DROUGHT RESISTANCE IN SUNFLOWER. FACTORS AFFECTING YIELD AND THEIR VARIABILITY UNDER STRESS.

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Abstract
This study was carried out in 1990 and 1991 with 16 and 20 sunflower hybrids obtained from a sample of inbred lines, following a "Nested" design of crosses. The material was grown in a split-plot design with three replications with the wet and drought treatments in the main plots and the different genotypes in the sub-plots. The drought stress was imposed from the pre-flowering time by the interruption of sprinkler irrigation. The characters analyzed in both years were: flowering date, dry biomass at flowering (I) and at maturity (II), seed weight 15 days after flowering (I) and at maturity (II), seed number per plant, harvest index (HI), oil seed content, seed yield and leaf water potential. Moreover in 1990 carbon exchange rate (CER) and relative water content (RWC) were analyzed and in 1991 leaf area index at flowering (LAI I) and 15 days after (LAI II). Strong variability among the genotypes under drought and wet condition was found and seed yield was shown to be reduced by stress more in 1991 (62.4 %) than in 1990 (32.9 %). The drought suscettibility index (S) did not shown any correlation with yield potential in wet condition, confirming the opportunity to combine drought resistance and yield potential in an improved sunflower genotype. Among the analyzed characters, the most important associations under stress with S were shown by harvest index and seed number per plant (espressed as % of the control) in both years. These two characters showed a significative additive variance component with values of heritability greater than 30% in 1991 and 40% in 1990. Improvement in these two characters in parental lines could be a new interesting aspect in the breeding programmes for drought resistance in sunflower.

Introduction

Altough breeding for high and stable yield in drought stress environments has become a subject of great interest in the past decade, adequate schemes of plant breeding are not yet formulated and methodologies differ according to the crop, the drought environment and the breeders philosophies.
Useful informations on the physiological background of drought resistance has been developed in recent years and the number of traits proposed as indicators of drought resistance is large (IRRI, 1982; Passioura, 1986; Turner, 1986; Blanchet and Merrien, 1984; Matin et al., 1989; Ritchie et al., 1990;

Schonfeld et al., 1988), but in sunflower their use as selection criteria is often lacking (Fereres et al., 1986;).
At least initially, in order to identify responses that could be used as selection criteria, the first steep in breeding programme for drought resistance is the evaluation of whole plant/crop responses (Fussell et al., 1991) in field experiments. To do this Fischer (1981) has proposed the "black box" approach, that permits the evaluation of the importance of yield potential and drought escape mechanism on yield under stress, the drought resistance or susceptibility of individual genotypes under stress by "S" index (Fischer and Maurer, 1978) and the evaluation of the usefulness of a wide range of plant chracteristics by correlation analysis under stress conditions.
But once such potential selection criteria are identified, their degree of genetic variability and their heritability under drought has to be adequately studied and evaluated before a decision on their use is made. For this reason in order to evaluate the variability for drought resistance among sunflower inbred lines randomly selected, their hybrid, obtained following a genetic scheme of crosses, have to be analyzed in the field under drought stress conditions (Baldini et al.,1991).
This paper illustrates the use of above method of analysis on data from two years of advanced field trials of sunflower genotypes grown under stress conditions.

Materials and Method
Trials were carried out at the Experimental Station "Baslini s.p.a.", situated at Migliarino (Pisa), in order to study the effects of limited water availability on 16 and 20 experimental hybrids in 1990 and 1991 respectively. Hybrids were obtained following a "nested" design of crosses (Gardner and Lonnquist, 1966)), in which the inbred lines, 4 in the first year and 5 in the second, were crossed with 4 different fertility-restoring lines. All hybrids were growed according to an experimental split-plot design with three replications, with a water regime as main treatment and genotypes as subtreatments. The well irrigated control received complete watering by sprinkler irrigation up to physiological maturing by means of weekly 60 mm irrigation, in dryland conditions (drougth stress) the irrigation was interrupted at the stage of appearance of the flower bud. The experimental unit was composed of 4 rows each 5 metres long, spaced at 50 cm. Sowing took place on June 3 1990 and June 12 1991, on soil with predominantly sandy texture. The temperature was on the average of the last twenty year, while only two rainfalls on 30 July (10 mm) and 7 August (25 mm) occurred, during the stress period, in 1990. Main characters determined in both trial years were:
- date of flowering;
- achene production per hectare:
- total plant dry weight at flowering (I) and at physiological maturing (II);
- seed weight at physiological maturing (II) and 15 days after flowering (I);
- seed oil %;

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- seed weight at physiological maturing (II) and 15 days after flowering (I);
- seed oil %;
- number of achenes per plant;
- harvest index (HI);
- leaf water potential, by means of Sholander pressure chamber according to Turner's methodology (1981), and drought susceptibility index S in plants undergoing water stress (Fischer and Maurer, 1978).

In the first year, at the end of the flowering stage, values for the following were also determined:
- leaf relative water content (RWC) according to Turner's methodology (1981);
- carbon exchange rate (CER) by means of a ADC (Analytical Development Co., England) system composed of a solid state I.R.G.A., a leaf chamber, an air supply unit (A.S.U.) and a data logger (Steduto et al., 1986).

