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COMBINING ABILITY ANALYSIS FOR AGRONOMIC TRAITS IN SUNFLOWER (*Helianthus annuus* L.)

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SUMMARY

The general and specific combining abilities among 20 cytoplasmic male sterile inbred lines and four testers were estimated in order to study the potential of these materials in a sunflower (*Helianthus annuus* L.) breeding program. Test cross progenies were evaluated in three environments. Plant height, days to 50% flowering, 1000-kernel weight, seed oil content and grain yield were evaluated. Seed oil content, plant height and 1000-kernel weight presented the largest proportional contribution of *cms* inbred lines and testers, indicating the predominant role of the additive component for these traits. On the other hand, line × tester interaction exhibited the greatest contribution to grain yield suggesting the presence of non-additive genetic effects. The testers showed capacity to discriminate within the set of inbred lines.

Key words: agronomic traits, GCA effect, SCA effect, line × tester analysis

INTRODUCTION

Sunflower hybrids are cultivated at more than 18 million ha in the world. Hybrid cultivars, due to heterosis, show better performance than open pollinated populations and have led to an increase in crop productivity. Sunflower breeders have extensively used and exploited heterosis to improve seed and oil yields in sunflower. In a systematic breeding program it is essential to identify superior parents for hybridization and crosses to expand the variability reservoir for selection of superior genotypes (Ganappa *et al.*, 1997). Estimates of genetic variation and combining ability are useful to determinate the breeding value of genotypes in a breeding program. Specific combining ability (SCA) effects are important indicators of the value of inbred lines in hybrid combinations. The objectives of the present study

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were: i) to estimate the general and specific combining abilities of cytoplasmic male sterile inbred lines from different geographical selection sites and ii) to analyze the proportional contribution of inbred lines, testers and their interaction in the expression of traits of interest.

MATERIAL AND METHODS

Twenty cytoplasmic male sterile (*cms*) inbred lines of different geographic origins were crossed with four fertility restorer lines in a factorial design (Table 1).

Table 1: Type, code and geographical origin of the materials used

Type of material	Code	Geographical origin
cms inbred lines	AF 62356	France
	AG 33684	Argentina
	AG 33747	Argentina
	AGA 20412	Argentina
	AGC 6552	Argentina
	AGC 6749	Argentina
	AGE 34627	Argentina
	AGE 33741	Argentina
	AGG 90067	Argentina
	AGH 35959	Argentina
	AGT 15400	Argentina
	APH 117	Argentina
	APSS 151	South Africa
	APSS 195	South Africa
	APSS 204	South Africa
	AU 3A	USA
	AU 9003	USA
	AU 92160	USA
	KLM 295	Argentina
	LXN 621	Argentina
Restorer inbred lines	RG 32989	Argentina
	RGC 26342	Argentina
	RPSS 531	South Africa
	RU 9247	USA

Test cross progenies were evaluated in three environments in Argentina: in Patricios (35° 26' S) with an early sowing date (10/15) and in Patricios and Pergamino (33° 56' S) with a late sowing date (11/20) during the summer 1999/2000. The experiment was conducted in a three-replicated, randomized complete block design. The plot size consisted of 2 rows 5 m long with a distance of 0.7 m between them. The following variables were evaluated: plant height (m), days to 50% flowering (days), 1000-kernel weight (g), seed oil content (%) and grain yield (kg/ha).

Grain yield was determined for the whole plot and was corrected by humidity percent. Observations for plant height were recorded for five randomly selected plants from each entry. Seed oil content was determined by a nuclear magnetic resonance procedure in all replications. Data were subjected to a combined analysis of variance across environments using the GLM procedure of the SAS program (Statistical Analysis System, version 8.12-2001). General combining ability (GCA), specific combining ability (SCA) and the proportional contributions of lines, testers and their interaction were estimated in accordance to Singh and Chaudhary (1977).

