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YIELD RELATIONSHIPS UNDER DROUGHT IN SUNFLOWER GENOTYPES OBTAINED FROM A WILD POPULATION AND CULTIVATED SUNFLOWERS IN RAIN-OUT SHELTER IN LARGE POTS AND FIELD EXPERIMENTS

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SUMMARY

The objective of this study was to investigate the effect of different water availability on the main agronomic characteristics in several cultivated sunflower inbred lines and other inbred lines obtained by a divergent selection for physiological traits starting from a wild species (*Helianthus argophyllus* T&G). The trial was carried out at the Experimental Farm of the University of Udine, during 1996 under rain-out shelter conditions and during 1997 in the field. At incipient flowering of the crops, water stress was imposed and maintained until physiological maturity. Of the genotypes examined, L28, which was selected as the plus variant of the wild population for gas exchange and tissue hydration, had the highest water use efficiency, (WUE), the best drought susceptibility index, (S), and an increased harvest index, (HI) under drought conditions. Genotype differences in S were mostly attributed to adjustments in the number of filled seeds per head and not to individual seed weight, in a late drought period. The results obtained indicate that high HI values under drought, which are closely related to dryland yield under field conditions, in the presence of genotypic variability should be a selection criteria to breeding for drought resistance. The lack of correlation between S and seed yield potential indicated that a high level of drought resistance and high yield potential may be combined in improved sunflower cultivars.

Key words: Drought tolerance, drought susceptibility index, divergent selection, wild population, sunflower

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INTRODUCTION

Sunflower is a crop grown mainly in the Mediterranean and some other tropical and sub-tropical regions characterized by semi-arid environments, where crops grow almost exclusively on stored soil moisture which, especially at the end of the crop cycle, appears to be a severe limitation to seed yield.

Yield improvement under dryland conditions can be obtained by breeding plants for drought resistance, which has been the subject of a great deal of discussion in the literature over the past two decades. Of the approaches, the one suggested by Blum (1983), involving a selection under stress conditions for the expression of traits associated with drought tolerance, seems the most appropriate. Despite the fact that a large number of physio-morphological traits which may confer drought resistance (i.e., putative traits) have been identified in sunflower (Fereres *et al.*, 1986; Passioura, 1986; Turner, 1986; Cox and Joliff, 1987; Matthews and Boyer, 1984; Merrien *et al.*, 1981; Baldini *et al.*, 1991; Sadras *et al.*, 1992), the development of drought-resistant cultivars has been slow (Baldini and Vannozzi, 1998). The lack of drought-tolerant genotypes in sunflowers is mainly due to a limited genetic variability for tolerance to drought in cultivated material and the difficulty in identifying simple physiological traits which confer an advantage to yield under a specific stress condition, which are reliable, effective and easy to measure for screening progeny in a suitable breeding program.

Of the many traits analyzed, stomatal conductance and photosynthesis maintenance during limited water availability seem to be associated with positive yield in wheat (Morgan, 1984) and in soybean (Sloane *et al.*, 1990), and genotypic differences in some characteristics related to adaptation to drought were found among wild and cultivated species of sunflower (Sobrado and Turner, 1983). Baldini *et al.* (1993) and Martin *et al.* (1993) found that the wild species *Helianthus argophyllus* T&G, when used as a source of tolerance to drought in large programs in many countries (Seiler, 1988; Škorić, 1992), showed higher leaf hydration, physiological activity and WUE than the cultivated sunflower under drought.

Identification of the best lines in the *per se* evaluation involves the evaluation of a great number of lines and the elimination of the worst ones before their performance can be assessed in hybrid combinations, although these take time and are expensive (Espinosa *et al.*, 1992).

The aim of this study was to assess the effects of drought on yield and main yield character parameters of several divergent sunflower inbred lines which were obtained from the above selection compared with cultivated inbred lines, grown in a partially controlled environment. Drought resistance was defined here as a superior absolute and relative phenological and agronomic water-related characters under drought stress, where the characters were estimated by the ratio of the characters under stress and non-stress conditions. The condition of drought stress, as imposed in this study, was typical of the summer season in the Mediterranean area, where it continues from flowering to the physiological maturity of the crop.

MATERIAL AND METHODS

Genetic material

Seven different sunflower inbred lines were grown in large pots under well-watered and drought treatments in 1996. They included 'HA 343' and 'HA 89' released by USDA, North Dakota, USA, 'AC', a semi-dwarf type selected by DPVTA (Department and Crop Production and Technology) of the University of Udine. The other four inbred lines were selected from a population obtained from an original cross between a cultivated inbred line 'C' (selected by the DPVTA of the University of Udine) and an accession of the wild species *Helianthus argophyllus* T&G, furnished by USDA-ARS, USA (coded as Arg400) and previously utilized by Baldini *et al.* (1993). They were obtained by adopting three cycles of divergent selection for physiological traits (Baldini *et al.*, 1996). In particular, L28 was selected as plus variant in the gas exchange activity and relative leaf water content under drought, and L 56 and L76 as medium and L12 as minus variants for the same above mentioned physiological traits.

Rain-out shelter experiment in large pots: experimental conditions

The site of the experiment was the Experimental Farm of the University of Udine (46° 02' N, 13° 13' E and 110 m altitude). Air temperature, relative humidity and solar radiation were measured at an automated weather station located near the experiment (Table 1).

