Performance and some physiological traits of Iranian corn (*Zea mays* L.) varieties as impelled by drought stress

Comportamiento y algunos caracteres de variedades iraníes de maíz (*Zea mays* L.) afectadas por el estrés hídrico

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ABSTRACT

Plants are exposed to various environmental stresses. One of these factors is the amount of accessible water, which restricts the crop production. To study the effect of water deficit on physiological traits of five corn varieties (SC108, SC500, SC647, SC700 and SC704) at both vegetative and reproductive stages, two separate field experiments were carried out based on a randomized complete blocks design with five replications. Furthermore, by using poly ethylene glycol (PEG) 6000, the influence of dehydration on both normal and stressed seeds of field experiment was assessed in glasshouse. Results revealed that grain yield (-48%), relative water content (-26%), leaf chlorophyll (-32%) decreased and electrical conductivity (+98%), potassium (+104%), carbohydrates (+47%) contents increased under drought. Maximum and minimum grain yield were obtained in SC704 and SC108, respectively. In glasshouse experiments, radicle and plumule length and dry weight declined when comparing to non-stress conditions. SC704 and SC500 were identified as the most tolerant varieties at both field and glasshouse experiments, respectively. None of the stressed seeds of the field experiment germinated using PEG 6000.

Key words*:* Corn varieties, drought stress, polyethylene glycol.

RESUMEN

Las plantas están expuestas a varios estreses ambientales. Uno de estos factores es la cantidad de agua accesible, lo que limita la producción de cultivos. Para estudiar el efecto del déficit hídrico sobre los caracteres fisiológicos de cinco variedades de maíz (SC108, SC500, SC647, SC700 y SC704) en las etapas vegetativas y reproductivas, se realizaron dos experimentos de campo independientes en un diseño de bloques completos al azar con cinco repeticiones. Además, mediante el uso de poly ethylene glycol (PEG) 6000, se evaluó en el invernadero, la influencia de la deshidratación de semillas normales y bajo estrés provenientes del experimento de campo. Los resultados revelaron que el rendimiento de granos (-48%), contenido relativo de agua (-26%) y la clorofila en las hojas (-32%) disminuyeron y la conductividad eléctrica (+98%), potasio (+104%) y contenido de carbohidratos (+47%) aumentaron bajo la sequedad. El rendimiento máximo y mínimo del grano fue obtenido para las variedades SC704 y SC108, respectivamente. En los experimentos de invernadero, la longitud y peso seco de las raíces y de la plúmula se redujeron en comparación con la condición sin estrés. SC704 y SC500 se identificaron como las variedades más tolerantes en experimentos de campo y de invernadero, respectivamente. Ninguna de las semillas bajo estrés del experimento de campo germinó utilizando PEG 6000.

Palabras clave: Variedades de maíz, estrés hídrico, polietilenglicol

INTRODUCTION

Corn is the most important cereal in the world after wheat and rice (Lerner and Dona, 2005). Drought stress reduces grain yield by three main mechanisms (Hugh and Davis 2003): (1) photosynthetically active radiation (PAR) absorption by whole-canopy may be decreased (Xianshi *et al.*, 1998); (2) drought decreases the efficiency with which absorbed PAR is used by the crop to produce new dry matter (Stone *et al.*, 2001) or, as a reduction in the whole-canopy net CO_2 exchange rate (Jones and Setter, 2000); and (3) drought may limit grain yield by reducing the harvest index (REF).

Several researchers indicated that different levels of drought stress could cause limit of corn grain yield (Hugh and Davis 2003; Osborne *et al.*, 2002). Grain yield is closely associated with kernel number at harvest time (Otegui and Andrade, 2000). Early kernel growth and development in corn is highly dependent on assimilate supply concurrent photosynthesis (Zinselmier *et al.*, 2000). According to Andrade *et al.* (2002) and Banziger *et al.* (2002) crop stresses imposed during flowering have similar adverse effects on the physiological status. This in turn, adversely affects the ability of corn plant to set kernels during critical reproductive growth stages.

Corn is thought to be susceptible to stress at flowering, because of the large distance between male and female organs, exposing pollen and fragile stigmatic tissue to desiccating conditions during pollination (Banziger *et al.*, 2000). Finally, silk growth and kernel number are extremely sensitive to PAR availability during flowering (Schussler and Westgate, 1991). Studies comparing the response of different levels of susceptible varieties found tolerant genotypes set more grains than susceptible ones (Tollenaar *et al.*, 1992). The aim of this study was to investigate the influence of drought on corn varieties and determine the most suitable genotypes for the alike climate conditions in both whole and seedling stages.

