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EFFECTS OF OSMOTIC AND WATER STRESSES ON ROOT AND SHOOT MORPHOLOGY AND SEED YIELD IN SUNFLOWER (*Helianthus annuus* L.) GENOTYPES BRED FOR MOROCCO OR ISSUED FROM INTROGRESSION WITH *H. argophyllus* T. & G. AND *H. debilis* Nutt.

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SUMMARY

The effect of osmotic and water stresses on various morphological traits was studied in eight experimental varieties of sunflower bred for Moroccan conditions or issued from interspecific hybridization with *H.argophyllus* or *H.debilis*. Seed yield of the same genotypes was also evaluated under rainfed and irrigated field conditions. Shoot and root growth were significantly reduced by osmotic stress (-0.6 and -1.0 MPa) induced with polyethylene glycol (PEG 6000). Considerable genotype variation was expressed for all traits. Significant genotype by stress interaction was observed for root dry weight and volume as well as seed yield. The morphological traits were not related to seed yield in the correlation and principal component analyses. Four genotypes issued from introgression with *H.argophyllus* were grouped and distinct from other genotypes according to hierarchical ascending classification. One genotype issued from introgression with *H.debilis* and three non-introgressed sunflower varieties were found to be very distinct from each other and from those introgressed with *H.argophyllus*.

Key words: **sunflower, *Helianthus*, drought resistance, osmotic stress, root, introgression**

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INTRODUCTION

In 1996, Morocco was about 15% self-sufficient for vegetable oils. The domestic consumption of vegetable oil was about 442,000 t, of which about 66,000 t was essentially olive oil (40,000 t) and sunflower oil (25,000 t), both produced in Morocco from oil plants grown within the country (FAO and International Olive Council figures). Sunflower is therefore by far the main annual oil crop (about 75,000 to 100,000 ha harvested each year). In this country, rainfall shortage is the most important limiting factor of sunflower production. Our analysis of annual rainfall over 40 years in the Saïs area around Meknès, showed a 50% chance of sufficient rainfall to fill the soil water-holding capacity. Early planting (from mid-January to mid-February) has been carried out in an attempt to ensure good crop establishment and to avoid water stress during grain maturation in spring and summer. Unfortunately, erratic rainfall and low winter temperatures increase the hazards for crop establishment, with the result that this cultural practice is of limited benefit. Thus, failure of sunflower establishment and frequent drought occurring from flowering to maturity stages both severely reduce yield. The use of drought-tolerant genotypes could help to overcome these constraints.

Traits for stress tolerance breeding

Breeders are still looking for traits that are suitable for screening germplasm for characters affecting plant-water relations under drought conditions (Bittman and Simpson, 1989; Martin *et al.*, 1989; Al Hakimi *et al.*, 1995; Begg and Turner, 1996; Teulat *et al.*, 1997; Merah, 2001). The lack of a reliable method for identifying drought tolerant genotypes and the multitude of factors involved in tolerance to water stress makes it difficult to choose traits conferring an advantage under such conditions. However, osmotic adjustment (Moustafa *et al.*, 1996; Teulat *et al.*, 1997), relative water content in barley (Martin *et al.*, 1989) and wheat (Al Hakimi *et al.*, 1995; Merah, 2001), stomatal conductance (Martin *et al.*, 1989; Bittman and Simpson, 1989), leaf water potential in barley (Martin *et al.*, 1989) and wheat (Moustafa *et al.*, 1996; Seropian and Planchon, 1984) and leaf osmotic potential (Moustafa *et al.*, 1996; Teulat *et al.*, 1997; Merah, 2001) have all been identified as potential criteria for drought tolerance.