Table 1: Weather conditions during the experiments. Average values of temperature (T), relative humidity (RH), solar radiation (R), and rainfall for pre- (first row) and post-flowering (second rows) periods, expressed in days of the years (DY), for AC genotype are given

	Period (DY)	T (°C)	RH (%)	R (MJ $m^{-2}d^{-1}$)	Rainfall (nm)
1996	142-203	19.8	59.3	19.4	326
	204-247	21.7	68.8	18.6	207
1997	140-205	20.3	61.1	21.0	398
	206-254	21.1	71.9	18.7	98

The experiment was carried out under a rain-out shelter, in drainage lysimeters (1.1 m long; 0.8 m wide; 0.65 m deep) filled with sandy loam soil over a 0.1 m layer of fine gravel, in 1996. A two-factor completely randomized design with three replications was used. The first factor consisted of two irrigation treatments, namely well-watered (wet) and drought (drought) treatments, while the second one consisted of 7 genotypes. In the control, wet treatment, the tanks were irrigated from sowing to maturity, maintaining available water at more than 80% of field capacity.

A similar irrigation schedule was employed in the drought treatment (dry) except for the beginning anthesis (28th July) to the physiological maturity period for each genotype, when available water was maintained at about 40% of field capacity. Irrigations were applied every 5 days during the crop cycle to each pot (18 irrigations for both treatments, in total) by a tank with measured amounts of water. The total amount of water applied was about 450 mm ha^{-1} for the wet treatment and 200 mm ha^{-1} for the drought treatment; the total water used was calculated as the difference between final and initial pot water content plus the amount of water supplied to each pot and did not differ between genotypes within treatments (Table 2).

Table 2: Water consumption (in liters per plant) as affected by genotypes in wet and drought conditions during the whole cycle

Genotype	wet	drought
HA 343	64.7	27.8
L 76	67.5	28.7
L 28	66.2	26.2
L 12	67.0	26.6
AC	68.4	27.6
HA 89	69.2	27.0
L 56	66.6	27.7
	n.s.	n.s.

Data are the means of three replicates.

Seeds of each genotype were planted by hand on May 22nd. 80 kg ha^{-1} urea fertilizer were added to the soil before planting. The plants emerged on May 30th and were thinned to six plants per pot. Weeds were controlled by hand during the experiment. All tanks were pre-irrigated (May 20th) to ensure that the soil profile was at field capacity at planting time. Soil moisture was monitored every 3 days by TDR (Time Domain Reflectometry) (equipment Tektronic 1502C). For this purpose, a TDR was installed in the middle of each plot and the readings were taken at 20 and 40 cm. In order to measure the soil water content in soil cores, gravimetric samples were also collected when the TDR rods were installed at sowing, at harvest and on June 13th, 26th, July 3rd, 16th, 31st and August 21st, at soil depths of 20 and 40 cm near the center of the pots. The soil moisture over time is presented in the Figure 1.

The time of flowering was estimated following the method of Schneiter and Miller (1981) and the sowing-flowering period (SF) was calculated. The physiological maturity was recorded in correspondence to the maximum seed weight per genotype, determined by sampling every 5 days from completed anthesis (Schneiter and Miller, 1981) for each genotype until the maximum seed weight was observed. The samples consisted of five adjacent seeds from the outer fraction of the head. The large variability between the samples did not allow a calculation of seed growth rate by fitting linear regressions to the dynamic seed weight data. Thus, the average seed growth rate (SGR) was calculated as the ratio between the single-seed weight at physiological maturity and the duration of anthesis and the physiological maturity period (FM).

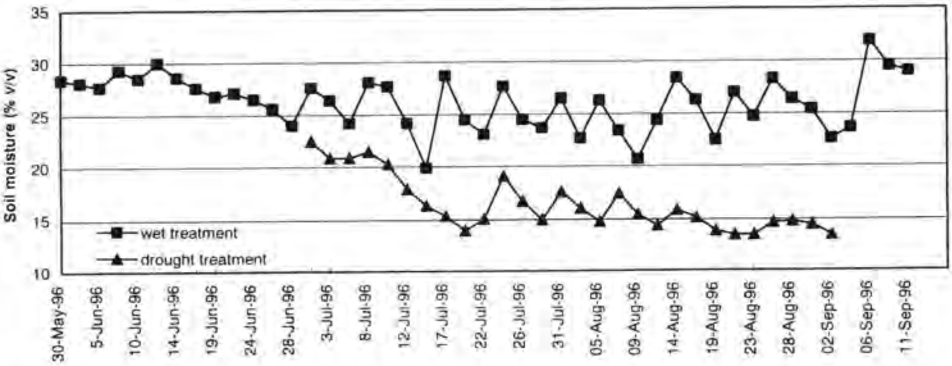

Figure 1: Soil water content for wet and drought treatments in large pots conditions, during the 1996 trial.

At physiological maturity, all plants per plot were harvested, separated into stems, leaves and heads and dried at 80°C to constant weight. Above-ground dry weight (TDW) and stover dry weight (stem + leaves + head excluding achenes) (SDW) were measured. Floret number was estimated by counting all seeds (including flats) at physiological maturity (FN) and filled seeds (FS) were counted and collected for seed yield determination per plant (SY). The weight of 100 seeds was determined (SW). Harvest index (HI) was obtained as the ratio of grain yield to total dry weight at maturity.