MATERIALS AND METHODS

Field experiment

During the growing season of 2006-2007, two separate field experiments were conducted at Kahriz station (37.53N, 45.10E) of Agricultural Research Center of Western Azerbaijan, Iran. Meteorological parameters of the region are detailed in Table 1. Seeds of five corn varieties (SC108, SC500, SC647, SC700 and SC704) (SC: single cross) were planted on June 25th 2006 following furrow. Fertilizer applications were made at pre-sowing (45 Kg N ha^{-1}, 60 Kg P ha^{-1} and 75 Kg K ha^{-1}) and topdressing (135 Kg N ha^{-1}). The experiment was arranged in two separate randomized complete blocks design with five replications close to each other. Water treatments (withholding and adequate irrigation) were conducted at two vegetative growth stages (around 8 leaves) and after pollination.

During vegetative stage, around 10 leaves, the concentration of non-structural carbohydrates was determined by using an ATAGO refractometre Relative water content (RWC) and relative water loss (RWL) were calculated according to Gonzalez *et al.* (1999) and Clark and McCaig (1982), respectively, where, W_0 Sample fresh weight, W_2 and W_4 sample weight in 2 hr intervals.

$$RWC = \frac{\text{Fresh weight - Dry weight}}{\text{Saturated weight - Dry weight}} \times 100$$

and

$$RWL = \frac{(W_0 - W_2) + (W_2 - W_4)}{2 \times Wd\,(T_2 - T_1)} \times 100$$

Chlorophyll *a* fluorescence measurements were made in each plot approximately within 2h of solar noon, using a chlorophyll fluorometer equipped with a leaf clip holder (Opti- Science, OS1P) (Hugh and Davis, 2003).

Leaf potassium content was determined by using of flame photometer (Munns *et al.*, 2000).

At physiological maturity, total grain yield for each plot was determined by harvesting grain samples of all the ears from 4m length of two center rows of the plots.

Greenhouse experiment

In greenhouse two independent experiments were arranged. In the first experiment, the effect of PEG 6000 (1%) on seedling growth was evaluated, applying a randomized complete block design with five replications used for the normal seeds of field

Table 1. General characteristics of the field trials in 2006-2007 from April to August at Kahriz Station of Agricultural Research Center of Western Azerbaijan, Iran.

Variable	Value
Number of cultivars	5
Number of experiments	2
Number of treatments	2
Plot Size	3 × 4 m2
Number of replications per experiment	5
Number of rows per plot	4
Average minimum temperature	14.13 ºC
Average maximum temperature	25.8 ºC
Average minimum relative humidity	27.65 %
Average maximum Relative humidity	61.18 %
Soil type	silt loam
Electrical conductivity	0.81 dSm^{-1}
P	7.55 ppm
K	223.75 ppm
Cu	1.40 ppm
Zn	0.96 ppm
Mn	7.09 ppm
Fe	4.09 ppm

experiment. Ten seeds were germinated in petri dishes of 10×1 cm with Wattman paper, containing 10 ml distilled water (normal treatment) or PEG 6000 (stress treatment). After 10 days radicle and plumule length and dry weight were recorded. In the second experiment, the same design was applied to the stressed seeds of field experiment. Data of both experiments was analyzed by Mstat-c software.

RESULTS

Field assay

Combined analysis of variance for conditions, variety and interaction between them were significantly different (Table 2). This indicates the high genetic variations between varieties and probably different mechanisms against drought stress that could be used in corn breeding programs.

Comparing drought stress with normal conditions showed that grain yield (-48%), chlorophyll content (-32%) and RWC (-26%) decreased. On the other hand, K content (+104%), electrical conductivity (+98%) and non-structural carbohydrates (+47%) increased (Figure 1A).

The highest level for grain yield (229.10 g m^{-2}) and electrical conductivity (361.18 mM) belonged to SC704, and the lowest value for the same traits belong to SC108 (188.3 g m^{-2} and 330.65 mM, respectively) (Figure 2A and D). Decrease in grain weight and number was the main cause of grain yield loss under stress. Grain yield decreased sharply in SC108 but it was fairly constant in other varieties.

As for potassium, the highest accumulation was found after drought stress in SC108 (1463 mM).