Root traits and stress tolerance

The kinetic parameters of mineral and water absorption and growth are neither constant nor homogeneous within the root system (Habib *et al.*, 1991). Moreover, the role of the root system in absorption also varies widely depending on the physiological status of the plant. Under conditions of limited water, water uptake from the soil by plants is directly related to root growth and extension (Hurd, 1974; Richard and Passioura, 1981). However, while root characteristics vary with edaphic and climatic conditions (Baldy, 1973; Souty, 1987), relationships between some root parameters and stress tolerance have been found in some species. Hurd (1974, 1976), Quisenberry (1982), Sullivan (1983) and Turner (1986) found positive correlations between seed yield and root development in cereals, especially in barley, wheat and sorghum. Matsuura *et al.* (1996) reported that total root length was reduced in maize but increased in sorghum and millet under water stress conditions. Khaldoun *et al.* (1990) found relationships between root dry weight and root volume under stress conditions in barley. Matsuura *et al.* (1996) also reported a positive relation between drought tolerance and root length in sorghum and millet. Lorens *et al.* (1987) reported that maize genotypes showed different root lengths and root densities and that these were reflected in differences in leaf water potential under limiting water conditions. Cruiziat (1974), Benlaribi *et al.* (1990), Ali Dib and Monneveux (1992) and Matsuura *et al.* (1996) hypothesized that a strong and extended root system of genotypes under water stress conditions might confer an advantage by increasing water supply to the shoot.

Sunflower root traits

Relatively few data are available on morphological and physiological root parameters of sunflower and related xerophytic species under abiotic stress. Sobrado and Turner (1986) compared *H.petiolaris* and sunflower in response to water deficits and found an increased percentage of deep roots in water stressed sunflower. A large range of genetic variation for root morphology has been described by Seiler (1994) among annual *Helianthus* species, including the cultivated sunflower. Rapid changes in sunflower shoot cells in response to the exposure of roots to polyethylene glycol have been described by Hebbar *et al.* (1994). Studies have also been undertaken on the role of hormones in the response of sunflower roots to abiotic stress. As early as 1973, Glinka investigated the effect of abscisic acid on sunflower roots and the relation with osmotic stress: application of abscisic acid increased the response to mannitol. Robertson *et al.* (1985) and Shashidar *et al.* (1996) found that water stress increased the abscisic content of roots. Several studies have been undertaken on the effect of drought on aeroponically grown sunflower. Hubick *et al.* (1986) compared the effect of drought on different hormones in roots and shoots of sunflower. They found that abscisic acid was higher in drought-affected plants while cytokinin levels were lower. Robertson *et al.* (1990a, 1990b) compared the effects of drought stress and abscisic acid and hypothesized that abscisic acid mediated drought-induced changes in the primary development of sunflower roots. Abida *et al.* (1994) found that root-shoot communication in drying soil was mediated by the stress hormones abscisic acid and cytokinins in sunflower.

Sunflower root cDNAs belonging to the tonoplast intrinsic protein family with differential response under water stress was isolated by Sarda *et al.* (1999). They proposed that these aquaporins could by involved in drought response in sunflower.

Helianthus biodiversity for abiotic stress tolerance. Sunflower (*Helianthus annuus* L.) is an oil crop with a narrow genetic background. Introgressed plants from wild forms and foreign species are used successfully by breeders (Korell *et al.*, 1996). Various attempts to characterize and use xerophytic *Helianthus* species in order to breed sunflower for tolerance have been developed (Baldini and Vannozzi, 1998). Serieys (1991) showed that transpiration rates and relative water content were heritable in a breeding experiment based on divergent selection for leaf permeability (i.e., excised leaf desiccation rate) in an interspecific hybrid between *H.argophyllus* and the cultivated sunflower (*H.annuus*). The present study examines the response of several morphological traits to osmotic stress induced by the osmoticant polyethylene glycol (PEG 6000). Eight genotypes of sunflower were used, of which 5 were issued from interspecific hybridization, and three varieties bred or adapted for drought stressed Moroccan conditions. The usefulness of morphological root and shoot characters as screening criteria for drought tolerance in sunflower is tentatively assessed.