A stress susceptibility index (S) was used to characterize the response of each genotype to drought and was calculated as $S=(1-Y_D/Y_P)/D$, where Y_D= mean SY of a specific genotype in the drought experiment, Y_P= mean of SY of the same genotype in well-watered experiment, and D (drought intensity)= 1-(mean Y_D of all genotypes/ mean Y_P of all genotypes) (Fischer and Maurer, 1978).

Water use efficiency (WUE) was obtained as the total seed yield divided by the total water use (Ehdaie and Waines, 1993).

The data obtained were analyzed by ANOVA using a two-way completely randomized design with three replications. Duncan's multiple range test was used to separate the means when the ANOVA F-test indicated a significant effect of the treatments.

Field experiment: experimental conditions

A field experiment was planted on 12 May 1997 at the Experimental Farm of the University of Udine (46° 02' N, 13° 13' E and 110 m altitude) Italy. The soil is superficial (about 50 cm), characterized by a sandy-clay texture with prevailing gravel, without shallow water table and with a very low water retention capacity.

One treatment was irrigated with sprinklers as required to minimize water shortage until plants reached maturity. In the other treatment irrigation was withheld from July 2nd (pre-flowering stage) until physiological maturity of HA89 line. Both treatments received 448 mm, including rain, during pre-flowering period. Additionally, the first treatment (wet) received 215 mm including rain during the post-flowering period, while the second (dry) received only 98 mm of rain during the same period. A split-plot design with three replications was used. Each plot consisted of 4 rows, 5 m long, with 50 cm interrow spacing, with a plant population of about 6 plants/m^2. The crops emerged on May 21st and were thinned to their definitive density on June 5th. Weeds were controlled by hand during the experiment and nitrogen as urea (120 kg N ha^{-1}) was applied at planting time. The two middle rows in each plot were used for all the measurements and for harvesting 3 meter lengths of plants at maturity to measure the above ground dry weight in both plots. The following agronomic characteristics, determined as in the previous experiment, were recorded: days from sowing to flowering (SF) and from flowering to physiological maturity (FM), above-ground dry weight (TDW), stover dry weight (SDW), seed yield (SY), floret number (FN) and filled seed (FS), weight of 100 seeds (SW), harvest index (HI) and stress susceptibility index (S).

Oil concentration in the seed (OIL) was determined for all samples by Nuclear Magnetic Resonance (NMR) and nitrogen concentration by micro-Kjeldahl method (protein = 6.25 x N).

The data obtained were analyzed by ANOVA using a split-plot design with three replications. Where irrigation treatments were the main treatment (main plot) and the cultivars in the sub-plot. Duncan's multiple range test was used to separate the means when the ANOVA F-test indicated a significant effect of the treatments.

RESULTS AND DISCUSSION

Rain-out shelter experiment in large pots

No significant effects of drought on the duration of the phenological periods were observed (Table 3). The means across treatments of the seven genotypes differed in terms of the sowing-flowering period (SF), which ranged from 60 (L12) to 67 days (L76) and the flowering-physiological maturity period (FM), which varied from 35 (HA343) to 45 days (HA89).

Both TDW and SDW, as means across genotypes, decreased significantly with drought with respect to their controls, by about 48% and 37%, respectively (Table 3).

Genotype mean total dry weight (TDW) ranged from 83.1 g (AC) to 141.9 g (L56) and stover dry weight (SDW) ranged from 53.2 g to 94.1 g in the same genotypes.

Table 3: Means values of treatments, genotypes and their interaction for sowing-flowering (SF) and flowering-physiological maturity (FM) periods, total dry weight (TDW), stover (leaf+stem+recaptacle) dry weight (SDW), seed yield (SY), of single plants of sunflower genotypes grown in tanks in well-watered (wet) and drought (dry) conditions

	SF		FM		TDW		SDW		SY	
Treatment	days		days		g		g		g	
Wet	63		40		148.3 a		86.7 a		30.3 a	
Dry	62		39		76.9 b		54.9 b		15.4 b	
Genotype										
HA 343	62 c		34 c		122.1 bc		81.6 b		32.0 a	
L 76	67 a		39 b		95.7 de		68.6 c		15.4 e	
L 28	64 b		39 b		127.2 ab		81.3 b		27.9 b	
L 12	60 d		37 b		106.8 cd		82.2 b		17.1 e	
AC	60 d		43 a		83.1 e		53.2 d		24.5 c	
HA 89	64 b		45 a		111.2 bd		78.5 bc		22.2 cd	
L 56	61 c		37 b		141.9 a		94.1 a		20.7 d	
Interaction	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
HA 343	63	61	35	34	153.8	94.2	97.4	65.9	42.6 a	21.4 dh
L 76	67	66	39	40	112.9	72.9	83.5	53.7	18.6 eh	12.3 gh
L 28	65	64	38	40	167.3	89.6	103.2	59.4	33.4 ac	22.3 cg
L 12	60	60	39	36	147.0	67.8	111.8	52.7	24.0 cf	10.2 h
AC	61	60	44	42	119.6	51.4	74.1	32.4	35.3 ab	13.6 fh
HA 89	63	64	47	44	153.1	65.5	108.9	48.1	31.4 bd	13.1 fh
L 56	62	61	38	36	187.0	96.7	116.4	71.9	26.9 be	14.5 fh

Means followed with the same letter are not significantly different at $P=0.05$.

