OSMOTIC ADJUSTMENT, ITS EFFECTS ON YIELD MAINTENANCE UNDER DROUGHT IN SUNFLOWER.

Claudio Chimenti, **Jorgelina Giuliano**, and **Antonio Hall**, IFEVA, Facultad de Agronomía (UBA)/CONICET, Departamento de Biología aplicada y Alimentos, Avda. San Martín 4453 (1417DSE), Buenos Aires, Argentina
E-mail: chimenti@agro.uba.ar
E-mail: giuliano@agro.uba.ar
E-mail: hall@agro.uba.ar

Abstract

Families derived from crosses between lines exhibiting high and low capacities for osmotic adjustment via disruptive selection were grown under a rain-out shelter and subjected to a 36-day drought starting at anthesis. High osmotic adjustment families extracted more water from the profile during the stress period, and had greater grain yield and leaf area duration than families with a low degree of osmotic adjustment. There was no effect of osmotic adjustment on these variables in the irrigated controls. Grain size and number were the yield components most affected by the level of osmotic adjustment. We conclude that osmotic adjustment can contribute to post-anthesis drought tolerance in sunflower through increased water uptake, reduced impact on grain number, grain size and greater leaf area duration.

Introduction

The identification of attributes useful in the process of screening genotypes for drought tolerance is a major challenge to the plant breeder. Improved drought tolerance involves the identification of physiological traits responsible for drought resistance in high-yielding cultivars. While disagreement and even confusion may characterize some of the discussions on what constitutes a significant and effective mechanism of drought resistance in crop plants, osmotic adjustment (OA) is receiving increasing recognition as a major mechanism (Zhang et al., 1999). OA is an effective component of drought tolerance, which has a positive direct or indirect effect on plant productivity under drought stress (Ludlow and Muchow, 1990).

An evaluation of the usefulness of this trait for drought tolerance in sunflower must be grounded on the demonstration of an association between yield maintenance under water stress and the capacity for OA in cultivars of similar genetic background. Chimenti et al. (2002) demonstrated a strong association between OA, water uptake and yield maintenance in families with different level of OA exposed to water stress deficit during a period immediately prior to anthesis. The present paper contains results of an evaluation of the effect of varying OA on crop water extraction patterns, leaf area duration and grain yield production in F5 families exposed to water stress during anthesis and grain-filling.

Materials and Methods

Growth Conditions and Applications of Water Stress. Plots of four families, two of high (#28 and #47) and two of low (#25 and #37) OA, obtained via disruptive selection from initial crossing between lines exhibiting high and low OA, were grown under a 6-block rain shelter. Each block was fitted with a separately controlled set of drip irrigation lines. There were two treatments (control and water deficit) and three replicates per genotype. Each replicate F5 family plot had five rows, 0.65 m apart and 3 m long, and plant population density was 5.6 plants m sq. There were three border plants at the extremes of each row and two border rows at the outer limits of the experiment. Contiguous plots were not separated by paths. Soil was an 180 cm deep layer of typical argiudol plow layer resting on native loess (C-horizon). Each treatment block was isolated from contiguous blocks and the surrounding area by 2m deep 500 µm polyethylene film barriers to impede lateral flow of water. Within each block, family plots were contiguous and randomly arranged. At R5 stage (R5=anthesis, Schneiter and Miller, (1981) the irrigation in the drought blocks was cut off until the crop reached the R8/R9 stage (R8= back of the head is yellow but the bracts remain green, R9=the bracts become yellow and brown; this stage is regarded as physiological maturity). Families did not differ in development or morphology. The water deficit period lasted 36 days. Stressed plots were irrigated again when wilting became widespread (at least the lower two-thirds of all leaf positions). This effect was more noticeable in the low OA plots, which also exhibited wilted leaves in the upper one-third of the stem. During the anthesis period the capitula were covered and each family/treatment was pollinated with its own pollen.

Water Status Measurements. Osmotic adjustment was estimated at full turgor on the basis of the method described by Turner (1981), using the youngest fully expanded leaves from three plants per family, treatment and replicate of the control and water deficit treatments. These were sampled at predawn on three occasions (6, 15 and 35 days after cutting off irrigation) during the drying cycle. Soil water content at the beginning and end of the stress period was measured gravimetrically at 20cm intervals to a depth of 2.0 m. Soil water extraction was estimated as the difference between initial and final values of soil water. Total soil water extraction for the entire profile was taken as the sum of the soil water extracted in all soil layers.

Leaf Area Measurements. Before anthesis, twice-weekly observations of leaf area per plant were made on six plants per treatment. Individual leaf area was estimated from measurements of leaf width (Pereyra et al., 1982). Leaf area duration was estimated as the integral of functions fitted to the relationship between leaf area per plant and time.