MATERIALS AND METHODS

Plant materials

Eight sunflower genotypes (one commercial hybrid, six experimental hybrids and one population) including introgressed material issued from interspecific hybridization were used in the present investigation. Five three-way hybrids were obtained after crossing a cytoplasmic male sterile tester F_1 hybrid “63 × 10” with male parents issued from interspecific hybridization (Table 1). Males of the three-way hybrids A1 to A4 were issued from hybrids with *H.argophyllus* T.&G. Males T+1 (A1), T+2 (A2), T-18 (A3) are F_2 generation plants of the interspecific hybrid: *H.argophyllus* accession 92×sunflower (Serieys, 1991) individually bred for increased (+) or decreased (-) excised leaf desiccation traits related to leaf permeability and transpiration. Males ARG-REC-88 (A4) and DEB-DEB 88 (DE) are a bulked pollen sample of interspecific gene pools made in 1988 from crosses between *H.argophyllus* acc. 92 and 93 and sunflower, and *H.debilis* ssp. *debilis* acc. 215 and sunflower, respectively (Griveau *et al.* 1998). Genotype OR “Oro9” is an open-pollinated variety-population, bred and grown in Morocco, genotype MO “125 × 83HR4” is an experimental hybrid bred for Moroccan conditions, and FL “Flamme” commercial hybrid was bred for drought stressed conditions and used as a standard in Morocco.

Experimental conditions

Various levels of osmotic stress were induced by adding polyethylene glycol PEG 6000 to a commercial nutrient solution “Hakaphos” (15% N, 11% P and 15% K, plus microelements). Three osmotic pressures (0, -0.6 and -1.0 MPa) were applied to the 8 genotypes in a factorial design, with three replicates by osmotic pressure and plots of three seedlings per replicate.

Amounts of PEG were calculated (Ahmadi, 1983) from the osmotic pressure determined by an automated osmometer (Herman Roebling). Seeds were germinated in Petri dishes without osmotic stress, and seedlings transplanted into plastic containers (10 × 10 × 30 cm) containing sand issued from Biot French city as substrate (Cruiziat, 1974) and then grown in a greenhouse under continuous osmotic stress or no stress. Day / night temperature was 26°C / 20°C, respectively; relative humidity ranged from 60 to 70% and light intensity was about 20 klux. Seventeen days after transplantation, seedlings were harvested and separated into shoot and root parts. The two fractions were oven-dried at 80°C for 48h in order to obtain the root dry weight for 3 plants (RDW, mg) and shoot dry weight (SDW, mg). Root volume for 3 plants (RV, cm^3) was determined by the immersion method as described by Musick *et al.* (1965). Fresh plant height (PH, mm) and root length (RL, mm) were also recorded.

Seed yield (SY) in all genotypes was estimated both in rainfed and irrigated field conditions in Mauguio near Montpellier (France) in a separate design for field drought stress reaction during the 1990 cropping season. For one treatment, 300 mm irrigation was added to 150 mm water resources of soil. There was no rainfall between starbud-stage and physiological maturity. Five replicates of each treatment were harvested. Plant density was $6/m^2$.

Statistical analysis

We used SAS software (GLM procedure principal component analysis and cluster hierarchical ascending classification). The results of classification were obtained through squared Euclidean distance with the centroid method.

Table 1: Origin and main characteristics of the genotypes

Code	Genetic structure	Female parent	Male parent	Genetic origin of male parent	Observations
A1	Experimental 3 way hybrid	63×10	F_2 plant T+1	*H.argophyllus* 92 / Sunflower	Male selected for fast desiccation of excised leaf
A2	Experimental 3 way hybrid	63×10	F_2 plant T+2	*H.argophyllus* 92 / Sunflower	Male selected for fast desiccation of excised leaf
A3	Experimental 3 way hybrid	63×10	F_2 plant T-18	*H.argophyllus* 92 / Sunflower	Male selected for slow desiccation of excised leaf
A4	Experimental 3 way hybrid	63×10	ARG-REC-88 gene-pool	(*H.argophyllus* 92 and 93 / Sunflower) recurrent gene-pool	Interspecific gene pool
DE	Experimental 3 way hybrid	63×10	DEB-DEB-88 gene-pool	(*H.debilis* ssp. *debilis 215* / Sunflower) genepool	Interspecific gene-pool
OR	Variety-population	"Oro 9"	'Oro 9'		Open pollinated Variety Population bred in Morocco
MO	Experimental F_1 hybrid	125	83HR4	Complex cross between male fertility restorers	Drought tolerant hybrid bred for Morocco
FL	Commercial F_1 "Flamme"				Drought tolerant hybrid adapted in Morocco (Asgrow)

RESULTS

A) Effect of osmotic constraint on root system

Root dry weight. Osmotic constraint effect, genotype and the interaction between them were highly significant for root dry weight (RDW, Table 2) when compared with error. Osmotic constraint was significant ($p<0.005$) when compared with interaction. Genotype effect was not significant when compared with interaction. The 0 MPa treatment mean was found to be superior to –0.6 and –1.0 MPa, and the –0.6 MPa treatment was superior to –1.0 MPa treatment (Newman and Keuls test). Root dry weight of genotype A1 was significantly greater than the values of genotypes MO and FL with the same test (Figure 1). The effect of stress was particularly evident on genotype DE (Figure 1).