In the second year, values determined also included the following:
- LAI at the flowering stage (I) and 15 days after the end of flowering (II), according to Sobrado and Turner's methodology (1981).

All data obtained were subjected to ANOVA statistical analysis, adopting the following general model:

$Y_{ijk} = m + r_K + a_i + b_j + E_{ijk}$ where:

Y is the measure of the k^{th} character considered to be corresponding;

m is the general mean;

r_K is the effect of the k^{th} replication;

a_i is the variability due to the i^{th} hybrid;

b_j is the control situation (j=1) and stress situation (j=2);

E_{ijk} is the random error considered to be normally distributed.

Phenotypical correlations between the characters examined were also calculated, and in addition the drought susceptibility index S was computed. Furthermore, components of variance were calculated, according to the nested crossing design adopted (Feher 1987), for the characters of achene production, harvest index and seed number per plant, all of which were measured under conditions of water stress and calculated as % compared to the control. Estimation of the following components was carried out both by analysis of variance and also from expected mean squares, in accordance with the hypothesis on the model:

Source	D.F.	Mean Squares	Expected mean squares
replication	r-1		
females	f-1	M3	$\sigma^2 + r\sigma^2_{m/f} + rm\sigma^2_f$
males/females	f(m-1)	M2	$\sigma^2 + r\sigma^2_{m/f}$
error	(r-1)(fm-1)	M1	σ^2

where:

$\sigma^2_f = 1/4\sigma^2A$

$\sigma^2_{m/f} = 1/4\sigma^2A + 1/4\sigma^2D$

σ^2A = additive genetic variance

σ^2D = genetic variance of dominance

Heritability was computed according to Falconer's proposal (1967)

$$h^2 = \frac{1/2\sigma^2A}{1/2\sigma^2A+1/4\sigma^2D+\sigma^2}$$

Results and Discussion

Table 1 highlights the marked variability between the genotypes analyzed, affecting almost all the characters studied both in the control situation and also under limited water availability (significance of variance). Diverging mean production recorded in the two experimental years (3.67 and 2.38 t/ha in 1990 and 1991 respectively) was attributed to differing environmental conditions, deriving from the fact that the second trial year was distinguished by high temperatures and scanty rainfall, especially during the second part of the crop cycle. Confirmation of this hypothesis is provided by the difference in water stress intensity, evaluated as "pre-dawn" water potential (Sobrado and Turner, 1983; Turner, 1986) at full flowering in the plants in which irrigation was interrupted. In the first year this value was -1.13 Mpa, whereas in the second it reached -1.85 Mpa. Consequently, the drop in production recorded in 1991 (63.4%) was sharper than the drop observed in 1990 (31.9%).Table 2 lists the correlations between S and all the characters examined. No significant correlations with yield potential measured in the control situation were observed in either trial year. This is consistent with results obtained previously by Fereres et al. (1986) and Baldini et al. (1991), confirming that sunflower, unlike other crops, allows the possibility of uniting yield potential and resistance to water stress within a single genotype. Table 2 also demonstrates the absence of significant correlation between S and the flowering period in both trial years. From these results it may be desumed that the mechanism of "drought escape" does not seem to play an important role in this case, even when progressive water stress has set in during the pre-flowering stage. The results presented here pertaining to the genetic material examined also reveal, however, that despite the statistical significance obtained, the difference in date of flowering between the earliest and latest hybrid (8 days in 1990 and 6 in 1991) is insufficient to emphasize the mechanism in question. In 1990 the most important and significant associations between S and the characters measured under stress conditions, excluding achene production, were RWC (-0.76) and CER (-0.736), as regards physiological activities. Productive characters worthy of mention, for both trial years, are the HI (-0.708 and -0.693 in 1990 and 1991 respectively) and number of achenes per plant, evaluated as % compared to the control (-0.645 and -0.621 in 1990 and 1991 respectively). This confirms that despite the different intensity of water stress and different type (interrupted in the first year by short rainy spells), these two characters appear to be fundamental in genotypes that are to be resistent to limited water supply (Fereres et al. 1986).

Table 1 - Mean values and mean squares of the genotypes for analyzed characters in wet and stress conditions

