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AN EVALUATION OF CROSSES BETWEEN SOME FRENCH MALE STERILE AND UK RESTORER LINES OF THE SUNFLOWER

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SUMMARY

A primary requirement of sunflower varieties for the UK is early maturity to avoid yield loss from infection by *Botrytis cinerea* of *Scelerotinia sclerotiorum*. Recombinant inbred lines selected in the UK following two cycles of inbreeding are being assessed in hybrid combination. The results of a trial of testcrosses produced between some French cytoplasmic male sterile lines (CMS) and the UK restorer lines are presented. Combining ability analysis indicated significant differences between both the CMS and restorer lines in their general combining abilities, but no differences in specific combining abilities for the yield-related characters. It was concluded that a number of these parental lines show potential as parents of hybrids for the UK. Analysis of correlations between the characters suggested that there were no barriers to obtaining hybrids with a favourable combination of traits for early flowering, short height and high yield. There was evidence of genetic control of resistance to *Botrytis* and *Sclerotinia* infection and selection of such resistance should be an important breeding objective. The commercial varieties "Avante" and "Allegro" did not perform well in this trial.

Key words: Early flowering, *Botrytis*, *Sclerotinia*, recombinant inbreds, fertility restoration, CMS, combining ability

INTRODUCTION

Success of sunflower as an alternative crop in the UK depends largely on the availability of varieties adapted to the UK climatic conditions. Early maturity is considered to be one of the primary requirements to minimise the loss of yield from infection by *Botrytis cinerea* or *Sclerotinia sclerotiorum* under damp conditions typical at the end of the season (AFRC, 1987). Although late maturing varieties may be associated with higher yields, early varieties secure a more reliable yield in most seasons (Long, 1991). Church and Rawlinson (1991) have specified the following criteria for the ideal "UK sunflower":

- early maturing (<85 days to first anther stage, <140 days to maturity equivalent to 1100-1200 accumulated day degress (ADD) measured above a base temperature of 6°C)
- dwarf (<100 cm tall)
- high yielding (>2.5 tons/ha) with high oil content (>45% oil at 90% dry matter).

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Sells (1993) indicated that varieties maturing with 1200 ADD and yielding 2.0 tons/ha could also prove to be profitable.

All of the varieties currently being marketed in the UK have been bred in France (NIAB, pers. comm.) and thus are not specifically suited to UK conditions. At the University of Birmingham, however, a sunflower breeding and research programme has been ongoing since 1986. Following two cycles of inbreeding, recombinant lines have been selected for a range of important agronomic characteristics (Virk and Pooni, 1994), and are undergoing testing in hybrid combination. The results of an initial diallel and testcross trial of a subset of the selected lines have already been reported (Pooni et al., 1994). A further assessment of the combining abilities of the selected recombinant lines with four cytoplasmic male sterile (CMS) lines of French origin is reported in this paper.

MATERIALS AND METHODS

During the winter of 1992-93 fourteen selected second cycle inbreds (SB1-SB14) and ten parental first cycle inbreds (P1-P10) were crossed with four cytoplasmic male sterile lines (MS1-MS4) obtained from a French source. Only 66 of the crosses, however, produced sufficient seed for inclusion in the testcross trial.Two commercial hybrids "Avante" and"Allegro" were also included in the trial for comparison.

All of the crosses were assessed in replicated (2 plots/cross) and randomised single-row plots (5 plants/plot). The seed was sown on 26th May 1993 in biodegradable peat pots in the glasshouse which were randomised at the time of sowing. The seedlings were hardened in a cold frame before transplanting into the field on 9th June 1993, two weeks after sowing. The plant spacing was 75cm between rows and 20cm between plants within rows (corresponding to 67000 plant/ha). The experimental block was surrounded by a single row of guard plants to protect against edge effects and covered with a net to prevent bird predation. The experiment was harvested on 23rd September 1993.

The characters scored on individual plants over the course of the experiment are described in Table 1. The data were subjected to various statistical and genetic analyses.

Table 1. Description of the characters scored.

Character	Abbrev.	Description
Flowering:		
Flowering time	FT	Number of days from sowing to first anthesis (days) Equivalent accumulated day degrees (ADD) above 6°C also given
Height at flowering	HF	Height from base to top of apical head (cm)
Maturity:		
Head diameter	HD	Diameter of apical head (cm)
Seed set	SS	Percentage of apical head set with seed (to nearest 10%)
Botrytis infection	BI	Percentage of apical head infected with *Botrytis cinerea* (to nearest 10%)
Sclerotinia infection	SI	Percentage of apical head infected with *Sclerotinia sclerotiorum* (to nearest 10%)
Post-harvest:		
Dry weight	DW	Dry weight of seed collected from the apical head (g)

Hierarchical one-way analyses of variance with the following structure were performed to test for genetic variation:

between crosses

between plots within crosses

between plants within plots

Combining ability analysis requires two-way analysis of variance to partition the between-crosses component into the general combining ability (GCA) of the parental lines and the specific combining ability (SCA) or interaction of the lines (Simmonds, 1979). Thus two-way analyses with the following structure were performed assuming a fixed effects model:

between CMS

between restorers

CMS x restorers

between plots within crosses.