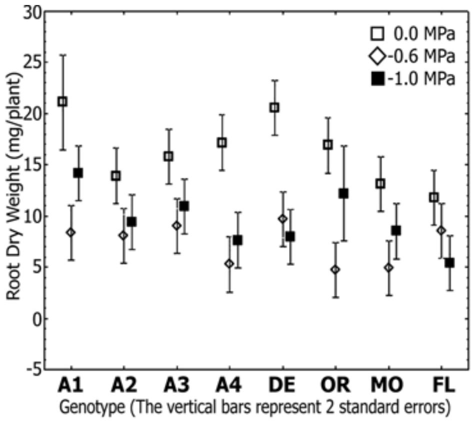

Figure 1: Root dry weight of genotypes in different stress conditions.

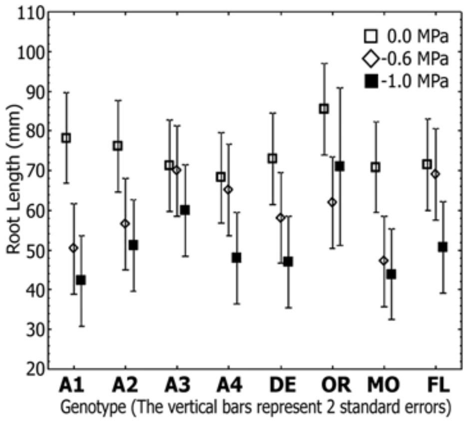

Figure 2: Root length of genotypes in different stress conditions.

Root length. The effects of osmotic constraint and genotype were highly significant whereas the interaction between genotype and osmotic treatment was not significant (Table 2). Root length (RL) was greatly reduced by osmotic stress and highly significant differences were noticed between the three osmotic treatments (Figure 2). Hybrids N°1 to DE were mostly intermediate between the extreme values of genotypes OR (high) and MO (low).

Root volume. The effects of osmotic constraint and genotype were both highly significant, as was the interaction between them (Table 2). Osmotic constraint was significant ($p<0.05$) when compared with interaction, while the genotype effect compared with interaction was not significant. Root volume (RV) was significantly reduced by osmotic stress for all genotypes tested (Figure 3). Root volume decreased as the osmolarity of the nutrient medium increased. The mean of the 0 MPa treatment was greater than those of the -0.6 and -1.0 MPa treatments. The -0.6 and -1.0 MPa treatments were not significantly different (Newman and Keuls test). A comparison of all the data means (Figure 3) suggested that the root volume of genotypes 1 and 5 was high and more affected by osmotic constraint compared with other genotypes. Root volume results were very similar to those for root dry weight (RDW).

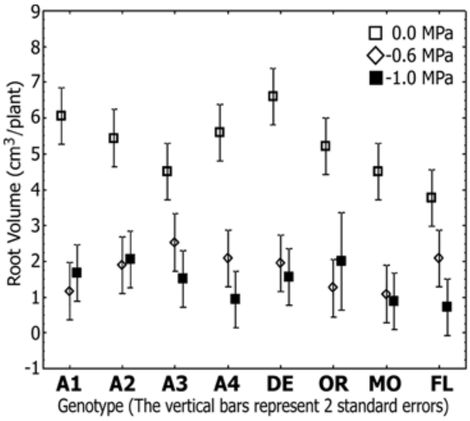

Figure 3: Root volume of genotypes in different stress conditions.

