3.14	178	0.15
234 x 4/68-3	32.3	8.37*	14.2	3.93**	58.0	6.90*	224	0.80	173	-0.19
299 x 8/8-9	36.9	2.89	16.1	1.31	56.0	8.40**	218	5.53	173	-0.28
299 x 8/8-53	32.0	-1.07	13.7	-0.66	48.0	-3.75	207	-6.47	174	-0.61
299 x 8/8-59	33.3	3.02	14.5	1.19	43.0	-0.70	201	0.98	174	-0.06
299 x 8/8-83	32.6	2.80	14.3	1.28	43.0	0.05	208	-3.13	176	0.39
299 x 25/80-2	36.8	2.41	16.8	1.47	48.5	-0.50	235	10.76	177	0.61
299 x 25/80-5	34.9	1.87	15.9	0.97	43.0	-1.15	229	0.20	179	0.39
299 x 25/80-11	33.8	4.87	14.9	2.18	46.5	0.55	216	-3.80	177	-0.84
299 x 41/48-2	33.8	4.05	14.5	1.60	58.0	3.65	207	-7.24	175	-0.28
299 x 41/48-4	33.7	2.97	15.1	1.56	45.5	0.70	198	4.42	174	1.16*
LSD	9.1		4.0		8.4		17		2	

and days to flowering, but not for TSW and plant height, indicating the important contribution of the SCA effects for the first three traits to the variation among test crosses.

Table 9: Analysis of variance for five characters in 21 new CMSs and their testers

Source of variation	df	Yield ($q\ ha^{-1}$)	Oil yield ($q\ ha^{-1}$)	Thousand seed weight (g)	Plant height (cm)	Days to 50% flowering
Replication	2	23.78	4.41	48.5	673	8.44
Crosses	62	49.6**	9.50**	41.0**	373**	11.43**
CMS (L)	20	62.9	11.02	68.2**	523**	18.82**
RHA (T)	2	74.8	30.24*	244.8**	2637**	134.25**
L x T	40	41.6**	7.70**	17.2	185	1.57*
Error	124	22.5	4.15	14.6	144	0.99
GCA		0.07	0.02	0.22	1.73	0.09
SCA		6.37	1.18	0.87	14.00	0.19
SCA/GCA		87.43	71.12	3.96	8.09	2.13

Table 10: General combining ability effects for new CMSs and their tester (RHA) for five characters in sunflower (Osimo, 1997)

Parent	Yield ($q\ ha^{-1}$)	Oil yield ($q\ ha^{-1}$)	Thousand seed weight (g)	Plant height (cm)	Days to 50% flowering
CMS					
305/NP2	3.40*	0.75	5.71**	8.83*	0.56
35 E	0.03	0.07	-1.74	4.05	1.11**
19 UPR	1.66	0.71	-1.02	1.27	0.56
28 UPR	0.01	-0.02	-1.88	-7.95*	1.89**
18 UPR	-4.23**	-1.79**	-5.88**	-3.84	0.89*
270	-0.61	-0.07	-0.14	-0.62	0.67
232/1-3	1.33	0.54	3.57**	8.16*	-2.00**
22 UPR	-0.21	-0.10	0.69	2.27	1.56**
305/4	-3.26*	-1.60*	-2.84*	-17.29**	-2.89**
3 UPR	1.21	0.44	-2.50*	3.38	1.44**
1 UPR	0.79	0.54	-1.82	-1.84	0.78*
37 E	2.81	1.12	0.24	9.71*	0.89*
2 UPR	0.48	0.40	-0.87	3.94	1.33**
30 UPR	-0.32	-0.22	-3.69**	-2.95	1.44**
229/2-1	2.36	1.16	3.73**	7.05	-0.89*
16 UPR	5.71**	2.51**	1.80	0.05	-0.78*
219/1-4 A	-3.51*	-1.29*	0.67	7.27	-0.56
218/3-2	-5.65**	-2.34**	3.06*	-9.29*	-2.33**
219/1-3	-0.48	0.20	1.99	7.83	-1.78**
237/2-2	-0.56	-0.41	0.46	-14.06**	-1.67**
219/6-1	-1.04	-0.62	0.48	-5.95	-0.22
RHA					
339	1.25*	0.68*	2.01**	0.56	0.03
365/1-10	-0.54	0.03	-1.93**	6.17**	1.44**
Pisa	-0.72	-0.71**	-0.08	-6.73**	-1.48**

The lack of interaction for TSW and plant height indicates the absence of SCA and in general that the hybrid is influenced by the mean breeding value of the parents (Table 9). As a consequence of the non-significant variance among test crosses for GCA, the average variance was low and when compared with the variance for SCA, the difference was large for yield and oil yield, but also for traits with L x T not significant, confirming that SCA is very important.