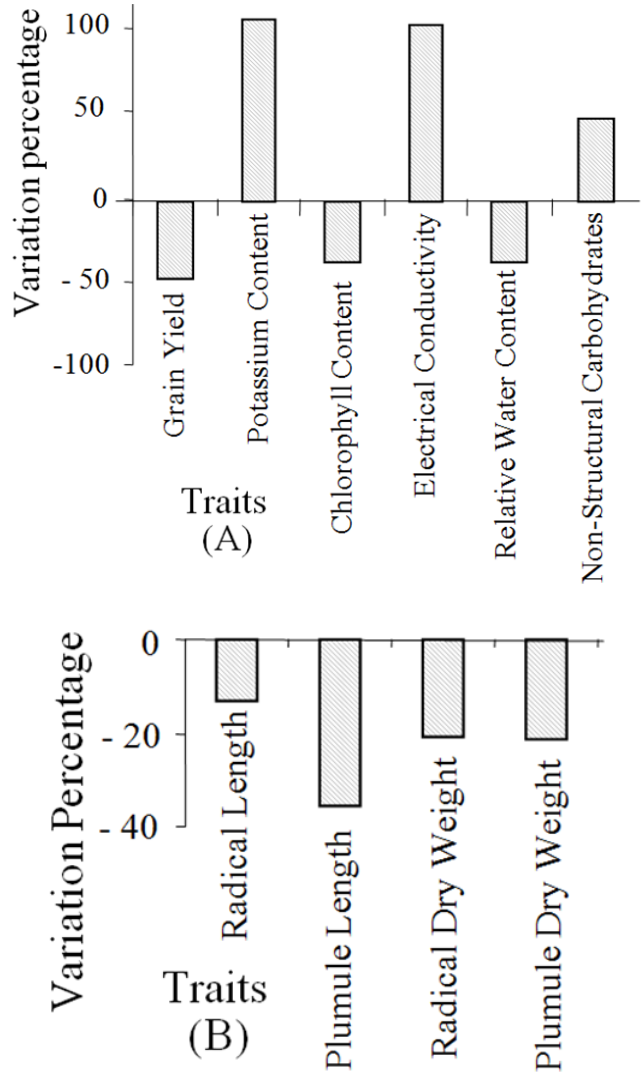

Figure 1. Variation percentage of drought stress *vs.* normal conditions of traits in (A) field and (B) greenhouse experiments of five corn (*Zea mays* L.) varieties during 2006-2007 season at Kahriz Station of Agricultural Research Center of Western Azerbaijan, Iran.

Table 2. Combined analysis of variance of traits of five corn (*Zea mays* L.) varieties for field assay during 2006-2007 season at Kahriz Station of Agricultural Research Center of Western Azerbaijan, Iran.

Source of variation	Degree of freedom	Means of squares					
		NSC (mM)	RWC (%)	EC (mM)	Ch (%)	K^+ (mM)	GY (g/m^2)
Condition	1	283/22**	14020/42**	424728/50**	5070/24**	6353899/52**	38**/226195
Error	8	0/18	44/96	15/61	5/02	6866/00	70/291
Variety	4	0/40	9/03	1687/25**	1/50	10912/33	2806/37
Condition×Variety	4	1/12**	52/43**	1438/25**	3/03**	14192/57*	1653/85**
Error	32	0/04	50/91	51/12	0/75	6180/37	35/425
Coefficient of Variation (%)		1/75	1/82	2/35	2/05	7/66	2/73

NSC: non-structural carbohydrates; RWC: Relative water content; EC: Electrical conductivity; Ch; Chlorophyll; K^+: Potassium accumulation and GY: Grain yield

*, ** Significant at 0.05 and 0.01 confidence level, respectively.

This was followed by SC700 (1402 mM), and SC647 with the lowest value (1311 mM). Unlike stress conditions, SC108 had the lowest accumulation of potassium in normal conditions (value) (Figure 2B).