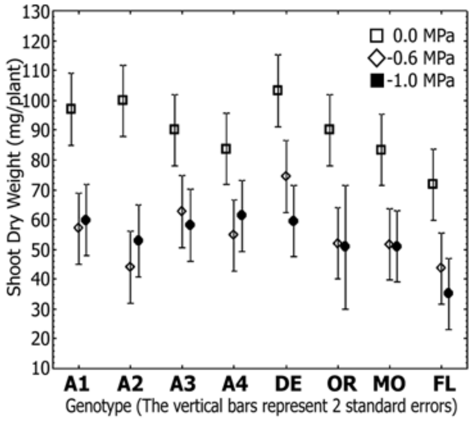

Figure 4: Shoot dry weight of genotypes in different stress conditions.

B) Effect of osmotic constraint on shoots

Shoot dry weight. The effects of osmotic treatment and genotype were also highly significant (Table 2). The interaction between genotype and osmotic treatment was not significant. Shoot dry weight (SDW) was drastically lower under induced osmotic stress conditions (Figure 4), but the reduction was similar at both -0.6 and -1.0 MPa, (-39% and -41%, respectively). The highest shoot dry weight was observed for genotype DE, the lowest for genotype FL.

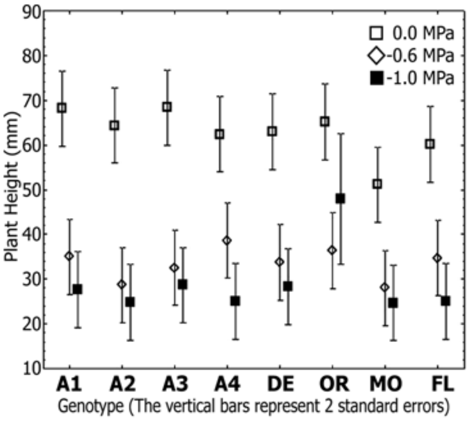

Figure 5: Plant height of genotypes in different stress conditions.

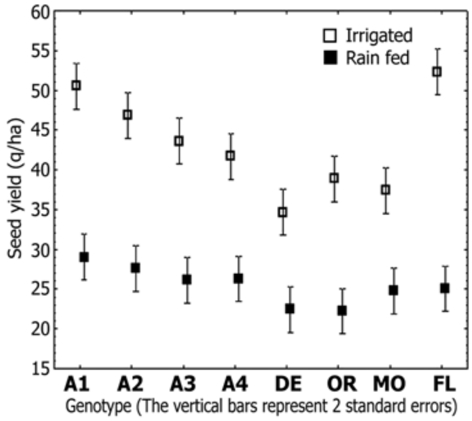

Figure 6: Seed yield of genotypes in different stress conditions.

Plant height. Osmotic treatment and genotype also had significant effects on plant height (Table 2), but the interaction between genotype and osmotic treatment was not significant: lowering the osmotic potential of the medium shortened plant height (PH) for all genotypes (Figure 5). The average percentage of reduction was 47% and 57%, at -0.6 MPa and -1.0 MPa, respectively. Genotypes MO and FL were shortest.

Table 2: Variance analysis for genotype, osmotic stress and interaction effects measured on root and shoot

Effect		Osmotic stress	Genotype	Interaction osmotic stress by genotype	Error
	D. F.	2	7	14	44
Root dry weight (RDW)	S.S.	898	206	212	234
	M.S.	449.0	29.5	15.1	5.3
	F test	84.4 ***	5.5 ***	2.8 ***	
	p	0.0000	0.0001	0.0041	
Root length (RL)	S.S.	5670	1574	1686	3573
	M.S.	2835	225	121	81
	F test	34.9 ***	2.8 **	1.5	
	p	0.0000	0.0178	0.1575	
Root volume (RV)	S.S.	174	11	16	20
	M.S.	86.9	1.6	1.11	0.46
	F test	188.4 ***	3.4 *	2.4 **	
	p	0.0000	0.00516	0.0128	
Shoot dry weight (SDW)	S.S.	16415	4236	1468	4879
	M.S.	8208	605	105	111
	F test	74.0 ***	5.5 ***	0.9	
	p	0.0000	0.0001	0.5207	
Plant height (PH)	S.S.	12555	883	647	2348
	M.S.	6277	126	46	53
	F test	117.6 ***	2.4 *	0.9	
	p	0.0000	0.0386	0.5978	

D.F.: degrees of freedom, S.S.: sum of squares, M.S.: mean square,
F test: Fisher test, p: associated probability.