Table 2: Analysis of variance for plant height, days to flowering, 1000-kernel weight, seed oil content and grain yield

S.V.	d.f.	S.S.				
		Plant height (m)	Days to flowering (days)	1000-kernel weight (g)	Seed oil content (%)	Grain yield (kg/ha)
Environment	2	78.61	498.35	63528.84	630.45	677433324.02
Rep./Environment	6	0.21	21.71	471.64	10.68	6477729.69
Line	19	5.74**	1079.94**	16316.81**	2564.43**	36188368.56**
Tester	3	4.17**	1180.16*	9816.07**	550.84**	16648839.48*
Line × Tester	57	2.17**	424.56**	6261.62**	484.11**	40348938.58**
Line × Environment	38	1.72**	260.87**	2472.9**	292.59**	21792697.54**
Tester × Environment	6	0.56**	303.18**	1452.58**	74.18**	5321214.92**
Line × Tester × Environment	114	1.13	296.26**	5002.41**	406.66**	30050860.64**
Error	474	4.69	327.63	12516.86	654.58	71176948.55
Media		1.63	67.14	64.69	49.03	3061.98
C.V. (%)		6.12	1.24	7.94	2.40	12.65
R^2		0.95	0.93	0.89	0.88	0.92
D.E.		0.10	0.83	5.14	1.75	387.51

*,** Significant at 5% and 1% levels, respectively

RESULTS AND DISCUSSION

The combined analysis of variance across environments is presented in Table 2. The variance due to general combining ability of *cms* inbred lines and testers and the variance due to specific combining ability were significant for all traits. The significance of the line × tester interaction suggests that testers were able to discriminate within this set of inbred lines. For the traits plant height, days to 50% flowering, 1000-kernel weight and seed oil content, the variances due to general combining ability were higher than the variances due to specific combining ability. This indicates the importance of this additive component in the determination of these traits. In agreement with previous results (Gangappa *et al.*, 1997; Škorić *et al.*, 2000; Laureti and Del Gatto, 2001), non-additive genetic effects were predominant for grain yield. The interactions line × environment and tester × environment were significant for all traits, suggesting that lines and testers interacted in different ways across the environments. The interaction line × tester × environment was significant for all traits except for plant height.

Table 3: General combining ability effects for *cms* lines and testers for plant height, days to flowering, 1000-kernel weight, seed oil content and grain yield

Parents	Plant height (m)	Days to flowering (days)	1000-kernel weight (g)	Seed oil content (%)	Grain yield (kg/ha)
			cms inbred lines		
AF 62356	-0.08**	0.69**	5.44**	-0.14	-312.54**
AG 33684	-0.06**	-2.06**	-1.56	0.25	218.03**
AG 33747	-0.04	-2.01**	0.18	1.93**	-145.72*
AGA 20412	0.09**	0.12	1.14	-3.14	502.96**
AGC 6552	0.08*	-0.68**	8.24**	-1.99**	85.49
AGC 6749	-0.03	-1.01**	6.03**	-0.82**	-185.94**
AGE 34627	-0.07**	0.82	-4.45**	-1.03**	47.36
AGE 33741	-0.12**	0.35*	-1.76*	0.35	152.95*
AGG 90067	0.21**	0.69**	11.38**	-1.68**	-134.93*
AGH 35959	0.07**	1.85**	-2.73**	2.42**	79.7
AGT 15400	-0.13**	-0.12	-2.49**	-0.09	189.48**
APH 117	-0.02	0.08	-2.6**	1.44**	-78.38
APSS 151	0.08**	1.77**	-0.26	0.88**	191.43**
APSS 195	0.03	0.47**	-2.37**	0.10	72.39
APSS 204	-0.02	-0.09	-5.78**	2.53**	-47.05
AU 3A	-0.07**	-1.23**	-5.12**	2.83**	-348.63**
AU 9003	-0.02	-0.42**	-4.92**	1.17**	-26.02
AU 92160	-0.07*	-1.70**	1.87*	1.43**	-366.48**
KLM 295	0.17**	2.58**	4.84**	-4.09**	322.01**
LXN 621	0.01	0.16	-5.01**	-2.37**	-216.1**
SE GCA/ lines	0.02	0.14	0.86	0.2	0.14
			Testers		
RG 32989	0.02*	0.8**	6.45**	-1.32**	258.39**
RGC 26342	0.02*	0.36*	-2.14*	0.61**	-132.5*
RPSS 531	0.084*	0.95**	-2.11*	-0.24*	-55.5
RU 9247	-0.125**	-2.11**	-2.2*	0.95**	-70.39*
SE GCA/ testers	0.01	0.10	0.38	0.10	0.10