Table 11: Mean squares of test-crosses for each parent for five characters in sunflower in 1997

Parent	Yield (q ha^{-1})	Oil yield (q ha^{-1})	Thousand seed weight (g)	Plant height (cm)	Days to 50% flowering
CMS					
305/NP2	9.4	3.4	74.6**	352	5.33**
35 E	5.1	2.1	3.2	225	6.78**
19 UPR	59.3	15.3*	2.6	283	9.00**
28 UPR	83.3*	10.4	25.2	193	16.33**
18 UPR	3.8	2.0	2.2	147	9.33**
270	14.1	5.4	6.5	26	4.11*
232/1-3	36.2	9.6	10.3	467*	0.78
22 UPR	211.0**	43.2**	128.0**	8	1.00
305/4	88.6*	14.8*	4.8	410	13.44**
3 UPR	16.3	1.5	3.3	800**	8.77**
1 UPR	34.1	5.4	12.3	479*	4.11*
37 E	22.0	3.3	8.7	185	10.33**
2 UPR	15.7	6.0	0.6	224	4.11*
30 UPR	56.0	12.6	0.5	652*	15.44**
229/2-1	1.8	1.1	37.5	650*	8.44**
16 UPR	85.2*	17.7*	53.7*	389	6.33**
219/1-4 A	37.1	4.7	1.9	43	11.44**
218/3-2	49.4	7.8	136.0**	226	4.11*
219/1-3	16.8	4.6	1.1	107	10.33**
237/2-2	22.6	3.7	31.4	171	14.11**
219/6-1	39.9	9.6	44.8*	301	2.11
RHA					
339	49.4**	8.6**	61.2**	206	9.15**
365/1-10	68.2**	13.3**	16.2	431**	6.75**
Pisa	28.6	4.5	25.2*	256*	6.10**

The estimates of GCA reported in Table 10 show that among RHA lines the best combiner was 339 with significant estimates for yields and TSW, whereas Pisa, which was best in the previous trial, was shown to combine well only for plant height and days to flowering. Among the CMS lines, 16 UPR had very good estimates for yield, oil yield, and days to flowering. Line 16 UPR also had a significant variance with all three testers (Table 11) for yield, oil yield, TSW and days to flower-

Table 12: Values of traits of the most productive test crosses and their specific combining ability in the trial of new CMSs

Crosses	Yield ($q\ ha^{-1}$)		Oil yield ($q\ ha^{-1}$)		Thousand seed weight (g)		Plant height (cm)		Days to 50% flowering	
305/NP2 x 339/3-2	26.1	0.17	10.4	-0.16	53.1	3.41	180	-4.33	184	-0.33
22UPR x 339/3-2	30.7	8.31**	13.3	3.58**	49.9	5.18*	178	0.22	184	0.30
1 UPR x 339/3-2	25.5	2.13	11.2	0.86	42.3	0.13	162	-12.0	183	0.08
16 UPR x 339/3-2	32.9	4.61	14.0	1.69	48.3	2.53	174	-1.89	181	-0.70
305/NP2 x 365/1-10	25.3	1.10	10.6	0.67	43.3	-2.46	196	6.05	184	-0.11
19 UPR x 365/1-10	26.8	4.41	11.6	1.73	41.7	2.65	182	-0.73	184	-0.44
232/1-3 x 365/1-10	25.4	3.28	11.1	1.43	43.4	-0.19	194	4.38	181	-0.89
37 E x 365/1-10	25.6	1.99	11.3	1.06	40.5	0.22	191	0.49	185	0.56
30 UPR x 365/1-10	25.4	4.95	11.2	2.25*	37.9	1.53	189	10.49	186	0.33
16 UPR x 365/1-10	25.7	-0.79	11.7	0.09	39.9	-1.90	187	5.83	183	0.22
28 UPR x PISA	26.4	5.84*	10.7	2.34*	42.2	2.15	168	7.40	183	-0.19
37 E x PISA	25.8	2.39	10.1	0.60	43.9	1.77	176	-1.94	182	-0.19
LSD	7.7		3.3		6.2		19		2	

ing. Also 339 and 365/1-10 were confirmed for their ability of testing, whereas Pisa was not confirmed for its ability for yield and oil yield testing.

The estimates of SCA of best test crosses (Table 12) showed that 22 UPR x 339/3-2 and 28 UPR x Pisa were the best combinations for yield and oil yield. Test cross 30 UPR x 365/1-10 was a good combination for oil yield. The test cross with the highest absolute yield (16 UPR x 339/3-2) did not have a significant estimate at P≤0.05, but the value was very close to being significant.