C) Ratio of root dry weight to shoot dry weight

Osmotic stress induced a significant decrease of the RDW/SDW ratio in the -0.6 MPa treatment, but not in the -1.0 MPa treatment. Genotype effects on RDW / SDW ratio were not significant.

D) Field seed yield

Irrigation versus rainfed effect, genotype, and the interaction between them were all very highly significant (Table 3). Irrigation versus rainfed and genotype effects were significant ($p<0.05$) when compared with interaction. Irrigated yield was significantly higher for all genotypes (Newman and Keuls test). The highest seed yields in rainfed conditions were found in genotypes A1 to A4 (Figure 6). Genotype A1 was the highest yield in rainfed conditions and the second highest under irrigation, whereas genotype FL was the highest yield under irrigation and only the fifth under rainfed conditions.

Table 3: Variance analysis for field seed yield data, genotype, irrigation versus rainfed and interaction

Seed yield	Irrigated/rainfed	Genotype	Interaction irrigation/ rainfed by genotype	Error
D.F.	1	7	7	64
S.S.	6337	1155	426	657
M.S.	6337	165	61	10
F test	617.7	16.1	5.9	
p	0.000000	0.000000	0.000024	

D.F.: degrees of freedom, S.S.: sum of squares, M.S.: mean square,
F test: Fisher test, p: associated probability.

E) Correlation between traits

From the 136 correlation coefficients between the 17 elementary traits of the different genotypes, only 6 correlation coefficients were significant ($P<0.05$, 6 degrees of freedom): root dry weight at -1.0 MPa with root length at 0.0 MPa, root volume at 0 MPa with root dry weight at 0 MPa, root volume at 0 MPa with shoot dry weight at 0 MPa, root volume at 0 MPa with shoot dry weight at -1.0 MPa, root volume at -0.6 MPa with root length at -0.6 MPa.

From the 15 correlation coefficients between average traits across environments, 3 correlation coefficients were significant ($P<0.05$, 6 degrees of freedom): shoot dry weight with root dry weight, root dry weight with root volume, shoot dry weight with root volume.

F) Principal component analysis of traits and genotypes

A multivariate principal component analysis of the 8 genotypes for 6 traits (RDW, RL, RV, SDW, PH, SY) across osmotic and drought stress treatments was performed. Two principal components were extracted accounting for 74% of total variance in the analysis of genotype average over all treatments (Figure 7) and 51% of total variance of genotype by treatment means. Root dry weight, root volume and shoot dry weight means were tightly grouped, well separated from the other trait means (root length, plant height, seed yield). The last 3 trait means were not grouped (Figure 7).

Hierarchical ascending classification of genotypes based on the 17 elementary trait means (Figure 8) clearly showed that the grouping of genotypes A1 to A4 introgressed from *H.argophyllus*. The other genotypes (OR, MO, FL, i.e., *H.annuus* sunflower varieties) and DE (introgressed from *H.debilis*) were very far from the genotypes introgressed by *H.argophyllus* and very distant from each other also.

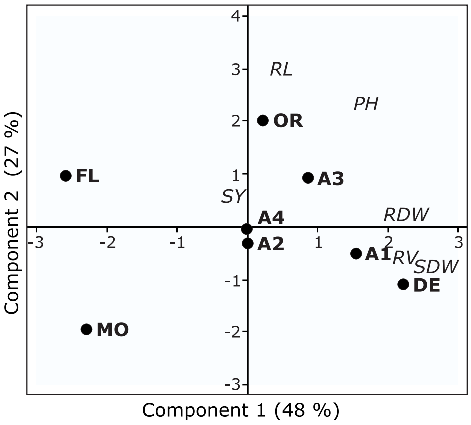

Figure 7: Principal component analysis of genotypes and traits.

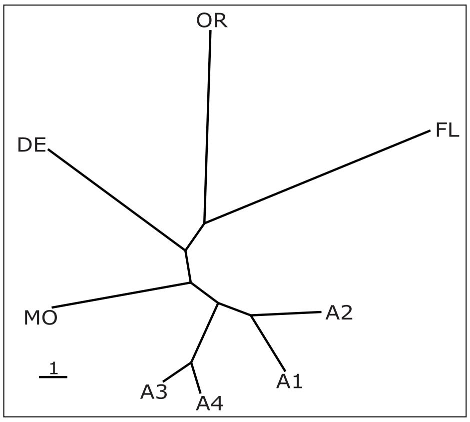

Figure 8: Ascending hierarchical classification of genotypes.