Carbohydrates and potassium accumulation are main osmoregulaters (Turner and Jones, 1994). Therefore, decreased osmotic potential due to increased inter cellular solutions content is known as

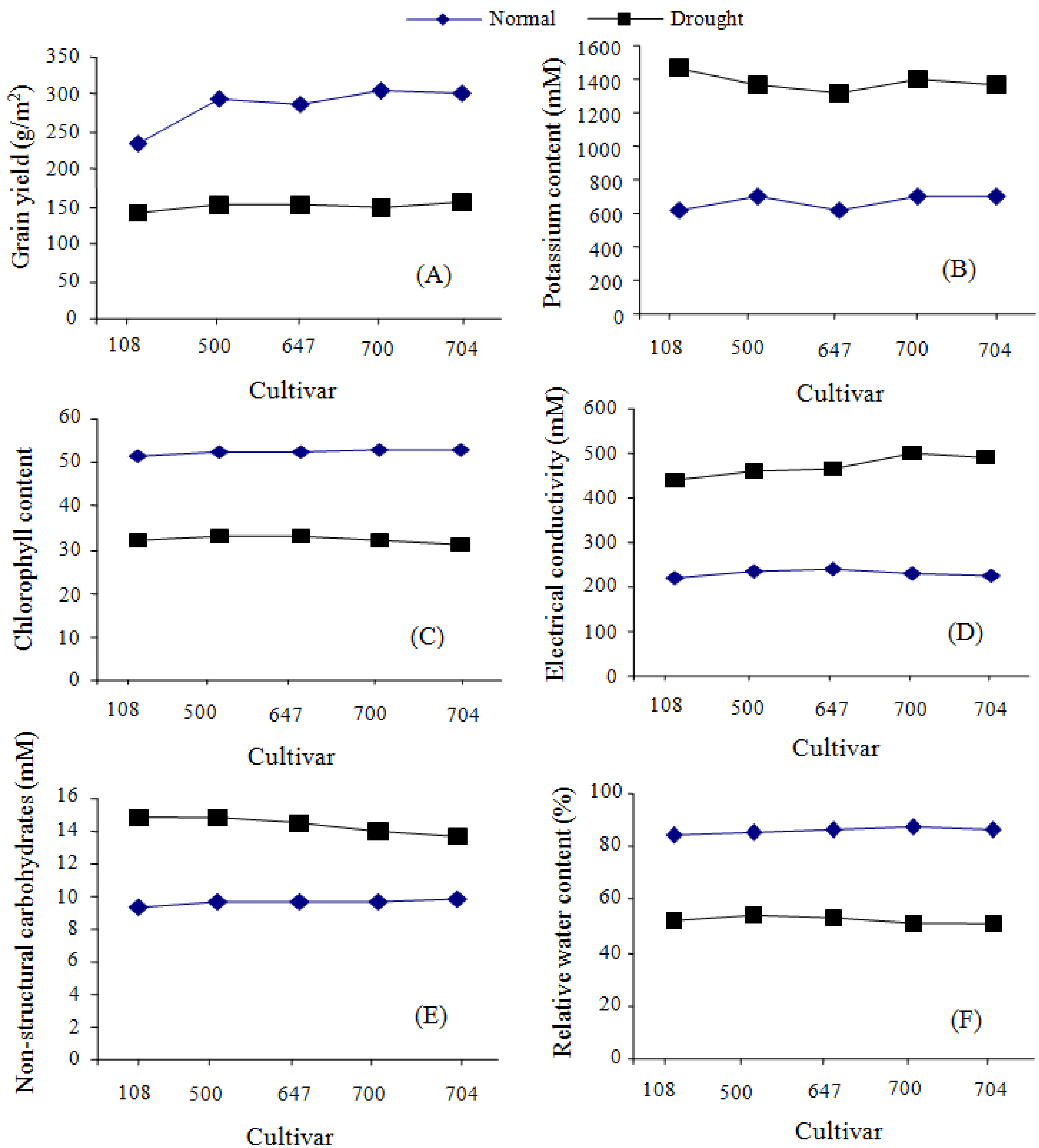

Figure 2. Means of (A) grain yield, (B) potassium accumulation, (C) chlorophyll content, (D) electrical conductivity, (E) non-structural carbohydrates and (F) relative water content under normal and drought stress conditions for five corn (*Zea mays* L.) varieties under field conditions during 2006-2007 season at Kahriz Station of Agricultural Research Center of Western Azerbaijan, Iran.

an adaptive mechanism against drought stress in many plants (Griffith and Bray, 1996). The highest and lowest amounts of non-structural carbohydrate were measured in SC500 with 14.90 mM under drought stress and SC108 with 9.30 mM in normal condition (Figure 2.E). Setter (2001) reported similar results.