Where significant, subsequent combining ability analysis allowed identification of the parents with superior GCA and also those combinations of lines with good SCA.

One-way analysis of covariance was used to partition the phenotypic covariation between the characters into genotypic and environmental components (Steel and Torrie, 1981; Falconer, 1989) and to calculate the corresponding correlation coeficients (Toms et al., 1994).

RESULTS AND DISCUSSION

The one-way analyses of variance, summarised inTable 2, provided evidence of highly significant levels of genetic variation for all of the characters scored. *Botrytis* infection was not included in this analysis because of its very low incidence in the trial.

Table 2. One-way analyses of variance.

	FT		HF		HD		SS		SI		DW	
	dr	MS	df	MS	df	MS	df	MS	df	Ms	df	MS
Between Crosses	41	228.63**	41	104554.33**	41	1345.87**	41	836.14**	41	4197.99**	38	172.36**
Between Plots/Crosses	41	6.68*	41	19722.94**	36	1112.72**	35	383.44**	38	1478.15*	30	130.44**
Between Plants/Plots	309	4.39	309	6527.97	240	484.85	238	149.10	264	972.45	188	68.14
Significance levels: p>0.05				ns								
0.05≥p>0.01				*								
p≤0.01				**								

For two-way analysis of variance a complete set of data is necessary. With missing plots and plants the analysis is carried out using a general linear model. Since a complete two-way table is also essential for a valid combining ability analysis (Sprague and Tatum, 1942), the data set was reduced to obtain a complete set of crosses for three CMS lines (MS1-MS3) and fourteen restorer lines (11 SB and 3 P lines). Analyses were conducted on plot means. Any plots with only one surviving individual were discounted and treated

as missing plots: missing plot means were replaced with those of the replicate plots and the degrees of freedom adjusted accordingly.

The results of the two-way analyses of variance, shown in Table 3, provided clear evidence of differences in the general combining abilities of the lines for all of the characters except head diameter. The lines also differed in the specific combining abilities for flowering time and height, but not for the other characters. This apparent lack of significant specific combining ability may be a result of working with a small set of data. It is also possible that the CMS lines, having come from the same source in France, may have been genetically very similar, and thus may not have differed much in specific combining ability (Pooni et al., 1994). It is therefore difficult to comment on the non-additive effects of the restorer lines.

Table 3. Two-way analyses of variance based on plot means, where the main effects test general combining ability and the interaction test specific combining ability of the parental lines.

	FT		HF		HD		SS		SI		DW	
	df	MS	df	MS	df	MS	df	MS	df	MS	df	MS
Between CMS	2	843.33**	2.	182086.49**	2	494.63^{ns}	2	971.06**	2	9764.11**	2	148.23*
Between Restorers	13	31.08**	13	33305.39**	13	490.87^{ns}	13	331.26**	13	1314.64**	12	84.96**
CMS x Restorers	26	5.88**	26	8510.79*	26	285.71^{ns}	26	152.67^{ns}	26	438.61^{ns}	24	29.86^{ns}
Between Plots/Crosses	41	1.42	41	4378.71	36	263.99	35	108.84	38	403.77	30	33.23

Table 4: Average performance of all the testcrosses of a line, ordered according to the general combining abilities of the parents.