*,** Significant at 5% and 1% levels, respectively

Estimates of general and specific combining ability effects for plant height, days to flowering, 1000-kernel weight, seed oil content and grain yield are presented in Tables 3 and 4a-b, respectively. The *cms* inbred lines AGA 20412, AGC 6552, AGG 90067, AGH 35959, APSS 151, APSS 195 and KLM 295 showed significant positive GCA effects for plant height. Among the testers, the restorer line RU 9247 showed GCA effects in the desired direction, thus this inbred line could be used as a parent for reducing plant height. The combination KLM 295 × RPSS 531 showed the high-

Table 4a: Specific combining ability effects of crosses involving testers RG32989 and RGC26342 for plant height, days to flowering, 1000-kernel weight, seed oil content and grain yield

F_1 hybrid	Plant height	Days to flowering	1000-kernel weight	Seed oil content	Grain yield
AF 62356 × RG 32989	0.027	0.50	1.36	-0.22	80.85
AG 33684 × RG 32989	-0.083*	0.58	-0.20	1.32**	-75.04
AG 33747 × RG 32989	-0.029	-0.80*	0.82	-0.53	-260.49
AGA 20412 × RG 32989	0.012	-0.14	-5.55*	0.87	-166.28
AGC 6552 × RG 32989	0.042	-0.91**	2.79	-1.43**	-80.60
AGC 6749 × RG 32989	0.034	-0.14	-1.67	-0.03	351.16*
AGE 34627 × RG 32989	-0.067	-0.30	-1.58	0.14	-185.39
AGE 34741 × RG 32989	-0.123**	0.39	-0.32	0.08	-281.38
AGG 90067 × RG 32989	0.072 *	-0.27	2.04	-0.06	110.46
AGH 35959 × RG 32989	0.059	0.78 *	0.21	-0.60	-74.80
AGT 15400 × RG 32989	0.003	-0.03	-0.16	-0.96*	202.72
APH 117 × RG 32989	0.007	0.12	1.46	-0.05	-19.90
APSS 151 × RG 32989	0.091**	1.08**	1.74	-0.64	121.41
APSS 195 × RG 32989	0.032	-0.05	2.35	-1.51**	-94.57
APSS 204 × RG 32989	0.014	-0.61	0.97	1.07*	-11.55
AU 3A × RG 32989	0.007	-0.36	-5.34 *	1.14*	-13.14
AU 9003 × RG 32989	-0.098**	-0.49	-3.27	-0.48	-181.86
AU 92160 × RG 32989	0.059	-0.11	0.72	0.97 *	-93.71
KLM 295 × RG 32989	-0.126**	-0.50	-0.92	1.07 *	213.05
LXN 621 × RG 32989	0.067	1.25**	4.54*	-0.16	459.07**
AF 62356 × RGC 26342	-0.001	-0.40	-0.22	0.18	162.30
AG 33684 × RGC 26342	0.005	-0.42	-1.40	1.21*	3.09
AG 33747 × RGC 26342	-0.036	-0.48	-1.27	0.26	151.51
AGA 20412 × RGC 26342	0.027	-0.48	1.82	1.08 *	281.72
AGC 6552 × RGC 26342	0.047	1.86 **	3.26	0.43	119.81
AGC 6749 × RGC 26342	-0.101**	0.08	-2.42	-1.21**	-688.11**
AGE 34627 × RGC 26342	0.034	0.47	2.01	1.10**	35.68
AGE 34741 × RGC 26342	0.069*	-0.06	-3.18	-0.41	-185.73
AGG 90067 × RGC 26342	0.011	1.61**	3.84	-1.28**	-682**
AGH 35959 × RGC 26342	0.019	0.22	-1.33	0.13	231.96
AGT 15400 × RGC 26342	-0.005	-0.48	3.60	-0.53	-71.47
APH 117 × RGC 26342	0.058	0.22	-2.90	-0.46	-6.78
APSS 151 × RGC 26342	0.023	1.19**	4.54*	-0.43	140.77
APSS 195 × RGC 26342	0.022	0.50	-3.30	1.22**	501.18**
APSS 204 × RGC 26342	-0.025	0.05	-3.39	-1.00*	84.05
AU 3A × RGC 26342	-0.093*	-0.14	-2.27	-0.73	-279.43
AU 9003 × RGC 26342	0.103**	-1.4**	-0.02	0.43	-6.76
AU 92160 × RGC 26342	-0.020	-0.56	-1.15	-1.47**	-150.44
KLM 295 × RGC 26342	-0.115**	-1.62**	0.30	1.79**	148.40
LXN 621 × RGC 26342	-0.013	-0.20	3.47	-0.33	210.28
S.E. ACE	0.030	0.28	1.71	0.39	129.17

