OSMOTIC ADJUSTMENT IN COMMERCIAL COTTON CULTIVARS UNDER DROUGHT STRESS

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Abstract

Water is one of the most important factors for crop growth and productivity. Cotton is considered to be a relatively drought tolerant crop but plant metabolism and yield are still compromised under drought conditions. Differences in drought tolerance exist between cultivars but the metabolic reasons for this that could be used to find traits for enhancing drought tolerance have not been clearly elucidated. Under drought stress, osmotic adjustment occurs in plant cells through accumulation of compatible solutes in the cytosol and plays a role of reducing the osmotic potential of the cell in order to maintain cell turgor and growth. The objective of this study was to characterize the osmotic adjustment of two commercial cotton cultivars under drought stress during the flowering stage. A field experiment was conducted in Lubbock, TX in 2013. Treatments consisted of two cotton (*Gossypium hirsutum* L.) cultivars, ST5288 and PHY499, and two water regimes, well-watered and water-stressed. Water was withheld for 10 days at flowering and the field was re-watered 12 hours before the measurements. Osmotic potential was measured and samples were collected for proline content. At the harvest, bolls from 1 m of harvest row of each plot were collected for number of bolls, weight of bolls, and yield. Osmotic adjustment was greater in leaves and ovaries under water stress in both cultivars compared with well-watered conditions. But the difference in osmotic potential was significantly higher in leaves of the ST5288 and the ovaries of the PHY499. Water stress increased proline concentrations in both organs of the two cultivars. However, the proline accumulation due to the water stress was considerably higher in the ovaries than in the leaves in both cultivars. As in most plants, leaf osmotic potential is reduced under drought conditions, but cotton seems to have the ability to osmotically adjust and maintain a higher leaf turgor potential. Drought stress caused shedding of bolls reducing the yield, but the osmotic adjustment contributed for the plants to maintain the weight of retained bolls.

Introduction

Water deficit is the most important factor limiting crops yield worldwide (Kramer, 1983). Plant growth, including biochemical and physiological processes, is affected by water deficit stress (Gardner *et al*., 1983). The results of water stress depend on the severity and duration of drought as well as the growth stage and genotype of the plant (Kramer, 1983).

In cotton plants, the sensitivity to drought stress during flowering and boll development has been well established (Constable and Hearn, 1981; Turner *et al.*, 1986). Lint yield is reduced by decrease in boll production due to reduction in flowering sites and increased boll abscission when the plant is exposed to extreme drought during reproductive development (McMichael and Hesketh, 1982; Turner *et al.*, 1986; Pettigrew, 2004). There is a positive correlation between yield and number of bolls produced (Grimes *et al.*, 1969), but the biochemical and metabolic processes affecting boll maintenance are not well understood.

Under drought stress, osmotic adjustment occurs in plant cells through accumulation of compatible solutes in the cytosol (Xiong and Zhu, 2002). Compatible solutes, such as proline, glycine betaine, and sorbitol, are highly soluble and do not interfere with cell metabolism even in high concentrations (Bray *et al*., 2000). In most plants, osmoregulation through the accumulation of solutes has the function of reducing the osmotic potential of the cell in order to maintain cell turgor and growth (Mafakheri *et al*., 2010). Proline is one of the most common compatible solutes in plants under drought stress (Bray *et al*., 2000). Proline accumulation represents a

regulatory mechanism of water loss by reducing the cell water potential (Fumis *et al*., 2002). As in most plants, leaf water potential (ψ_l) is reduced under drought conditions. Cotton has the ability to osmotically adjust and maintain a higher leaf turgor potential (ψ_t) (Oosterhuis and Wullscheleger, 1987; Turner *et al.*, 1986; Nepomuceno *et al.*, 1998). However, water relations and osmotic adjustment in the ovaries of cotton flowers is uncertain. Therefore, the objective of this study was to characterize the osmotic adjustment of two commercial cotton cultivars under drought stress during the flowering stage.