The seed yield per plant (SY) was significantly reduced (by about 49% as a mean across genotypes) by the drought, with the exception of L76 and L28, which had a non-significant reduction with respect to their controls (34 and 33%, respectively). In contrast, HA89, L12 and AC exhibited the highest reduction of about 60% (Table 3).

The cultivated genotype HA343 had the highest yield potential (SY under wet conditions, 42.6 g) but L28, although obtained from the wild population, did not differ significantly from the above seed yield (33.42 g, Table 3).

The drought treatment significantly reduced the flowers per head (FL) and the filled seeds per head (FN), as means across genotypes, with respect to the wet controls (Table 4). Under wet conditions, FN and FS were significantly higher in the cultivated genotypes (HA343, AC and HA89) than those coming from the wild species (Table 4), confirming that these parameters are the most important for high seed yield under favorable environments (Cetiom, 1983).

FL was strongly reduced in the cultivated lines AC and HA89, while the other genotypes were unaffected by the drought (Table 4). FN decreased significantly in all genotypes under drought conditions with respect to their controls, with the exceptions of L76 and L28. In particular, the latter exhibited a slight increase in seed number with respect to its control (Table 4), as already well-documented in previous experiments under controlled conditions and with other genotypes when water stresses were imposed (Blanchet *et al.*, 1988; Flenet *et al.*, 1994 and 1996).

Table 4: Mean flowers per head (FL), filled seeds per head (FS), 100 seed weight (SW), seed growth rate (SGR), harvest index (HI) and water use efficiency (WUE) of single plants of sunflower genotypes grown in tanks in well-watered (wet) and drought (dry) conditions

	FL		FS		SW		SGR		HI		WUE	
Treatment	n		n		g		g d^{-1}				g l^{-1}	
Wet	1491 a		666 a		4.9 a		1.31 a		0.21		0.46 b	
Dry	1285 b		473 b		3.4 b		0.97 b		0.21		0.56 a	
Genotype												
HA 343	1647 b		688 b		4.5 b		1.26 b		0.26 ab		0.70 a	
L 76	1094 d		594 c		2.6 c		0.61 d		0.17 d		0.36 c	
L 28	740 e		450 d		6.4 a		2.06 a		0.23 bc		0.68 a	
L 12	1053 d		393 d		4.3 b		1.12 bc		0.16 d		0.37 c	
AC	1776 b		881 a		2.7 c		0.70 cd		0.29 a		0.52 b	
HA 89	2083 a		538 c		4.0 b		1.10 bd		0.21 c		0.48 b	
L 56	1309 c		433 d		4.6 b		1.12 bc		0.15 d		0.47 b	
Interaction	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
HA 343	1693 bc	1600 c	747 b	629 cd	5.8 b	3.1 fg	1.60	0.92	0.28 ab	0.23 ce	0.63 bc	0.77 ab
L 76	1101 ef	1086 ef	625 cd	563 de	3.0 fh	2.2 gh	0.83	0.39	0.16 gh	0.18 eg	0.28 f	0.43 df
L 28	703 g	776 g	414 fg	485 ef	8.1 a	4.6 cd	2.15	1.97	0.20 eg	0.25 bd	0.50 ce	0.85 a
L 12	1103 ef	1003 f	554 de	232 h	4.3 de	4.3 de	1.25	1.00	0.17 fh	0.15 h	0.36 ef	0.39 df
AC	2304 a	1248 de	1121 a	642 bd	3.2 fh	2.1 h	0.73	0.67	0.31 a	0.26 bc	0.53 cd	0.49 ce
HA 89	2320 a	1847 b	704 bc	371 g	4.5 de	3.5 ef	1.25	0.96	0.20 eg	0.21 df	0.47 ce	0.49 ce
L 56	1213 df	1404 d	492 ef	373 g	5.3 bd	3.9 df	1.34	0.90	0.14 h	0.15 h	0.41 df	0.54 cd

The fertility ratio (filled seeds/flower number at anthesis) was significantly lower under drought for all genotypes, except for HA343, L76 and L28 (Figure 2) and generally lower than the values found by Villalobos *et al.* (1994), probably due to the differences in environmental conditions between the two trials. Our trial was carried out under a partially-conditioned environment, while Villalobos *et al.* (1994) worked in the field. The seed weight (SW) under drought was significantly reduced in HA343 and L28 with respect to their controls, while the same value was nearly constant in all other genotypes (Table 4).

The seed growth rate (SGR) was higher under wet conditions than under drought (Table 4). L28 had the highest rate of growth (2.06 mg d^{-1}) as a mean across treatments, and L76 the lowest (0.61 mg d^{-1}, Table 4).

The harvest index (HI) was unaffected by drought in all genotypes, with the exception of HA343 and AC, which significantly reduced the HI, and L28, which improved its value from 0.20 to 0.25 under drought (Table 4). HI, as a mean across treatments, was highest in AC with values of 0.29 (Table 4), due to its particularly reduced height (semidwarf type).