Grain Yield. At the end of anthesis and at physiological maturity, six capitula of plants exposed to full competition per family, treatment and replicate were harvested from the central rows of each plot. Floret number was determined from the anthesis samples, and reproductive structure number from capitula harvested at physiological maturity. The latter were separated into non-functional flowers (those showing no development of the pericarp and with non-dehiscent floral organs), flats (empty hulls) and filled grain, and counted. Grains were dried and weighed, and individual grain weight was determined on a sample of 200 grain per family, treatment and replicate.

Statistical Analyses. Factorial analysis of variance was used to establish the significance of differences among treatments, families and level of OA.

Results

Differences between families in OA at full turgor measured at the end of the stress period were significant ($p = 0.05$) (0.5 and 0.42 MPa for families #47 and #28 [high OA] and 0.20 and 0.10 MPa for families # 37 and # 25 [low OA] respectively). The separation between high and low OA families identified in previous work was maintained. The OA values of the families increased from the beginning to the end of the stress period, while in the low level families there were no changes during this period (data not shown).

There were significant ($p = 0.001$) effects of stress on total (0-200 cm) soil water extraction during the drought period (Table 1). No differences were found between families in the control treatment (Table 1). During the stress period the high OA families extracted 17.4 % more than the low OA families, and below 1.20 m water extraction was significantly ($p < 0.001$) greater in the high OA families (# 47= 40.8 mm; # 28 = 28.4 mm; # 25 = 11.7 mm and # 37 = 4.7 mm).

Table 1. Mean values (n=3) for grain yield, its components and soil water extraction during the water stress period for F5 families with differing capacity for OA (#25 and #37, low OA; #47 and #28, high OA). Different letters within the same column indicate significant differences [($p< 0.05$) for grain yield and grain number and ($p= 0.001$) for grain size and soil water extraction]. T = control; S = water stress. Soil water extraction was measured for the 0-200 cm soil layer.

Family/treatment	Grain yield (g /plant)	Grain number (grain/capitulum)	Grain size (mg/grain)	Soil water extraction (mm)
37 T	60.7 a	1160 a	55.3 a	179.7 a
25 T	56.8 a	1160 a	49.2 a	183.8 a
47 T	55.4 ab	1056 abc	52.3 a	195.6 a
28 T	51.0 abc	1056 abc	47.0 a	196.3 a
28 S	44.6 bc	1056 abc	41.6 b	116.3 b
47 S	41.8 c	1024 abc	41.6 b	119.2 b
25 S	35.6 d	968 bc	35.9 c	78.5 c
37 S	29.0 d	944 c	34.0 c	76.6 c

Treatment by family interactions for grain yield were attributable to the absence of a family effect under control conditions and effects of stress on yield which varied between large and significant ($p < 0.05$) in families # 25 and 37 to small and nonsignificant in family # 28 (Table 1). The mean yield for the high OA group was 25% greater than the low OA group (Table 1). No effect of family, treatment or OA was found for floret number at anthesis; flats or non-functional flowers (data not shown). Grain size was significantly ($p = 0.001$) reduced by stress: the mean size of the low OA group was 33% lower than the high OA group (Table 1). Water stress significantly ($p < 0.05$) reduced grain number in the families with low OA, no effect was found in high OA families (Table 1).

The water stress significantly ($p < 0.001$) reduced the leaf area duration (Table 2) in the droughted treatment. These reductions were 13% for the high OA families and 55 % for the low OA families.

Table 2. Mean values (n=3) for leaf area duration (m2 plant-1 day) during the whole water stress period, and during anthesis and post-anthesis sub-periods for F5 families with differing capacity for OA (#25 and #37, low OA; #47 and #28, High OA). Different letters within the same column indicate significant differences ($p < 0.001$). T = control; S = water stress. Values in brackets after label of each column are durations (days) of the period (sub-period).

Family/treatment	Water stress (36)	Anthesis (15)	Post-anthesis (21)
37 T	24.8 a	5.9 a	21.6 a
28 T	20.1 ab	5.0 abc	16.4 b
47 T	19.6 b	5.7 a	14.8 b
25 T	19.4 b	5.2 ab	19.3 b
28 S	18.3 b	4.2 bcd	14.4 b
47 S	16.7 b	4.0 cde	12.7 b
37 S	10.2 c	3.6 de	4.9 c
25 S	9.3 c	3.0 e	4.0 c

Discussion

The differences in the levels of expression of the OA were associated with important differences in the soil water extraction of the different families (Table 1), particularly from the soil layers below 120 cm. This suggests greater growth and functionality of the root systems at depth for high OA families in relation to the families with low levels of OA. The differences in the water extraction between the drought treatments were clearly reflected in the leaf area duration differences during the water stress period (Figure 1).