Materials and methods

A field experiment was conducted in 2013 at the New Deal Farm – Texas Tech University in New Deal, TX. Treatments consisted of two cotton (*Gossypium hirsutum* L.) cultivars, Stoneville 5288 B2RF and Phytogen 499 WRF, and two water regimes, an untreated control with no water-deficit stress, and water deficit imposed at flowering stage. The experimental design was a split-plot with the water regimes as the main plots and the cultivars as split plots.

Cotton was planted on 21 May 2013 at a plant density of 3.5 plants/foot. Plots consisted of four rows, 50 feet in length. Row spacing was 38 inches. The experiment was uniformly fertilized according to pre-season soil tests and recommended rates. Weeds and insect control were performed according to recommendations. Mepiquat chloride as needed to control vegetative growth.

The field was maintained well-watered until the flowering stage. The "control treatment" received the optimum quantity of water throughout the duration of the experiment using drip irrigation system. Water stress was imposed by withholding water from the "stress treatments" for ten days. Then, the field was re-watered 12 hours before the measurements were taken.

Leaf discs from the 4th leaves at the main stems and ovaries from white flowers were collected for determination of osmotic potential (MPa). Samples were measured with screen-caged thermocouple psychrometers (model 74 series, J.R.D. Merrill Specialty Equipment, Logan, UT) equipped with stainless steel sample chambers using the technique described by Oosterhuis (1987). Osmotic potentials were determined after the psychrometer-chambers were frozen in liquid N for 5 minutes, thawed at room temperature for 30 minutes, and then allowed to equilibrate in waterbath at 25°C for 4 hours. Readings were made using a micro-voltmeter and chart recorder.

Proline concentration (µmol g^{-1} DM) was measured using methodology by Bates et al. (1973). For the colorimetric test, 1 mL of extract, 1 mL of acid ninhydrin, and 1 mL of glacial acetic acid were pipetted. After samples were maintained in waterbath at 95°C for 60 minutes, tubes were cooled and readings were made in spectrophotometer at 520 nm. L-proline p.a. was used as standard curve.

At the harvest, bolls from 1 m of harvest row of each plot were collected for determination of number of bolls and weight of bolls. Seedcotton yield was determined by mechanically harvesting the center two rows of each plot.

Results

Osmotic potential

Osmotic potential response to water regime was significant ($P \leq 0.05$) for the leaves of ST5288 and ovaries of PHY499 (Fig. 1). Under drought stress, the osmotic potential in the leaves of ST5288 and ovaries of PHY499 were approximately 57% and 240% higher, respectively, than the osmotic potential obtained in well-watered plants. Even though the leaves of PHY499 and ovaries of ST5288 under drought stress showed osmotic potential approximately 14% and 7% higher, respectively, compared with the well-watered treatment (Fig. 1), this increase in the osmotic potential could not be considered as osmotic adjustment of the plants grown under limiting water condition.

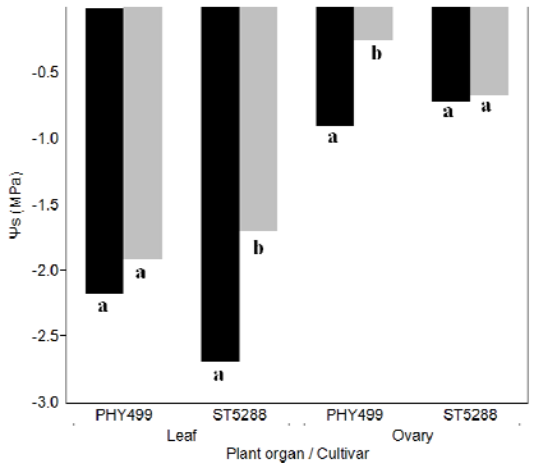

Figure 1. Osmotic potential (MPa) in the leaves and ovaries of two cotton cultivars, ST5288 and PHY499. Black bars: water stress treatment; gray bars: well watered treatment. Pairs of bars with the same lower case letters are not significantly different (P≤0.05).

Proline concentration

Accumulation of proline in the ovaries of plants from ST5288 and PHY499 cultivars was higher under drought stress compared with the well-watered treatment (Fig. 2). However, the proline concentration in the leaves of both cultivars was not significantly different between the water regimes (Fig. 2). It indicates that the osmotic adjustment in cotton plants is higher in the reproductive organs than the vegetative organs under limiting water conditions in the field.