	FT		HF		HD		SS		SI		DW	
CMS	MS2	73.5	(659)	MS2	161.0	ns	MS3	79.1	MS1	6.6	MS2	18.9
	MS3	76.0	(680)	MS3	164.0	ns	MS2	78.1	MS3	30.2	MS3	16.5
	MS1	84.0	(747)	MS1	176.2	ns	MS1	69.6	MS2	43.2	MS1	14.8
Restorers	SB7	75.1	(672)	P8	157.1	ns	P3	88.2	SB9	3.8	P3	22.4
	SB14	75.4	(675)	SB7	157.9	ns	SB10	84.4	SB6	7.2	SB10	21.6
	SB2	76.1	(683)	P10	159.8	ns	SB6	81.4	SB10	10.7	SB11	18.6
	SB8	76.2	(683)	SB13	160.2	ns	P8	80.6	SB11	12.3	SB5	18.4
	P8	76.2	(672)	SB14	162.4	ns	SB2	77.6	P3	21.5	SB8	18.2
	P3	76.6	(672)	SB2	164.4	ns	SB8	76.7	SB4	25.7	SB2	17.7
	SB5	77.1	(691)	SB8	166.2	ns	SB11	75.3	SB2	27.4	SB6	17.7
	SB13	77.2	(691)	SB6	166.8	ns	SB14	75.0	SB8	27.5	SB9	17.5
	P10	77.5	(692)	P3	169.5	ns	SB7	74.6	P10	33.3	P8	16.6
	SB9	78.8	(700)	SB5	169.7	ns	SB4	73.7	P8	34.8	SB7	14.4
	SB6	79.0	(700)	SB4	170.7	ns	SB9	73.6	SB7	38.2	SB4	13.0
	SB4	80.7	(722)	SB9	174.3	ns	SB5	72.0	SB5	39.7	SB13	11.1
	SB11	81.7	(718)	SB10	178.5	ns	SB13	63.3	SB13	40.1	P10	10.2
	SB10	81.9	(731)	SB11	181.2	ns	P10	61.5	SB14	51.0	SB14	-

The overall means of the testcrosses involving particular lines, ordered according to their general combining ability values, are given in Table 4. Together with the days to flowering, the accumulated day degrees (ADD) are also given. Of the three CMS lines assessed, MS2 consistently had the best GCA for flowering time, height and yield. The superiority of the male restorer lines, on the other hand, differed for different characters, but SB2, SB7, SB8 and P3 rated well for at least two of the three important characters. Comparing the GCA of the parental lines in this trial with the diallel and testcross trial from the previous season (Pooni et al., 1994) was not possible since two different subsets of lines were assessed. Nevertheless, there was some correspondence but also some differences between the ranks of those parents common to both trials.

It is evident from Table 4 that the testcrosses differed substantially in their susceptibility to infection by *Sclerotinia*, Unfortunately, crosses involving parents superior for flowering time, height and yield tended to be more diseased. The phenotypic correlations between flowering time and the levels of infection by *Sclerotinia* and by *Botrytis* are both highly significant (FT/SI r= 0.43; FT/BI r=0.23). This increased incidence of infection in the earlier maturing hybrids, however, may simply reflect the fact that these crosses were left longer in the field after maturing given a single harvest date for the whole trial.This conjecture is supported by Church et al., (1990). Futher investigation of this effect would require repeated assessment of disease levels relative to maturity.

Table 5. Phenotypic (r_p), genotypic (r_g) and environmental (r_e) correlations between characters.

		HF	HD	SS	SI	DW
FT	r_p	0.66	ns	-0.21	-0.43	-0.23
	r_g	0.81	ns	-0.39	-0.87	-0.41
	r_e	0.41	-0.18	ns	ns	-0.20
HF	r_p		0.19	ns	-0.32	ns
	r_g		0.49	ns	-0.75	ns
	r_e		ns	ns	ns	ns
HD	r_p			0.52	ns	0.74
	r_g			0.53	ns	0.80
	r_e			0.53	ns	0.73
SS	r_p				ns	0.45
	r_g				ns	0.63
	r_e				ns	0.41
SI	r_p					ns
	r_g					ns
	r_e					-0.16

The phenotypic correlations between characters partitioned into constituent genotypic and environmental correlations are summarised in Table 5. There were strong positive correlations between flowerinig time and height, and between head diameter and seed yield, which clearly had strong genetic components. There were also weaker positive correlations between height and head diameter, and between seed set and head diameter and also dry weight. The correlation between flowering time and height in particular is favourable, indicating that earlier flowering lines are also comparatively shorter than later flowering ones. These results generally support those of other studies

(Holtom et al., 1994; Toms, 1992). The negative correlations were also similar to those found in other studies with one exception. The negative correlation between flowering time and seed yield is rather unusual. Since this correlation appears to have a genetic basis it is potentially beneficial, implying that moderately early flowering crosses can also give high yields. The negative environmental correlation component, on the other hand, suggests that the late flowering crosses did not have sufficient warm weather for the seed to set and mature. A similar effect was found by Pooni et al. (1994). Since most other trials have shown flowering time and yield to be positively correlated (Holtom et al., 1994; Toms, 1992) this association needs to be investigated further.