Water use efficiency (WUE) was, on average, higher in the stressed treatments than in the control as found by other researchers in controlled experiments (Merrien *et al.*, 1981; Blanchet *et al.*, 1990; Flenet *et al.*, 1996), but, while the other genotypes had statistically similar WUE values to their controls, L28 exhibited a very high significant increase (about 70%) of the same character under drought (Table 4).

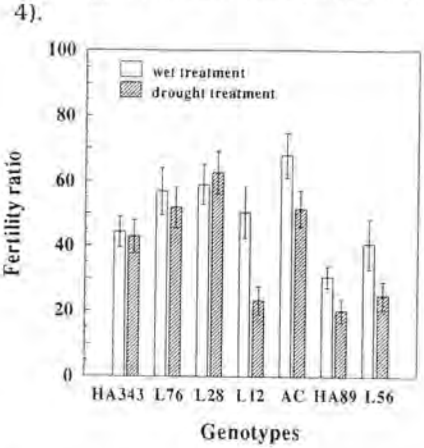

Figure 2: Fertility ratio (number of filled seeds/number of flowers) in sunflower genotypes under wet and drought treatments in tank conditions. Bars represent the standard deviation of the mean (n=3).

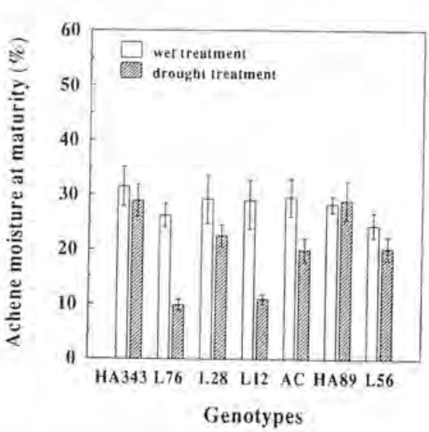

Figure 3: Seed moisture at physiological maturity in sunflower genotypes under wet and drought treatments in tank conditions. Bars represent the standard deviation of the mean (n=3).

Seed moisture content at maximum dry weight showed a slight variation between genotypes under wet conditions (Figure 3), but varied considerably from 9.9% (L76) to 28.9% (HA343 and HA89) under drought conditions, implying that seed moisture cannot be used as an indication of physiological maturity, especially under limited water availability.

No significant differences were observed in the S index values between field and pot conditions. The drought susceptibility index (S) showed L28 and L76 to be the most tolerant genotypes studied (Figure 4), with values of 0.67 and 0.68 under pot conditions, respectively. Figure 4 also shows that L28 had the lowest value of S under field conditions (0.63).

Field experiment

No significant effects of drought on the duration of the phenological periods were observed (Table 5). A significant variation was observed between the cultivars, as means across treatments, for sowing to flowering (SF), which ranged from 65 days for AC and L12 to 76 days for L76 and the flowering-physiological maturity period (FM) varied from 40 (L12) to 46 days (L28 and AC, Table 5).

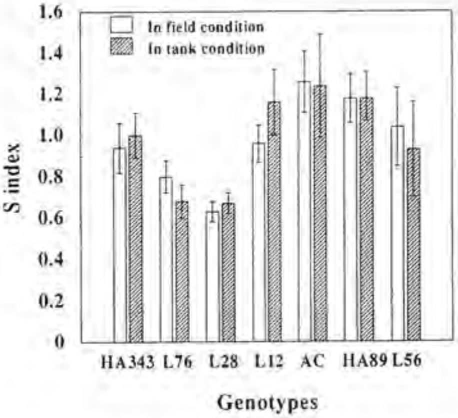

Figure 4: Drought susceptibility index (S) of sunflower genotypes in tank and field conditions. Bars represent the standard deviation of the mean (n=3).

Table 5: Mean sowing-flowering (SF) and flowering-physiological maturity (FM) periods, total dry weight (TDW), stover (leaf + steam + receptacle), dry weight (SDW), seed yield (SY), of sunflower genotypes grown in field in well-watered (wet) and drought (dry) conditions

	SF		FM		TDW		SDM		SY	
Treatment	days		days		$g\ m^{-2}$		$g\ m^{-2}$		$g\ m^{-2}$	
Wet	71		44		1106 a		868.8 a		255.3 a	
Dry	70		42		660.9 b		525.9 b		131.2 b	
Genotype										
HA 343	71		42		931.2 a		695.1 b		248.1 a	
L 76	76		42		797.1 bc		675.3 b		124.8 d	
L 28	74		46		905.7 ac		671.1 b		229.2 ab	
L 12	65		40		871.5 ac		725.1 b		161.4 d	
AC	65		46		723.0 c		523.8 c		199.2 bc	
HA 89	70		43		953.4 ab		753.3 ab		213.9 ac	
L 56	69		41		1009.2 a		837.9 a		176.4 cd	
Interaction	wet	dry	wet	dry	wet	dry	wet	dry	wet	dry
HA 343	72	71	44	41	1115.4	747.0	816.6	573.6	322.8 a	173.4 cf
L 76	77	76	42	43	931.8	650.4	795.0	555.6	154.8 dg	94.8 g
L 28	75	73	45	47	1138.8	672.6	871.2	471.0	271.2 bc	187.2 ce
L 12	66	64	42	38	1089.6	653.4	908.4	541.8	211.2 cd	111.6 fg
AC	65	65	49	44	987.0	459.0	697.8	349.8	289.2 ab	109.2 fg
HA 89	71	69	46	41	1199.4	707.4	925.8	580.8	301.2 ab	126.6 eg
L 56	69	69	43	39	1281.6	736.8	1066.8	609.0	237.0 bc	115.8 fg

Means followed with the same letter are not significantly different at P=0.05.