DISCUSSION

Stress effects

The results showed that osmotic stress induced by PEG 6000 had marked effects on both shoot and root parameters (Table 2). The reduction in shoot and root growth was most important at -1.0 MPa and affected root volume and root length. These results and those reported by El Midaoui (1993) suggest a close relationship between root volume and root dry weight. Reduction of root volume under osmotic stress originates not only from growth inhibition but also from a loss of turgidity, as reported in cotton (Huck *et al.*, 1970), sugar beet (Wendel and Davis, 1973) and wheat (Benlaribi *et al.*, 1990; Ali Dib and Monneveux, 1992).

Osmotic stress reduced the overall root growth rate but did not affect different plant organs in the same way. Root growth was more sensitive to the reduction of osmotic pressure than was shoot growth. The RDW / SDW ratio, high in the absence of PEG 6000, declined when the osmotic potential of the medium was decreased after adding PEG 6000. Jokhan *et al.* (1996) also reported that the ratio changed under drought conditions in castor bean.

Drought effect on seed yield was very strong, possibly in relation with duration of rain privation from flowering until physiological maturity.

Genotype effects

Significant differences were recorded among genotypes for root dry weight (RDW), root volume (RV), root length (RL), shoot dry weight (SDW), and plant height (PH). Root volume (Figure 3) was significantly lower for the Moroccan variety "Oro 9" (OR), the experimental hybrid 125×84HR4 (MO) and the commercial F_1 "Flamme" (FL) in contrast with the hybrids issued from introgression by *H.argophyllus* or *H.debilis* (A1 to DE).

Genotype×stress interaction effects

The varied response of the genotypes for root dry weight and root volume, to the intensity of the stress (treatment × genotype interaction) was significant.

This is to compare with results on other species such as soybean (Maertens *et al.*, 1987), rice (Ahmadi, 1983), barley (Khaldoun *et al.*, 1990), wheat (Benlaribi *et al.*, 1990; Ali Dib et Monneveux, 1992), corn, sorghum and millet (Matsuura *et al.*, 1996).

The detailed observation of means (Figure 1) suggested that the root dry weight of genotypes A1 and DE of interspecific origin was high and could be relatively more affected by osmotic constraint compared with other genotypes. Among the genotypes tested, the hybrid (63 × 10) × (T+1) (A1) introgressed from *H.argophyllus* showed the highest root dry weight and the cultivated varieties "Oro 9" (OR) and "Flamme" (FL) the lowest when irrigated with osmoticant PEG 6000 solution (-1 MPa).

Analysis of seed yield (Table 3) of the same sample of genotypes under field drought stress conditions showed that experimental hybrids A1 to A4, bred from *H.argophyllus* interspecific germplasm, produced the highest seed yield under rainfed or irrigated conditions and were conversely characterized by a higher root dry weight in comparison with DE (introgressed from *H.debilis*) and OR to FL (conventional sunflower varieties with some adaptation to Moroccan conditions).

Synthesis and concluding remarks

Much variation in root traits and seed yield was found between genotypes, stress, and the interaction of genotype by stress.

From the principal component analysis of traits across osmotic stress treatments (Figure 7), the distance of root length and plant height traits from each other and from other traits is difficult to interpret.

Root dry weight and shoot dry weight appeared to be associated in the same analysis and significantly correlated across osmotic stress treatments. This was coherent with the fact that RDW / SDW genotype effects were not significant in this study, even if RDW / SDW osmotic stress effects across genotypes were significant.

Seed yield (rainfed or irrigated or both), was set on its own, far apart from the points of other traits. Seed yield was never found correlated to another trait in this study. Taking in consideration the difference in experimental design for field yield and osmotic stress, however, this suggests that, according to this study, the possibility of predicting yield by using such morphological traits is not assessed.