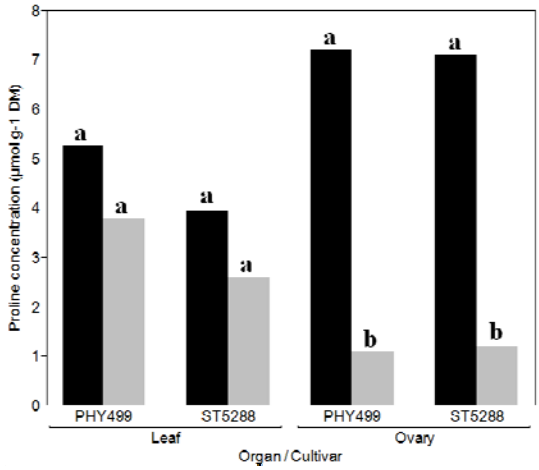

Figure 2. Proline concentration (µmol g^{-1} DM) in the leaves and ovaries of two cotton cultivars, ST5288 and PHY499. Black bars: water stress treatment; gray bars: well watered treatment. Pairs of bars with the same lower case letters are not significantly different (P≤0.05).

Yield

Cotton yield was reduced by the drought stress in both cultivars (Fig. 3). Weight of bolls of water-stressed plants was maintained similar to the well-watered treatment in the two cultivars (Fig. 4A). However, the number of bolls was reduced by the drought stress in plants from ST5288 and PHY499 (Fig. 4B). The drought stress was sufficiently severe to cause shedding of bolls despite osmotic adjustment, which contributed to the

lower yield in the water stress treatment. But the osmotic adjustment contributed for the plants to maintain the weight of retained boll.

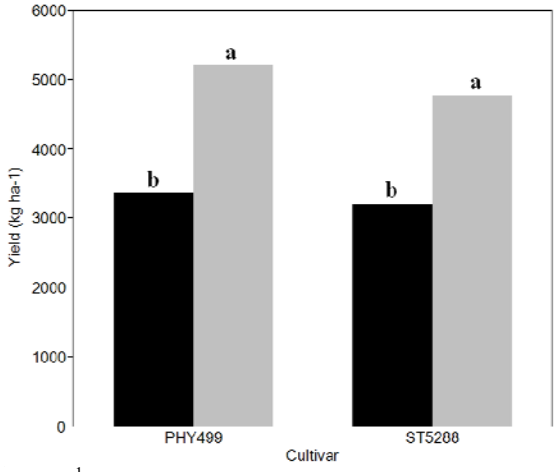

Figure 3. Seedcotton yield (kg ha^{-1}) of two cotton cultivars, ST5288 and PHY499. Black bars: water stress treatment; gray bars: well watered treatment. Pairs of bars with the same lower case letters are not significantly different (P≤0.05).