*,** Significant at 5% and 1% levels, respectively

Table 4b: Specific combining ability effects of crosses involving testers RPSS 531 and RU 9247 for plant height, days to flowering, 1000-kernel weight, seed oil content and grain yield

F_1 hybrid	Plant height	Days to flowering	1000-kernel weight	Seed oil content	Grain yield
AF 62356 × RPSS 531	-0.007	0.37	-2.09	0.67	97.94
AG 33684 × RPSS 531	0.008	-0.33	-0.19	-0.46	76.94
AG 33747 × RPSS 531	0.048	0.06	0.49	0.38	253.40
AGA 20412 × RPSS 531	-0.042	-0.05	5.68**	-0.92*	299.95**
AGC 6552 × RPSS 531	0.036	1.51**	-6.49**	0.70	112.66
AGC 6749 × RPSS 531	0.019	0.51	5.12*	0.41	-7.98
AGE 34627 × RPSS 531	0.007	-0.10	4.09*	-0.32	1.58
AGE 34741 × RPSS 531	0.019	-0.18	0.90	-0.27	281.71
AGG 90067 × RPSS 531	-0.037	-0.30	-3.57	-0.25	253.71
AGH 35959 × RPSS 531	-0.038	-0.46	-1.62	-0.03	-255.53
AGT 15400 × RPSS 531	-0.030	0.51	1.90	0.38	38.84
APH 117 × RPSS 531	-0.048	0.31	1.01	0.19	178.12
APSS 151 × RPSS 531	-0.073*	-1.16**	-5.93**	0.75	-190.14
APSS 195 × RPSS 531	-0.083*	-2.19**	-1.27	0.08	-386.94*
APSS 204 × RPSS 531	0.010	-0.63	0.14	0.79	70.59
AU 3A × RPSS 531	0.082*	0.29	9.15**	-0.57	169.00
AU 9003 × RPSS 531	-0.023	-0.08	1.98	0.62	74.96
AU 92160 × RPSS 531	0.005	0.53	0.13	0.09	70.98
KLM 295 × RPSS 531	0.16**	1.37**	-2.32	-2.08**	-388.93**
LXN 621 × RPSS 531	-0.038	0.23	-7.08**	-0.18	-750.85**
AF 62356 × RU 9247	-0.019	-0.47	0.95	-0.63	-341.08*
AG 33684 × RU 9247	0.069*	0.17	1.78	-2.08**	-4.98
AG 33747 × RU 9247	0.015	1.22**	-0.03	-0.12	-144.41
AGA 20412 × RU 9247	0.002	0.67*	-1.95	-1.04*	-415.39*
AGC 6552 × RU 9247	-0.126**	-2.44**	0.44	0.30	-151.87
AGC 6749 × RU 9247	0.047	-0.44	-1.03	0.83	344.94*
AGE 34627 × RU 9247	0.025	-0.05	-4.52*	-0.92*	148.14
AGE 34741 × RU 9247	0.034	-0.13	2.60	0.59	185.41
AGG 90067 × RU 9247	-0.047	-1.03**	-2.31	1.60**	317.82*
AGH 35959 × RU 9247	-0.041	-0.52	2.74	0.49	98.37
AGT 15400 × RU 9247	0.030	0.00	-5.34*	1.11**	-170.08
APH 117 × RU 9247	-0.017	-0.64*	0.43	0.32	-151.44
APSS 151 × RU 9247	-0.043	-1.11**	-0.34	0.31	-72.03
APSS 195 × RU 9247	0.027	1.76**	2.22	0.19	-19.67
APSS 204 × RU 9247	0.001	1.2**	2.28	-0.86	-143.09
AU 3A × RU 9247	0.002	0.23	-1.53	0.16	123.58
AU 9003 × RU 9247	0.018	1.97**	1.32	-0.57	113.67
AU 92160 × RU 9247	-0.045	0.14	0.31	0.41	173.17
KLM 295 × RU 9247	0.080*	0.75*	2.94	-0.78	27.48
LXN 621 × RU 9247	-0.018	-1.28**	-0.93	0.66	81.51
S.E. ACE	0.030	0.28	1.71	0.39	129.17