Both TDW and SDW, as mean values across genotypes, decreased significantly under drought conditions (Table 5).

Under drought conditions, the seed yield (SY) decreased significantly, by about 49% as a mean across genotypes, with respect to the control (Table 5). In particular, under drought, a significant reduction was observed in all genotypes with the exceptions of L76 (characterized by a low yield potential) and L28, with 29 and 31% reduction, respectively. The SY reduction under drought was probably due to different types of response in yield components, especially in grain number and grain weight, linked by a compensatory mechanism in sunflower, especially when the adjustment in number of grains takes place under drought (Gimenez and Fereres, 1986).

Table 6: Mean flowers per head (FN), filled seeds per head (FS), 100 seed weight (SW), and harvest index (HI) of sunflower genotypes grown in tanks in well-watered (wet) and drought (dry) conditions

	FN		FS		SW		HI	
Treatment	n		n		g			
Wet	1492 a		946 a		4.7 a		0.23 a	
Dry	967 b		654 b		3,4 b		0,20 b	
Genotype								
HA 343	1447 c		1024 a		4.0 b		0.26 a	
L 76	1144 b		716 c		2,9 c		0.16 c	
L 28	936 c		606 d		6.4 a		0.26 a	
L 12	1038 bc		666 cd		4.0 b		0.18 c	
AC	1478 a		974 a		3.3 bc		0.27 a	
HA 89	1377 a		877 b		4.0 b		0.22 b	
L 56	1188 b		739 c		3.9 b		0.17 c	
Interaction	wet	dry	wet	dry	wet	dry	wet	dry
HA 343	1693 b	1200 d	1056 c	992 e	5.1 bc	2.9 de	0.29 a	0.23 c
L 76	1302 cd	986 e	865 d	566 gh	3.0 de	2.8 de	0.17 d	0.15 d
L 28	984 e	887 e	569 gh	642 fg	7.9 a	4.9 bc	0.24 c	0.28 ab
L 12	1252 cd	823 e	856 de	475 h	4.1 bd	3.9 be	0.19 d	0.17 d
AC	2004 a	952 e	1352 a	596 gh	3.6 ce	3.1 de	0.29 a	0.24 c
HA 89	1788 b	966 e	1183 b	571 gh	4.2 bd	3.7 be	0.25 bc	0,18 d
L 56	1423 c	952 e	744 df	733 ef	5.3 b	2.4 e	0.18 d	0.16 d

Means followed with the same letter are not significantly different at P=0.05.

Table 6 shows that all genotypes had a significant reduction of filled seed (FS) per head and, simultaneously, a nearly constant individual seed weight under drought, with the exception of L56 and L28. The latter two genotypes (with HA343) had a significant decrease in individual seed weight, while their FS under drought did not significantly decrease with respect to the wet control (Table 6). The significant reduction of filled seeds under drought could have been due to the low capacity to tolerate low tissue water potential to correctly develop the pollination processes, such as anther dehiscence, pollen shedding, pollen germination, pollen viability and ovary metabolism (Connor and Sadras, 1992). In contrast, a low potential to mobilize pre-anthesis reserves towards the seed, combined with a limited supply of assimilated compounds to satisfy the sink request, as already reported for sunflowers by Sadras *et al.* (1992) and Hall *et al.* (1989), could be responsible for a reduction in the individual seed weight.

Harvest index (HI) was affected by drought treatment under field conditions (Table 6), as already observed in similar experiments (Fereres *et al.*, 1986; Turner and Rawson, 1982). The above result was due, in this experiment, to the strong reduction of HI in the cultivated genotypes (HA343, AC and HA89) under drought conditions with respect to their controls. The other genotypes coming from the wild population, were unaffected by drought, with L28 even improving its value from 0.24 to 0.28 (Table 6).

Figure 4 shows the significant and positive correlation (r=0.79**) between HI and seed yield in drought under field conditions, confirming that the greater susceptibility of some genotypes to drought could be due to their low HI values (Baldini *et al.*, 1992). The same association between HI and seed yield in partially conditioned environments was not observed. However, both the above correlation values increased significantly if the AC genotype, characterized by a reduced height (semi-dwarf type), was excluded from the analysis (Figure 5).