Leaf chlorophyll content was significantly higher in non-stressed varieties than in stressed ones (Figure 2C). Drought stress declined leaf chlorophyll content. This is probably related to free radicals produced during drought stress period. Free radicals, in turn, reduce chlorophyll content. Stone *et al* (2001) in a study reported that decreased solar absorption due to decline of chlorophyll content was one of the main factors in reducing grain yield because drought stress makes chlorophyll content decreased.

It could be concluded that the more tolerant varieties, the more RWC they have (Ateya, 2002; Smith *et al* 1988). Previous investigations also showed that drought stress decreased RWC (Erickson *et al.*, 1995). The highest RWC was obtained in SC704 with 86.67 %. Under stress condition no significant difference was observed between varieties (Figure 2F). It seems that decreased leaf water is due to high evaporation and debility to compensate it because of water unavailability by plant root.

A different level of plasma membrane resistance against ions is the reason for various electrical conductivity. The varieties having more resistant plasma membrane are apt to drought conditions due to low ionic loss. The most sensitive varieties were SC700 (498.01 mM) and SC7004 (489.10 mM). On the other hand, SC108 was more tolerant than to other varieties under drought stress.

Greenhouse trial

In green house two different experiments were conducted based on a completely randomized block design with five replications including: 1- The effect of drought stress on normal seeds of field experiment using PEG 6000 and 2- The effect of PEG 6000 on drought stressed seeds from field experiments. All traits at two conditions, plumule dry weight between varieties and radicle dry weight among them were different significantly (Table 3).

Drought stress on seedling growth decreased traits of plumule and radicle dry weight, and plumule and radicle length 21%, 20%, 36%, 12% than in control conditions, respectively (Figure 1.B). Decreased radicle length was because of low photosynthetic assimilates devoted to parts of plant due to decreased photosynthesis. Similar results also reported by many researchers referring to Springer (2005). The highest and the lowest lengths measured were 9.0 cm for SC500 and 8.6 cm for SC108. Interaction between variety and conditions for radicle dry weight was significant so that the highest value was in SC647 (54.0 mg) and the lowest value was in SC108 (36.0 mg) normal and drought conditions, respectively (Figure 3). The highest value of plumule dry weight measured was in SC500 (34.6 mg) and the lowest was in SC108 (29.0 mg) (Figure 4).

The effect of PEG 6000 on stressed seeds from field experiments at five replications showed that none of cultivars germinated (Figure 5). Probably the severity of drought stress conducted in the field prevented the seeds to germinate in the green house.

Table 3. Combined analysis of variance of traits of five corn (*Zea mays* L.) varieties for green house trial during 2006-2007 season at Kahriz Station of Agricultural Research Center of Western Azerbaijan, Iran.

Source of variation	Degree of freedom	Means of squares			
		RL (cm)	PL (cm)	RDW (mg)	PDW (mg)
Condition	1	19/09**	786/45**	1383/38**	438/08*
Error	8	0/03	3/10	9/13	44/49
Variety	4	0/30	5/36	85/33	53/05**
Condition×Variety	4	0/06	1/93	40/63*	10/93
Error	32	0/13	2/56	12/81	7/75
Coefficient of Variation (%)		4/10	8.79	8/04	8/83

RL: Radicle length (RL); PL: Plumule length; RDW: Radicle dry weight and PDW: Plumule dry weight.
*, ** Significant at 0.05 and 0.01 confidence level, respectively.

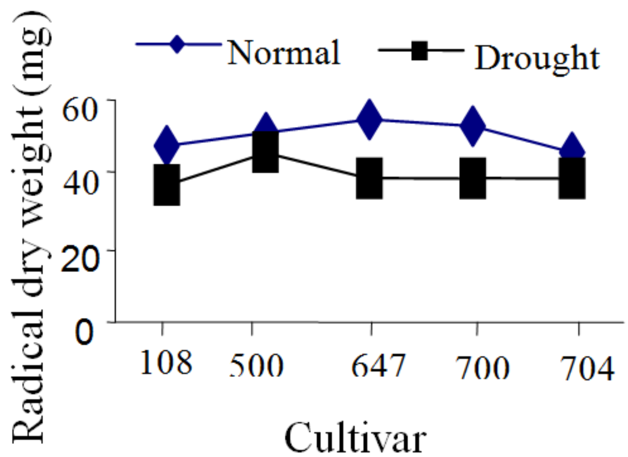

Figure 3. Means of radicle dry weight trait for five corn (*Zea mays* L.) varieties under normal and drought stress conditions caused by PEG 6000 at green house conditions during 2006-2007 season at Kahriz Station of Agricultural Research Center of Western Azerbaijan, Iran.

