Water is crucial for crop growth and productivity. Cotton metabolism and yield are compromised under drought conditions, especially at flowering stage. Differences in drought tolerance exist among 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. Research has been reported on osmotic adjustment of cotton leaves and roots. However, there is no information on the osmotic adjustment in the reproductive organ of cotton plants. Therefore, studies are needed on the response of the reproductive organ in order to fully understand the osmotic adjustment mechanism in cotton plants under drought stress.

Water deficit is the most important factor limiting crop 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 deficit 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 and Pedras, 2002). As in most plants, leaf water potential ($\psi_l$) is reduced under drought conditions. Cotton has the ability to osmotically adjust and maintain a higher leaf turgor potential ($\psi_t$) (Oosterhuis and Wullschleger, 1987; Turner et al., 1986; Nepomuceno et al., 1998). However, water relations and osmotic adjustment in the ovaries of cotton flowers is uncertain.

The purpose of this study was to characterize the osmotic adjustment of two commercial cotton cultivars under drought stress during the flowering stage.

**RESEARCH DESCRIPTION**

A field experiment was conducted in 2013 at the New Deal Farm, Texas Tech University in New Deal, Texas. 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 was added 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 a 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, Utah) 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 ($\mu$mol 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 AND DISCUSSION

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.

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.

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 (data not shown). However, the number of bolls was reduced by the drought stress in plants from ST5288 and PHY499 (data not shown). 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.

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 to the plant's ability to maintain the weight of retained bolls.

PRACTICAL APPLICATION

Studies have revealed that reproductive organs of several crops exhibit osmotic adjustment under water-deficit stress conditions, but this mechanism has not been shown in the reproductive organ of cotton plants. The knowledge of osmotic adjustment mechanism in cotton flowers is important, since we speculate that osmotic adjustment in the cotton reproductive organs could contribute to alleviate the effects of drought stress by maintaining active cells.
LITERATURE CITED


Fig. 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 lowercase letters are not significantly different ($P \leq 0.05$).

Fig. 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 lowercase letters are not significantly different ($P \leq 0.05$).
Fig. 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 lowercase letters are not significantly different ($P \leq 0.05$).