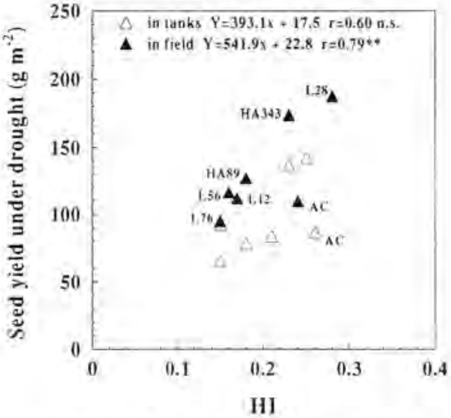

*Figure 5: Relationship between seed yield under drought and harvest index (HI) in tank and field conditions. Symbols represent the analyzed genotypes, Y the regression equations, r the correlation coefficients. *: $P < 0.05$; n.s.: not significant.*

In order to evaluate the effects of filled seed number and seed weight on seed yield under drought, the ratio of the number of filled seeds per head (FSd/FSw) and seed weight (SWd/SWw) between the dryland and the irrigated treatments were correlated with S. The results indicated a negative correlation between FSd/FSw and S (-0.75**) and no correlation between SWd/SWw and S (Table 7).

Table 7: Regression analysis of the ratio of full seed number (FSd/FSw), of the ratio of seed weight (SWd/SWw), of the seed yield under drought per head (SYd) and of the seed yield under wet condition (SYw) against the susceptibility index (S); a and b are coefficient of the equation, r is the correlation analysis and n is the number of data

Character	a	b	r	n
FSd/FSw	164.7	-92.9	-0.75**	21
SWd/SWw	53.5	19.2	0.25 n.s.	21
SYd	95.4	-44.9	-0.71**	21
SYw	24.4	6.03	0.15 n.s.	21

Thus, the genotype differences in S must be mostly attributed to adjustments in the number of filled seeds per head under dry conditions and not to individual seed weight, as already reported by Fereres *et al.* (1986).

Table 7 also shows a good correlation between S and seed yield under drought (SYd, -0.71**) and no correlation between S and seed yield under wet conditions

(SYw). These results, previously obtained by other authors (Fereres *et al.*, 1986; Baldini *et al.*, 1991), indicate that a high level of drought resistance and high yield potential may be combined in improved sunflower cultivars, suggesting that the selection for high yield potential genotypes in favorable areas should be an efficient selection criteria for identifying material suitable for drought-prone environments.

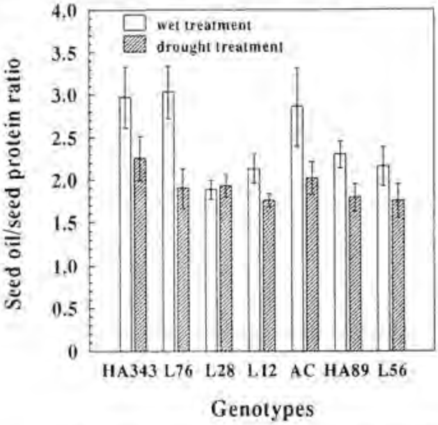

Figure 6: Seed oil/protein ratio (seed oil content/seed protein content) in sunflower genotypes under wet and drought treatments in field conditions. Bars represent the standard deviation of the mean (n=3).

The oil/protein ratio of seed under drought was lower than under wet conditions in all genotypes (Figure 6), as already reported by Blanchet and Merrien (1982). The exception, in our experiment, was L28, which had constant oil/protein ratio values (Figure 6). Steer *et al.* (1984) found that most protein accumulation in sunflower seeds occurs early, in the first anthesis period, while in contrast, accumulation of oil commences 7-14 days after first anthesis, reaching a maximum one week before physiological maturity (Goffner *et al.*, 1988). This asynchrony and continuing oil accumulation has the effect of diluting protein and may be the major cause of the inverse relationship between oil and protein concentrations in seeds (Goffner *et al.*, 1988; Connor and Sadras, 1992).

This study showed that, starting from a wild population with elevated genetic variability for physiological traits and selecting for high gas exchange and leaf hydration under drought, it was possible to obtain genotypes with a high tolerance to a terminal drought pattern, typical of Mediterranean environments. It appears difficult to compare the two experiments by the depth experimental condition differences, notwithstanding the efficiency under drought of L28 was shown by low S, high WUE and high HI values under drought in comparison to the wet controls, combined with an elevated yield potential. Its capability to compensate the yield components (filled seed number and individual seed weight) under drought, involving the mobilisation of pre-anthesis reserves to the seed, needs additional investigation and further confirmation under different environments.

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RENDIMIENTO, EN LAS CONDICIONES DE SEQUIA, DE GENOTIPOS DEL GIRASOL OBTENIDOS A BASE DE PABLACIONES SILVESTRES Y DEL GIRASOL CULTIVADO. EXPERIMENTOS EN GRANDES POTES PROTEGIDÓS CONTRA PRECIPITACIONES Y EN EL CAMPO