In considering the suitability of these crosses for cultivation in the UK, it is useful to compare their performance with that of two commercial varieties, "Avante" (Sigco47) and "Allegro". These hybrids flowered after approximately 59 days (522 ADD) and at a height of 81 cm. Yield data are not available since these varieties are highly susceptible to both *Botrytis* and *Sclerotinia*, and by the time of harvest the seed was almost entirely destroyed. It is worth questioning the suitability of these varieties for cultivation in the UK. In comparison, the earliest of the testcrosses flowered after 79 day (which would have been somewhat accelerated by glasshouse sowing). The trial was harvested 120 days after sowing, which corresponded to 1005 ADD. The earliest hybrids were ready for harvest at least one week earlier. These testcrosses clearly meet the criteria specified by Church and Rawlinson (1991) for early varieties maturing within 1000-1100 ADD from sowing to harvest. From the results of this study, it appears that such varieties would require 750 ADD to flowering, allowing for maintenance at 25°C in a glasshouse for one week after sowing. The yield of these testcrosses cannot meaningfully be expressed in tons/ha for comparison, since the planting density was substantially lower than the commercial density at which sunflower is grown in the UK.

The main limiting factor of the hybrids was their height, although the shortest at 150 cm tall may prove to be acceptable as varieties provided they meet other requirements. Futher assessment of the best hybrids in different seasons and locations is needed. It is also necessary to test the potential of the restorer lines against a larger and more diverse set of CMS lines, preferably ones that have been selected for short stature as well as ear liness.

CONCLUSIONS

A number of the selected restorer lines show potential as male parents of hybrids for the UK. Of the French CMS lines used as testers, the earliest may have some potential, but ideally the female parents also need to be selected specifically on UK criteria. There was evidence of genetic control of resistance to infection by *Sclerotinia* and *Botrytis* and it is essential that this character is included in the ideotype of the ideal UK sunflower. Assessment of the commercial varieties, "Avante" and "Allegro", has suggested that they are not particularly suited to the UK conditions, but can be grown as a stop gap until better varieties become available.

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EVALUACIÓN DE CRUCES ENTRE LÍNEAS FRANCESAS ANDROESTÉRILES Y LÍNEAS RESTAURADORAS DEL REINO UNIDO EN GIRASOL

RESUMEN

Un requerimiento primario para variedades de girasol para el Reino Unido es madurez temprana para evitar pérdidas de infección por *Botritis cinerea* or *Sclerotinia sclerotiorum*. Las líneas puras recombinantes seleccionadas siguiendo dos ciclos de autofecundación están siendo estudiados en combinaciones híbridas. Los resultados de un experimento de cruces "test-cross" producidos entre algunas líneas androestériles citoplásmicas franceasas y líneas restauradoras del Reino Unido son presentados. Los análisis de aptitud combinatoria indicaron diferencias significativas entre ambos las líneas CMS y restauradores en sus aptitudes combinatoria general pero no en la específica para caracteres relacionados con el rendimiento. Se concluyó que algunas de estas líneas parentales mostraron potencial como parentales de híbridos para el Reino Unido. El análisis de las correlaciones entre los caracteres sugiere que no hubo barreras para la obtención de híbridos con una combinación favorable de caracteres para precocidad, estatura reducida y alto rendimiento. Hubo evidencia de control genético de resistencia a infecciones de *Botritis* y *Sclerotinia* y selección para tales resistencias debería ser un importante objetivo de mejora. Las variedades comerciales "Avante" y "Allegro" no se comportaron bien en este experimento.

EVALUATION DE CROISEMENTS ENTRE LIGNÉES DE TOURNESOL MÂLE STÉRILES FRANÇAISES ET LIGNÉES RESTAURATRICES ANGLAISES

RÉSUMÉ

Une condition nécessaire pour les variétés de tournesol britanniques est la précocité de maturation pour éviter les pertes de rendement liées aux attaques de *Botrytis cinerea* ou de *Sclerotinia sclerotiorum*. Des lignées recombinantes sélectionnées au Royaume Uni, après deux cycles de fixation, sont évaluées en combinaison hybride. Les résultats d'une expérimentation de test-crosses issus de croisements entre lignées mâle stériles cytoplasmiques (CMS) françaises et lignées restauratrices anglaises sont présentés. L'analyse de l'aptitude à la combinaison montre des différences significatives entre les lignées CMS et restauratrices pour leur aptitude générale à la combinaison, mais pas de différences pour l'aptitude spécifique à la combinaison, pour les caractères de productivité. On en conclut que plusieurs de ces lignées révèlent des potentialités en tant que parents d'hybrides pour le Royaume Uni. L'analyse de corrélations entre les caractères suggère qu'il n y a pas de limites à l'obtention d'hybrides possédant une combinaison favorable de critères de précocité de floraison, de taille réduite et de productivité élevée. On a mis en évidence l'existence de facteurs génétiques de la résistance au *Botrytis* et au *Sclérotinia*, la sélection de teliles résistances devrait être un objectif important de l'amélioration. Les variétés commerciales "Avante" et "Allegro" ne se sont pas révélées performantes dans cet essai.