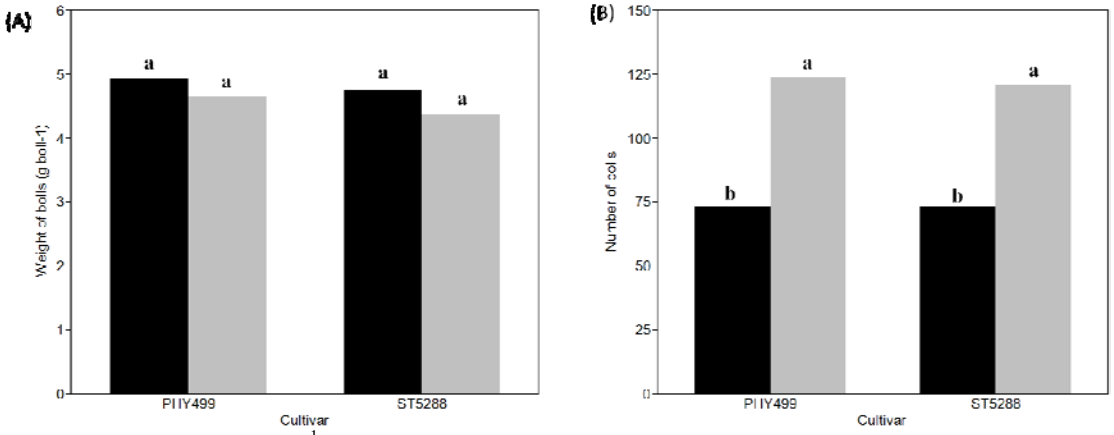

Figure 4. Boll weight (g $boll^{-1}$) of two cotton cultivars, ST5288 and PHY499 (A), and boll number of two cotton cultivars, ST5288 and PHY499 (B). Black bars: water stress treatment; gray bars: well watered treatment. Pairs of bars with the same lower case letters are not significantly different (P≤0.05).

Conclusions

Osmotic adjustment is an acclimation strategy for cotton to maintain the cells active. There were genotypic differences in osmotic adjustment. For PHY499, higher osmotic adjustment occurred in the ovaries, while for ST5288 it was in the leaves. Drought stress caused shedding of bolls reducing the yield, but the osmotic adjustment contributed for the plants to maintain the weight of retained bolls.

References

Bates, L.S., R.P. Waldren, and I.D. Teare. 1973. Rapid determination of free proline for water-stress studies. Plant Soil 39:205–207.

Bray, E. A.; J. Bailey-Serres, and E. Weretilnyk. 2000. Response to abiotic stresses. pp. 1158-1203. *In*: B. B. Buchanan, W. Gruissem, and R. L. Jones (eds.). Biochemistry e molecular biology of plants. Rockville, American Society of Plant Physiologists.

Constable, G. A., and A.B. Hearn. 1981. Irrigation of crops in a subhumid climate, 6: effects of irrigation and nitrogen fertilizer on growth, yield and quality of cotton. Irrig. Sci. 2:17-28.

Fumis, T. F. and J. F. Pedras. 2002. Variation in levels of proline, diamine and polyamines in wheat cultivars under drought stress (in Portuguese, with English abstract), Pesq. Agropec. Bras. 37:449-459.

Gardner, W.R. and H.R. Gardner. 1983. Principles of water management under drought conditions. Agric. Water Manage. 7:143-155.

Grimes, D.W., W.L. Dickens, and W.D. Anderson. 1969. Functions for cotton (*Gossypium hirsutum* L.) production from irrigation and nitrogen fertilization variables. II. Yield components and quality characteristics. Agron. J. 61:773- 776.

Kramer, P.J. 1983. Water deficits and plant growth. pp: 342-389. *In*: P.J. Kramer (ed.). Water relations of plants. Academic Press, New York.

Mafakheri, A., A. Siosemardeh, B. Bahramnejad, P. C. Struik, and Y. Sohrabi. 2010. Effect of drought stress on yield, proline and chlorophyll contents in three chickpea cultivars. Aust. J. Crop Sci. 4:580-585.

McMichael, B.L. and J.D. Hesketh. 1982. Field investigations of the response of cotton to water deficits. Field Crops Res. 5:319–333.

Nepomuceno, A.L., D.M. Oosterhuis, and J.M. Stewart. 1998. Physiological response of cotton leaves and roots to water deficit induced by polyethylene glycol. Environ. Exp. Bot. 40:29–41.

Oosterhuis, D.M., A technique to measure the components of root water potential using screen-caged thermocouple psychrometers. 1987. Plant Soil 103:285-288.

Oosterhuis, D.M., and S.D. Wullschleger. 1987a. Osmotic adjustment in cotton (*Gossypium hirsutum* L.) leaves and roots in response to water stress. Plant Physiol. 84:1154-1157.

Pettigrew, W.T. 2004. Moisture deficit effects on cotton lint yield, yield components, and boll distribution. Agron. J. 96:377–383.

Turner, N.C., A.B. Hearn, J.E. Begg, and G.A. Constable. 1986. Cotton (*Gossypium hirsutum* L.) physiological and morphological responses to water deficits and their relationship to yield. Field Crops Res. 14:153-170.

Xiong, L. and J. K. Zhu. 2002. Molecular and genetic aspects of plant response to osmotic stress. Plant Cell and Environ. 25:131-139.