The genotypes issued from introgression with *H.argophyllus* were grouped in the hierarchical ascending classification (Figure 8). In contrast, 3 intra-specific varieties "Flamme" (FL), 125 × 83HR4 (MO) and population "Oro 9" (OR) that yielded significantly less compared with the other genotypes under rainfed conditions, displayed the lowest root volume and root dry weight. Root dry weight, root volume, shoot dry weight under osmotic stress and seed yield under rainfed conditions appeared significantly higher in the introgressed hybrids compared with the intraspecific genotypes.

Genotype DE, issued from introgression from *H.debilis,* was also very distant from other genotypes.

These results should be compared with other studies indicating an increase in root / shoot ratio under drought stress in the wild species *H.argophyllus* compared with classical sunflower inbred lines (Baldini *et al.*, 1993).

These experiments strengthen us in the opinion that studies on sunflower response to water stress should make use of a broad genetic background including wild *Helianthus* species.

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INFLUENCIA DEL ESTRÉS OSMÓTICO E HÍDRICO EN LA MORFOLOGÍA DE RAÍZ Y BROTES Y RENDIMIENTO DE SEMILLA EN GENOTIPOS DE GIRASOL (*Helianthus annuus* L.) CREADOS PARA LAS CONDICIONES MAROQUÍES U OBTENIDOS POR LA INTROGRESIÓN CON ESPECIES *H.argophyllus* T.&G. Y *H.debilis* Nutt.

RESUMEN

La influencia del estrés osmótico e hídrico se ha estudiado en ocho variedades experimentales de girasol, creadas para las condiciones de Marruecos o las interespecies obtenidas por hibridización con la especie *H.argophyllus* o *H.debilis*. En el campo también fue investigado el rendimiento de la semilla de los mismos genotipos en condiciones de precipitaciones naturales y en las condiciones de riego. El estrés osmótico, inducido por polietilenglicolo (PEG 6000), disminuyó significativamente el crecimiento de brotes y de raíz (-0,6 y –1,0 Mpa). La significante variabilidad genotípica se ha manifestado para todas las características. Se ha determinado una significante interacción de genotipo x estrés para la masa seca y el volumen de la raíz, tanto como para el rendimiento de la semilla. El análisis correlativo y el análisis de componentes principales, han demostrado que las propiedades morfológicas investigadas no tenían que ver con el rendimiento de semilla. Según los resultados del análisis HAC (Hierarchical Ascending Classification), se ha apartado un grupo de cuatro genotipos, obtenido por introgresión con la especie *H.argophyllus*, que se diferenciaban claramente de los demás genotipos. Un genotipo creado por introgresión con la especie *H.debilis* y tres variedades de girasol no-introgesadas, destacadamente se diferenciaban una de la otra, tanto como de los genotipos obtenidos por introgresión con la especie *H.argophyllus*.

EFFET DE CONTRAINTES OSMOTIQUES ET HYDRIQUES SUR DES CARACTÈRES AÉRIENS, RACINAIRES ET DE RENDEMENT SUR DES GÉNOTYPES DE TOURNESOL (*Helianthus annuus* L.) SÉLECTIONNÉS POUR LE MAROC OU ISSUS D'INTROGRESSION PAR *H.argophyllus* T. & G. et *H.debilis* Nutt.

RÉSUMÉ

L'effet de contraintes osmotiques et hydriques sur différents caractères morphologiques a été étudié chez 8 génotypes de tournesol sélectionnés pour les conditions marocaines ou issus de croisements avec *H.argophyllus* ou *H.debilis*. Le rendement en grain des mêmes génotypes a également été étudié au champ en conditions pluviales ou irriguées. La croissance aérienne et racinaire a été significativement réduite par la contrainte osmotique exercée par le Polyéthylène Glycol (PEG 6000) à raison de –0.6 ou –1.0 MPa dans la solution nutritive. Une variation génétique importante a été mise en évidence pour tous les caractères. Une interaction significative entre génotype et contrainte a été observée pour la matière sèche racinaire et le volume racinaire ainsi que le rendement en grain. Les caractères morphologiques n'ont pas été corrélés au rendement en grain. La classification ascendante hiérarchique des génotypes a fait apparaître un regroupement entre les 4 génotypes issus de l'introgression par *H.argophyllus*. Un génotype issu d'introgression par *H.debilis* et les 4 génotypes non introgressés sont apparus très distincts les uns des autres ainsi que des génotypes issus d'introgression par *H.argophyllus*.