CONCLUSIONS

The combining ability of the lines studied was nearly always significant. Estimates for GCA were larger when many testers were used and were influenced by the breeding value of the germplasm evaluated. SCA was always higher than GCA. None of the lines used as testers can be used alone for testing new lines due to the lack of significant variability for some traits. This points to the need of using complementary testers if many traits are under evaluation. High GCA of a line is not always associated with its ability to test. The best hybrid was not the combination of lines with significant estimates for GCA or SCA. Nevertheless, lines with good estimates are often part of superior hybrids.

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APTITUD COMBINATORIA GENERAL Y ESPECÍFICA EN EL GIRASOL (*Helianthus annuus* L.)

RESUMEN

Todas las 245, test cross progenies, conseguidas cruzando líneas citoplasmicas masculinas (CMS) con líneas restauradoras (RHA), fueron valutadas en pruebas reiteradas en el 1995 y en el 1997. Los experimentos se efectuaron en el 1995 en dos lugares diferentes (Osimo en el centro-este de Italia y Budrio en el norde) mientras en el 1997 los experimentos se efectuaron sólo en Osimo. La aptitud combinatoria general (GCA) y específica de los progenitores fueron valutadas para identificar genotipos adecuatos para ser utilizados como testigos en programas de reproducción y para averiguar el comportamiento de los híbridos.

Los resultados conseguidos en el 1995 fueron usados para hacer los cruces en el 1996 por los test crosses que fueron valutados en el 1997. La GCA y SCA de las líneas RHA y CMS fueron casi siempre significativas por todos los caracteres cuando en el 1995 las líneas fueron tomadas casualmente. Cuando los testigos seleccionados fueron utilizados, según los resultados del primer año, la SCA de las nuevas líneas RHA y la GCA de las nuevas líneas CMS, si no fueron significativas por la producción de aquenio, lo fueron por muchos otros caracteres. Los mejores cálculos de la GCA de la RHA fueron con frecuencia más altos que los de las líneas CMS, mostrando, por conseguiente, que la selección por RHA podría ser más útil que por CMS. Como se pensaba, la GCA fue siempre más baja que la SCA. CMS y RHA con una grande variación entre sus test crosses por la producción y muchos otros caracteres mostran que ellos podrían ser usadas como testigos. La falta de un tester con una alta variación en todos los caracteres necesita más que un tester para valutar las líneas. La GCA de una línea puede cambiar según el germoplasma con el cual está combinada.

APTITUDE À LA COMBINATION GENERAL ET SPECIFIQUE CHEZ LE TOURNESOL (*Helianthus annuus* L.)

RÉSUMÉ

Une étude a été entreprise pour preciser l'aptitude à la combinaison de 245 test crosses issus obtenus par des lignées mâle stériles cytoplasmiques (CMS) et des lignèes restauratrices (RHA) de tournesol. Les hybrides ont été évalués in preuves repliquées en 1995 et 1997. Les études ont été menèes en deux differents regions (Osimo, Italie du Centre Adriatique, et Budrio, Italie du Nord) en 1995, tandis que en 1997 elles ont été menèes seulement à Osimo.

L'aptitude general à la combinasion (GCA) et l'aptitude specifique à la combinaison (SCA) des parents ont été évaluées pour identifier des genotypes qui peuvent être utilisés comme testeurs pour les programmes de selection et pour verifier la valeur propre des hybrides.

Les resultats obtenus en 1995 sont servi de guide à choisir les testeurs à croiser en 1996 pour obtenir les test crosses issus à evaluer en 1997.

La GCA et la SCA des lignes CMS étaient presque toujours significatives pour tous les caractères lorsque les lignées étaient choisies par hasard en 1995.

Lorsqu' on employeait des testeurs selectionnés, d'après les resultats de la première année, la SCA du nouveau RHA et la GCA du nouveau CMS n'avaient pas été significatives pour la production de grain mais avaient été significatives pour tous les autres caractères.

Les meilleures lignées évalués pour la GCA des RHA étaient souvent plus hautes que les CMS et ça indique que la selection pour RHA peut être plus avantageuse que pour CMS. Comme attendu, CGA était toujours plus faible que SCA. CMS et RHA, avec haute variance entre leurs test crosses issus pour production et beaucoup d'autres caractères, peuvent être employés comme testeurs. L'absence d'un testeur avec haute variance dans tous les caractéres exige plus qu'un testeur entre les lignes à evaluer. La GCA d'une lignée peut changer en function du germoplasme qui entre dans la combinasion.