*,** Significant at 5% and 1% levels, respectively

est positive effect for this trait, while KLM 295 × RG 32989 and AGC 6552 × RU 9247 showed highest significant negative SCA effects.

The highest negative effect for days to flowering was achieved by the tester RU 9247, while the testers RPSS 531, RG 32989 and RGC 26342 showed significant positive effects. Among the *cms* inbred lines, AG 33684 exhibited highest significant negative effects. Only 11 hybrid combination showed significant negative SCA effects for days to flowering. The testcross AGC 6552 × RU 9247 showed highest negative effects and was found to be the best specific combination for earliness.

The tester RG 32989 showed a high positive GCA effect for 1000-kernel weight. The lines AF 62356, AGC 6552, AGC 6749, AGG 90067, Au 92160 and KLM 295 achieved positive significant GCA effects for this trait. Only 6 testcrosses, LXN 621 × RG 32989, APSS 151 × RGC 26342, AGA 20412 × RPSS 531, AGC 6749 × RPSS 531, AGE 34627 × RPSS 531 and AU 3A × RPSS 531l, recorded significant positive effects for 1000-kernel weight. The combination LXN 621 × RPSS showed the highest significant negative effect.

The testers RU 9247 and RG 26342 showed significant positive GCA effects for seed oil content. The highest positive GCA value for this trait was achieved by the line AU 3A. Also, the lines AG 33747, AGH 35959, APH 117, APSS 151, APSS 204, AU 9003 and AU 9260 showed significant and positive values for this trait. These lines seemed to possess favorable alleles for seed oil content as deduced from the significant GCA effects they exhibited. Among the 80 hybrids, only AG 33684 × RG 32989, APSS 204 × RG 32989, AU 3A × RG 32989, AG 33684 × RGC 26342, AGA 20412 × RGC 26342, APSS 195 × RGC 26342, KLM 295 × RGC 26342, AGG 90067 × RU 9247 and AGT 15400 × RU 9247, expressed significant positive SCA effects for seed oil content.

Significant positive GCA effects for grain yield were observed in the tester RG 32989 and in the lines AGA 20412, KLM 295, AG 33684, APSS 151, AGT 15400 and AGE 34741. These lines appeared to transmit additive genes for high grain yield to their progenies and hence could be used as parents in crossing for improved yield performance. The highest negative effect for grain yield was found in the line AU 92160.