RESUMEN

El objetivo de estas investigaciones fue de constatar la influencia de diversos niveles de disponibilidad de agua sobre las propiedades agronomas principales de ciertas lineas inbred del girasol cultivado y de otras lineas inbred obtenidas por la seleccion divergente relativa a las propiedades fisiologicas de la especie silvestre *Helianthus argophyllus* T&G. Las investigaciones se hacian en el campo experimental de la Universidad en Udine bajo el tejado protector en 1996 y en el campo en 1997. Durante la fase de florecimiento, las plantas experimentales fueron expuestas al estres acuatico, que se retenia hasta la fase de madurez fisiologica. Entre los genotipos investigados en las condiciones de sequia, L28, escogido como la variante adicional de la poblacion investigada para el intercambio de gases y la hidratacion de tejido, ha sido el mas eficaz en la utilizacion de agua, teniendo el mejor indice de resistencia a la sequia y el indice de cosecha elevado. Las diferencias entre los genotipos con respecto a la resistencia a la sequis, que se manifestaron en la fase de sequia posterior, se atribuyeron generalmente al cambio del numero de granos rociados por cabeza y no por peso de granos singulares. Los resultados obtenidos mostran que los valores altos del indice de cosecha en las condiciones de sequia, los cuales son estrechamente liados con los rendimientos obtenidos en el cultivo con sequia, podrian servir, en presencia de variabilidad de genotipos, como un criterio de seleccion relativa a la resistencia a la sequia. La falta de correlacion entre la sensibilidad a la sequia y el potencial para el rendimiento de grano indica que el nivel alto de resistencia a la sequia y el potencial elevado para el rendimiento de grano pueden combinarse en las clases de girasol mejoradas.

RENDEMENT DES GÉNOTYPES DE TOURNESOL OBTENUS DE POPULATIONS SAUVAGES ET DE TOURNESOL DE CULTURE DANS DES CONDITIONS DE SÉCHERESSE. EXPÉRIENCES EFFECTUÉES DANS DE GRANDS RÉCIPIENTS ABRITÉS DE LA PLUIE ET DANS LES CHAMPS.

RÉSUMÉ

Le but de cette recherche était d'établir l'influence de différentes possibilités d'approvisionnement en eau sur les caractéristiques agronomiques les plus importantes de quelques lignes inbred de tournesol de culture et d'autres lignes inbred obtenues par une sélection divergente d'après les caractéristiques physiologiques de l'espèce sauvage *(Helianthus argophyllus* T&G*)*. L'expérience a été faite dans le champ expérimental de l'Université d'Udine en 1996 à l'abri de la pluie et en 1997 dans les champs. Au début de la phase de floraison, les semis expérimentaux ont été soumis au stress dû à la carence d'eau qui a été maintenu jusqu'à la phase de maturité physiologique. Parmi les génotypes examinés dans des conditions de sécheresse, le L28, choisi comme variante additionnelle de la population sauvage pour l'examen de l'échange de gaz et l'hydratation tissulaire, a montré la plus grande efficacité pour ce qui est de l'utilisation de l'eau, le meilleur index de résistance à la sécheresse et son index de récolte a augmenté. Pour ce qui concerne la résisstance à la sécheresse, les différences entre les génotypes qui sont apparues dans une phase tardive de la sécheresse ont été en général attribuées aux changements dans le nombre de graines arrosées par tête et non au poids de certaines graines. Les résultats obtenus indiquent que les hautes valeurs de l'index de récolte dans des conditions de sécheresse, qui sont étroitement liées aux rendements obtenus dans les champs, pourraient, en présence de la variabilité de génotypes, servir de critères de sélection pour la résistance à la sécheresse. L'absence de corrélation entre la sensibilité à la sécheresse et le potentiel de rendement de la graine montre que le haut niveau de résistance à la sécheresse et le grand potentiel de rendement de la graine peuvent être combinés pour l'amélioration des espèces de tournesol.

5) analysis of data which allow the interpretation of the G x E interaction, in particular, when we are in the situation of identifying a single genotype which is ideal for various environments with different types of stress,

Only after having obtained all these information and having analysed them in a combined and/or separate manner for each type of environment, will it be possible to supply a concrete contribution to those who work daily in these difficult environments and to accelerate the provision of material which is truly tolerant to water stress in each environment. Finally, help must also come from molecular marker technology, because difficulties in identifying and conducting reliable drought-resistance screens can be overcome by improving the efficiency of selection for drought resistance via the use of molecular markers.

Key words: Sunflower, agronomic traits, breeding, drought tollerance, environment, plant adaptation

INTRODUCTION

During last 20 years, crops of sunflower have extended throughout the European Mediterranean countries due to its capacity to adapt to dry environments. Although a plant moderately tolerant of drought, production from this oil crop is strongly influenced by the presence of water stress which is found fairly regularly.

In fact, summer drought is a permanent feature in Mediterranean areas and may also periodically influence the economies of the countries adjoining of the true Mediterranean zone from the north.

The threat from the trends in the global climate render this property ever more important. At a scientific level there is a mass of work on the relationship between water supply and plant yield, but most deal with crops under irrigation. In contrast, useful knowledge concerning the improvement of the species to environments with trophic, especially water, limitations are still scarce and fragmentary. In our paper we have attempted to establish the state of the art of research into the strategies to adopt for improving drought resistance in sunflower, whilst trying to identify which of the many agronomic factors may be used to improve the efficiency of selection processes. We have chosen not to consider the importance of physiological parameters, for reasons of brevity, even though the latter have often been used both by ourselves and other researchers when faced with genetic variability in the genus *Helianthus* obtained with interspecific crosses

European agriculture in the 1990's

The increase in yield per unit surface area, which was the main objective of European agriculture in the 1970's has, during the course of the overproduction of some crops in the 1990's, been joined by other objectives such as the improvement of quality, stability of yield and the need for sustainable agriculture, by which we mean agriculture with compatible the environment.