Variable	wet	Mean squares	stress	Mean squares
1990				
Flowering (days)	55.1	11.5*	54.4	8.02*
Dry Biomass I (g)	188.6	484*	119.7	783*
Dry Biomass II (g)	225.5	790*	171	509.2*
1000 seed weight I (g)	29.4	23.1	24.7	15.9
1000 seed weight II (g)	59.4	105.9*	44.8	48.3*
Seed number (plant-1)	1242	55841*	954	33982*
CER (µMCO2 m-2 sec-1)	27.7	19.3	10.9	5.8*
RWC (%)	0.8	8.7 10-4	0.6	5.5 10
Water Potential (MPa)	-0.48	0.01	-1.13	0.25*
Harvest Index	0.32	1.4 10-3	0.25	2.2 10
Oil seed (%)	50.5	7.8*	46.9	9.5*
Yield (tons ha-1)	3.67	5.8*	2.5	1.38*
1991				
Flowering (days)	61.3	7.8*	60.8	8.4*
Dry Biomass I (g)	95.4	172.8*	80.1	210.5*
Dry Biomass II (g)	88.3	371.6*	57.4	112.6*
LAI I	2.63	1.12	1.78	0.6*
LAI II	1.32	0.21	0.19	0.01
1000 seed weight I (g)	26.7	21.2	24.2	11.2
Water potential (Mpa)	-0.55	0.01	-1.18	0.52*
1000 seed weight II (g)	56.1	39.2*	40.4	20.2*
Seed number (plant-1)	561	26598	300	7982.2*
Harvest Index	0.27	1.7 10-3	0.15	7.2 10-4*
Oil seed (%)	45.3	6.8*	37.7	7.7*
Yield (tons ha-1)	2.98	38.7*	1.27	7.2*

* differences among genotypes are significative for $P < 0.01$

Table 2 - Correlation among S index, harvest index, seed number and other analyzed characters

1990

	RWC	WATER POT.	DRY BIOM. I	DRY BIOM. II	% OIL SEED	1000 SEED WEIGHT I	1000 SEED WEIGHT II	HARVEST INDEX	SEED NUMBER	CER	YIELD STRESS	WET YIELD
S INDEX	-0.760*	0.489	-0.37	-0.335	-0.636*	0.249	-0.427	-0.708*	-0.645*	-0.736*	-0.903*	0.143
HARVEST INDEX	0.585	-0.317	0.138	-0.299	0.647*	-0.517	0.169	-	0.715*	0.578	0.810*	0.371
SEEDS NUMBER	0.558	-0.37	0.05	0.06	0.639*	-0.51	-0.26	0.715*	-	0.621	0.775*	0.623*

1991

	LAI I	LAI II	DRY BIOM. I	DRY BIOM. II	1000 SEED WEIGHT I	WATER POTENTIAL	1000 SEED WEIGHT II	HARVEST INDEX	SEED NUMBER	% OIL SEED	YIELD STRESS	YIELD CONTROL
S INDEX	-0.383	0.203	-0.274	-0.585*	-0.364	0.151	-0.482	-0.693*	-0.621*	0.2	-0.799*	0.404
HARVEST INDEX	0.218	0.008	0.256	0.519	0.215	-0.058	0.404	-	0.725*	-0.046	0.832*	0.623*
SEEDS NUMBER	0.546	0.087	0.661*	0.860*	0.172	-0.125	0.143	0.725*	-	-0.071	0.882*	0.751*

* significative value for P< 0.01

Table 3 - Analysis of variance, estimates of variance components and heritability (h^2) for three characters expressed as % of wet controls.

Characters		yield %			seed number %			HI %		
Source	D.F.	Mean squares	Variance component	h^2	Mean squares	Variance component	h^2	Mean squares	Variance component	h^2
					1990					
Females	3	143.9*	2.58	0.38	484*	8.9	0.45	347.8*	6.4	0.46
Males/Females	60	19.8*	4.47		52.6*	10.8		39.2*	8.8	
Error	126	6.4	6.41		20.2	20.2		12.7	12.7	
					1991					
Females	4	148.2*	2.08	0.24	512*	7.5	0.34	175.3*	2.5	0.32
Males/Females	95	22.8*	4.02		59*	11.1		24.7*	5.7	
Error	198	10.7	10.74		25.9	25.9		7.7	7.7	

The above two characters, and in addition, production under water stress, were computed as percentage compared to the control. Table 3 shows that variability between female parents and between male parents within the females proved to be significant in both experimental years. Particularly interesting is the hereditability of the characters of seed numer and harvest index (h^2 = 0.45 and 0.46 respectively). Hereditability obtained in the first trial year exceeded that of the second year, h^2 = 0.34 and 0.32 respectively). This can probably be explained by assuming that in the second year, the greater intensity of water stress masked existing variability. Achene production, which is the synthetic character *par excellence*, presented lower hereditability than the above.described characters and was always greater in the first year (h^2 = 0.38) than in the second (h^2 = 0.24).

CONCLUSIONS

This study shows that sunflower, unlike many other species, offers the concrete possibility of uniting yield potential and resistance to water stress within a single genotype. It is also shown that the strategy aimed at modifying several phenological plant stages to enable the crop to withstand the expected period of water stress does not seem to achieve any specific positive effects in sunflower, unlike in other crops. It should be noted, however, that genotypes examined in this study perhaps presented too little variability between phenological stages for significant effects to emerge in a situation of progressive and late water stress.

The characters of harvest index and number of seeds per head proved to play an important role in resistance to water stress in the hybrids analyzed. Significant variability between parental lines utilized was also recorded, together with an important additive component of variance and high hereditability, suggesting that a modern program of drought resistance breeding should evaluate these characters in parental lines of hybrids destined to drought-prone environments.

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