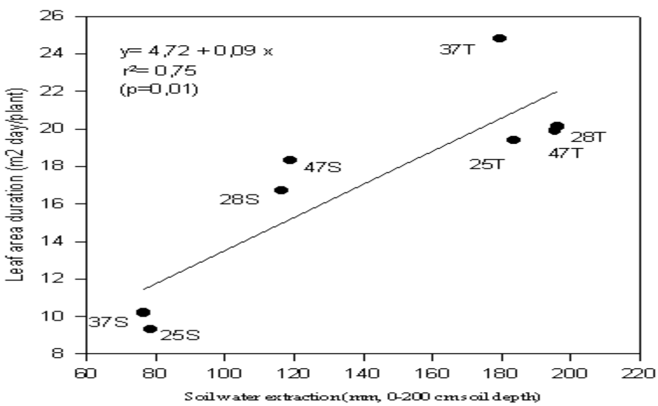
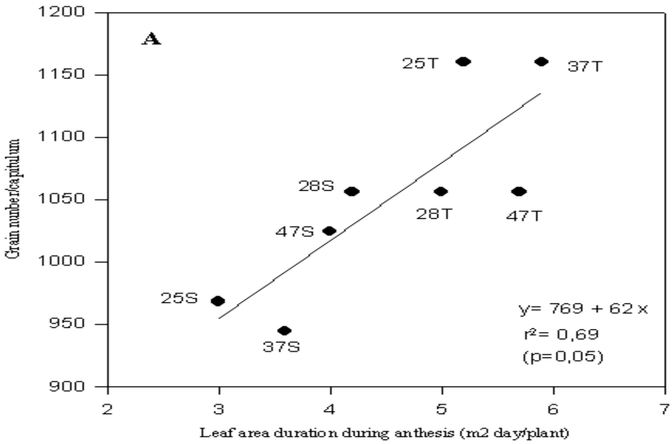


Figure 1. Relation between leaf area duration and soil water extraction (mm) during the water stress period for F5 families with differing capacity for OA (#25 and #37, low OA; #47 and #28, High OA). T= control; S = water stress.

Grain yield in all families was reduced by water stress, but in the families with high levels of OA this reduction was less than in those families with low levels of OA (Table 1). These differences in grain yield were associated exclusively with the expression of OA under drought, and no significant differences in grain yield were observed between families with different levels of OA in the irrigated treatment (Table 1).

The effects of OA appear to be related to the maintenance of different morphophysiological processes linked to grain yield determination. For example, grain number per capitulum proved to be associated with leaf area duration during anthesis (Figure 2A); while both grain size and grain yield were associated with post-anthesis leaf area duration (Figure 2B).



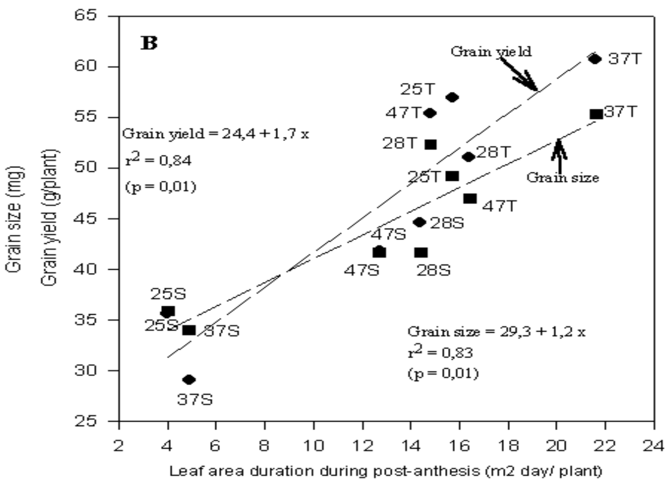


Figure 2. Relation between A) Grain number per capitulum and leaf area duration during the anthesis sub-period (m2 day/plant) and B) grain yield (g per plant) and grain size (mg per grain) and leaf area duration in the post-anthesis sub-period for F4 families with differing capacity for OA (#25 and #37, low OA; #47 and #28, High OA). T= control; S = water stress.

Finally, it is important to note that the families with low levels of OA exposed to water stress yielded the equivalent of 1.8 ton per hectare, a commercially significant amount. High

OA families yielded 35% more when exposed to drought, again a potentially interesting increase in commercial terms. Clearly, in sunflower, OA is not just a survival mechanism but a trait that can contribute to commercially significant levels of yield maintenance under quite extended droughts (36 days in the present case). These results, together with those obtained by Chimenti et al. (2002), clearly indicate the importance of the OA as an attribute that can contribute to the maintenance of the grain yield in sunflower during both anthesis and post-anthesis droughts.

References

Chimenti, C.A., Pearson, J. and Hall, A.J. 2002. Field Crops Res. 75:235-246.

Ludlow, M.M. and Muchow, R.C.. 1990. Adv. Agron. 43:107-152.

Pereyra, V.R., Farizio, C. and Cardinali, F. 1992. Proceedings of the 10th International Sunflower Conference. March 1982, Surfers Paradise, Qld. Australian Sunflower Association Toowoomba. Qld., pp 21-23.

Schneiter, A.A. and Miller, J.F.. 1981. Crop Sci. 21, 901-903.

Turner, N.C. 1981. Plant Soil. 53:339-366.

Zhang, J., Nguyen, H.T. and Blum, A.1999. J. Exp. Bot. 50:291-302.