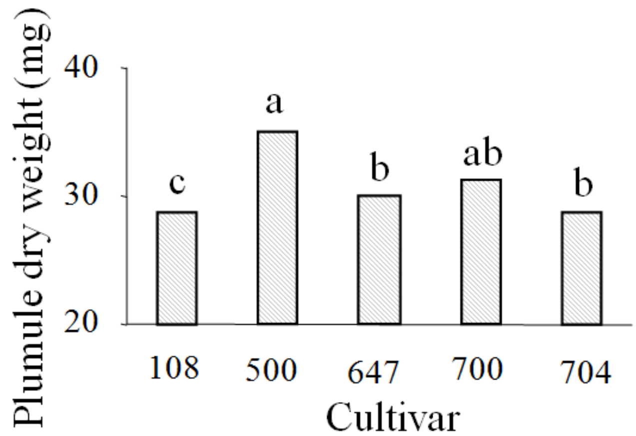

Figure 4. Mean comparison of plumule dry weight for five corn (*Zea mays* L.) varieties at green house conditions during 2006-2007 season at Kahriz Station of Agricultural Research Center of Western Azerbaijan, Iran.

Figure 5. The effect of drought stress using PEG6000 on (A) stressed and (B) non-stressed corn seeds from field experiments for five corn (*Zea mays* L.) varieties during 2006-2007 season at Kahriz Station of Agricultural Research Center of Western Azerbaijan, Iran.

DISCUSSION

In arid and semiarid environments, the response of plants to water deficits and variable environment is complex since conditions vary in the frequency of drought and normal periods, the degree of drought, the speed of onset of drought, and the patterns of soil and atmospheric water deficit. The sensitivity of a crop to different drought patterns varies during growth stages. Drought tolerance in terms of yield is a complex trait at the whole plant or crop level with a range of adaptive pathways and physiological mechanisms in the various types of drought environments that occur. Thus, there is a need to accurately understand the plants response to drought stress on real time basis. Drought stress during corn development reduces the duration of grain filling. If the rate of grain filling decreases, the final grain yield is reduced. An increased grain yield under drought stress depends on the supply of assimilates. An alternative source of assimilate is the water-soluble carbohydrates stored in stem. These reserves are readily utilized for grain filling and their availability may become a critical factor in sustaining grain filling and grain yield under drought stress. In current study, some hybrids (SC700 and SC704) were observed to yield relatively well under drought stress and adequate conditions of water, suggesting that it should be feasible to combine stress tolerance along with high yield potential in future.

Possessing physiological mechanisms conferring ability to maximize grain yield under drought stress condition was critical for hybrids. Previous researches have shown that grain yield is strongly linked to assimilate supply during the critical periods, which is in turn determined by ability to maintain photosynthetic rate during this time. Perhaps measurements of leaf photosynthetic rate of different genotypes grown under drought condition could provide additional insights regarding stress tolerance mechanisms. It seems that the orders in which crop physiological processes are affected by drought are growth, stomatal movement, transpiration, photosynthesis and translocation. These observations permit scheduling to be designed to reduce the water supply and at the same time minimize losses in corn yield.

Interestingly, in greenhouse treatment SC500, considering all traits measured, has better qualifications under drought stress. Alternative drought stress management practices can be implemented before the problem becomes unmanageable. Follow-up studies need to be done to verify other mechanisms of stressed corn.

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LITERATURE CITED

Andrade, F. H.; L. Echarte, R. Rizzalli, A. Della and M. Casanovas. 2002. Kernel number prediction in maize under nitrogen or water stress. Crop Sci. 42: 1173-1179.

Atteya, A. M. 2002. Characterization of growth and water relations in barely during water stress and after rewatering. Az. J. Pharm. Sci. 29: 285-296.

Banziger, M.; G. O. Edmeades, D. Beck and M. Bellon. 2000. Breeding for drought and nitrogen stress tolerance in maize: From theory to practice. CIMMYT, Mexico D. F., Mexico.

Banziger, M.; G. O. Edmeades, and H. R. Lafitte. 2002. Physiological mechanisms contributing to the increased N stress tolerance of tropical maize selected for drought tolerance. Field Crops Res. 75: 223-233.