The analysis of the SCA effects in the 80 evaluated F_1 hybrids showed that the highest positive value for grain yield was achieved by the combination APSS 195 × RGC 26342. Only six hybrids expressed significant positive SCA effects, while only five showed significant negative effects.

Table 5: Proportional contribution (%) of lines, testers and their interaction for plant height, days to flowering, 1000-kernel weight, seed oil content and grain yield

	Plant height	Days to flowering	1000-kernel weight	Seed oil content	Grain yield
Lines	47.52	40.23	50.37	71.24	38.83
Testers	34.52	43.95	30.3	15.31	17.87
Line × tester	17.96	15.82	19.33	13.45	43.3

The lines, testers and their interactions showed different proportional contributions to the expression of the studied traits (Table 5). The variance due to general combining ability was higher than the variance due to specific combining ability for plant height, days to flowering, 1000-kernel weight and seed oil content. These results suggest that genes affecting these traits have mainly additive effects. Conversely, the proportional contribution of line × tester interaction was greatest for grain yield, indicating the importance of non-additive effects involved in the control of this trait. These results are in agreement with those found by Marinković *et al.* (2000), who reported values over 50% for the contribution of interaction line × tester to the testcrosses sum of squares. Also in agreement with the above mentioned authors, the *cms* lines made the largest contribution to the expression of seed oil content in the F_1 hybrids.

CONCLUSIONS

On average, the *cms* lines made the largest contribution to the expression of seed oil content, plant height and 1000-kernel weight in the F_1 hybrids. For days to flowering the contribution of the lines and testers was found to be of equal importance. The line × tester interaction was highly significant for grain yield, suggesting that the hybrids showed differences between SCA effects due to the presence of non-additive genetic effect. This result and the importance of the proportional contribution of the line × tester interaction to testcrosses sum of squares suggest that testers can discriminate among the inbred lines.

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ANÁLISIS DE APTITUD COMBINATORIA EN GIRASOL (*Helianthus annuus* L.) PARA CARACTERES AGRONÓMICOS

RESUMEN

La aptitud combinatoria general y específica entre 20 líneas endocriadas androestériles con 4 probadores fue estimada con el objeto de estudiar el potencial de estos materiales en un programa de mejoramiento de girasol (*Helianthus annuus* L). Los cruzamientos de prueba se evaluaron en tres ambientes. Las variables evaluadas fueron altura de la planta, días desde emergencia a floración, peso de mil semillas, contenido de aceite y rendimiento. Contenido de aceite, altura de planta y peso de mil semillas presentaron la mayor contribución proporcional de líneas y probadores lo cual indica la importancia de la componente aditiva para estos caracteres. Por otra parte para rendimiento la mayor contribución proporcional fue la de la interacción línea × probador sugiriendo la presencia de efectos no aditivos. Los probadores mostraron capacidad para discriminar entre el conjunto de líneas.

ANALYSE DE L'APTITUDE DE LA COMBINAISON EN TOURNESOL POUR CARACTÈRES AGRONOMIQUES

RÉSUMÉ

L'aptitude de la combinaison générale et spécifique entre vingt lignées homozigotes androstériles avec quatre essayeurs a été estimée avec l' objet d' étudier le potential de ces matériaux dans un programme d' amélioration de tournesol (*Helianthus annuus* L.). Le croisements d'épreuve ont été, évalués dans trois environments différents. Les caractères évaluées ont eté: la taille de la plante, les jours dès l´émersion à la floreison, le poids de mille graines, le contenu de l'huile et le rendement. Le contenu de l´huile, la taille de la plante et le poids de mille grains ont présenté la plus grande contribution proportionnelle de lignées et d'essayeurs, ce qui indique l'importance de la composante additive pour ces caractères. D'autre part pour le rendement la plus grande contribution proportionnelle a été celle de l'interaction lignée × essayeur qui suggérait la présence des effets pas additifs. Les essayeurs ont montré la capacité pour discriminer entre l'ensemble de lignées.