Clark, J. M. and T. N. McCaig. 1982. Excised leaf water retention as an indicator of drought resistance of (*Triticum)* genotypes. Can. J. of Plant Sci. 62: 571-578.

Erickson, I. J.; D. L. Ketring and J. F. Stone. 1991. Response of internal- tissue water balance of peanut to soil water. Agron. J. 72:73-80.

Gonzalez, A.; I. Martin and L. Ayerbe. 1999. Barley yield in water stress conditions. The influence of precocity, osmotic adjustment and stomatal conductance. Field Crop Res. 62: 23-34.

Griffith, A. and E. A. Bray. 1996. Shoot induction of ABA-requiring genes in response to soil deying. Exp Bot 47: 1525-1531.

Hugh J. E. and F. Davis. 2003. Effect of drought stress on leaf and whole canopy radiation efficiency and yield of maize. Agron. J. 95: 688 – 696.

Jones, R. and T. Setter. 2000. Hormonal regulation of early kernel development. p. 25-42. *In:* M. Westgate and K. Boote (Eds.). Physiology and modeling kernel set in maize. CSSA Spec. Publ. 29. CSSA, Madison, Wisconsin, United States of America.

Lerner, B. L. and M. N. Dona. 2005. Growing sweet corn. Purdue University Cooperative Extension Service.

Ludlow, M. M. and R. C. Muchow. 1990. Acitical evaluation of traits for improving crop yield in water limited environment Adv. J. Agron. 43: 107-153.

Munns R.; R. A. Hare, R. A. James and G. J. Rebetzke. 2000. Genetic variation for improving the slat tolerance of durum wheat. Aust. J. Agric. Res. 51: 69-74.

Nesmith, D. S. and J. T. Ritchic. 1992. Short and long term responses of corn to a pre anthesis soil water deficit. Agron. J. 84: 107-113.

Osborne, S. L.; J. S. Schepers, D. D. Francis and M. R. Schlemmer. 2002. Use of spectral radiance to in-season biomass and grain yield in nitrogen and water-stressed corn. Crop Sci. 42: 165-171.

Otegui, M. E. and F. R. Andrade. 2000. New relationships between light interception, ear growth, and kernel set in maize. p. 89-102. *In:* M. Westgate and K. Boote (Eds.). Physiology and modeling kernel set in maize. CSSA Spec. Publ. 29. CSSA, Madison, Wisconsin, United States of America.

Schussler, J. R. and M. E. Westgate. 1991. Maize kernel set at low water potential: II. Sensitivity to reduced assimilate supply at pollination. Crop Sci. 31: 1196-1203.

Setter, T. L.; B. A. Flannigan and J. Melkonian. 2001. Loss of kernel set due to water deficit and shade in maize; carbohydrate supplies; abscisic acid and cytokinins. Crop Sci. 41: 1530-1540.

Smith, H. 1988. Signal perception, differential expression within multigene families and the molecular basis of phenotypic plasticity. Plant, Cell and Environment 13: 585-594.

Springer, T. L. 2005. Germination and early seedling growth of chaffy-seeded grasses at negative water potentials. Crop Sci. 45: 2075-2080.

Stone, P. J.; D. R. Wilson, J. B. Reid. and G. N. Gillespie. 2001. Water deficit effects on sweet corn: I. Water use, radiation use efficiency, growth, and yield. Aust. J. Agric. Res. 52: 103-113.

Tollenaar, M.; L. M. Dwyer and D. W. Stewart. 1992. Ear and kernel formation in maize hybrids representing three decades of grain yield improvement in Ontario. Crop Sci. 32: 432-438.

Turner, N. C. and M. M. Jones. 1994. Turgor maintenance lay osmotic adjustment. *In*: N. C. Turner, P. J. Carmer (Eds.). Adaptation of plants to water and high temperature stress. New York. Wiley 1980: 87-103.

Xianshi, G.; T. R. Sinclair and J. D. Ray. 1998. Effects of drought history on recovery of transpiration, photosynthesis, and leaf area development in maize. Soil Crop Sci: Soc. Fla. 57: 83-87.

Zinselmeier, C.; J. E. Habben, M. E. Westgate and J. S. Boyer. 2000. Carbohydrate metabolism in setting and aborting maize ovaries. p. 1-13. *In:* M. Westgate and K. Boote (Eds.). Physiology and modeling kernel set in maize. CSSA Spec. Publ. 29. CSSA, Madison, Wisconsin, United States of America.