Plasma Membrane Stability During High Temperature Stress and Its Effect on Electron Transport

T. R. FitzSimons and D. M. Oosterhuis

RESEARCH PROBLEM

Under any form of biotic or abiotic stress, a plant must make cellular adjustments to maintain homogeneity within the cell. Among the first cellular components to display a noticeable change is the plasma membrane responsible for maintaining cellular compartmentalization. Under high-temperature stress, the membrane loses its ability to properly regulate permeability, which alters the capability of the cell to maintain homogeneity. Research has focused on recognizing that the cellular membrane becomes more permeable during stress, but little data is currently available on how long the permeability may last. This research focuses on the longer term stress of cotton leaves and adaptation responses to determine the time required for stressed leaves to return to homeostatic levels.

BACKGROUND INFORMATION

Ideal maximal growing temperatures for cotton should not exceed 35 °C (Oosterhuis, 2002). Cotton that is grown in the Mississippi Delta often experience temperatures that surpass this baseline temperature. Thus, temperature stress for cotton remains the greatest unamendable factor affecting crops (Wahid et al., 2007) and is viewed as the most limiting factor associated with diminished crop yields (Crafts-Brandner and Salvucci, 2004). High-temperature stress affects cotton with particular severity due to the thermo-sensitive stages of flowering which occurs during the hottest months of the year (Singh et al., 2007).

Researchers have used both membrane permeability and fluorescence data as proxies to determine the amount of stress that a plant may be experiencing (Bibi et al., 2008). Higher amounts of cellular plasmolytes exuded during stress is representative of a cell’s lack of thermotolerance (ur Rahman et al., 2004). Fluorescence identifies the efficiency of the photosystem of the plant which requires a tightly regulated membrane of the thylakoid (Kotak et al., 2007). Using both together, we can make an assessment of the photo-chemical efficiency of the plant during high-temperature stress and its potential adaptation response.

1Graduate assistant and distinguished professor, respectively, Department of Crop, Soil, and Environmental Sciences, Fayetteville.
RESEARCH DESCRIPTION

Two growth chamber studies were conducted at the University of Arkansas System Division of Agriculture, Altheimer Laboratory in Fayetteville in 2012 and 2013. Cotton (*Gossypium hirsutum* L.) cultivar ST5288 B2RF was grown in 2-L pots with a day/night temperature of 30/20 °C, a relative humidity of 70%, and 14 h photoperiods of 500 µmol m⁻² s⁻¹ of photosynthetically active radiation in two growth chambers. Plants were watered daily to saturation using half-strength Hoagland’s solution. At the initiation of flowering, temperatures in one chamber were increased to 38/24 °C. Membrane leakage and fluorescence data were collected daily between 1200-1400 h. Leaf discs were collected on the fourth main-stem leaf of ten random plants in each chamber being careful not to include major leaf veins. Membrane leakages were calculated by comparing the differences from leaf discs held in double distilled water at both room temperature and after autoclaving. Fluorescence data was collected from the same leaves as were selected for membrane at three different locations on the leaf and averaged together for a relative electron transport rate (ETR) of the leaf. Measurements were collected daily for five days.

RESULTS AND DISCUSSION

Membrane leakage displayed a significant difference from the control at the onset of high temperature (Fig. 1). Leakage exhibited by the control remained fairly stable throughout the experiment with no value lower than 70%. On the first day of stress, membrane permeability values of the control plants were 43% lower than the control. Permeability further decreased on the second day with the stressed plants having permeability 84% less than the control. Stressed plants showed improvements on day three with a 33% difference from the control. Day four values of the stress plants were within 5% and 4% of the control on days four and five, respectively. The stabilized relative differences on days four and five indicate that the stressed plants permeability were similar to the control and had adapted to the heat.

Stressed measurements were lower than the control on all days measured (Fig. 2). A 15% decrease of electron transport rate of stressed plants was observed when compared to the control on day one. Day two plants had the biggest disparity between the control and heat-stressed plants with a 37% difference. Relative differences for days three, four, and five were 19%, 21% and 16%, respectively. All values of the heat-stressed plants were suppressed compared to the control, but it should be noted that the greatest disparity of ETR occurred on day two, which also coincided with the greatest disparity in the membrane permeability that same day.

PRACTICAL APPLICATION

The results of this study confirmed that fluorescence and membrane permeability could be used to monitor the stress adaptation of plants. The stressed plants
were unable to recover as indicated via the fluorescence data, but demonstrated a recovery from the membrane permeability analysis. This suggests that although the membrane structure is restored after three days following stress, the ability of the plant to return the photosystem to a similar recovery is limited. It should also be emphasized that dependent upon when the membrane permeability is taken can determine the effectiveness of the technique. Three days following the stress, values between both the control and stressed plants were similar. Fluorescence would appear to be a better indicator of identifying leaf related stress over a longer period of time. It is important to continue the research to assess both of these techniques as rapid indicators of stress \textit{in situ}.

**ACKNOWLEDGMENTS**

We thank Cotton Incorporated for providing the funding of this research.

**LITERATURE CITED**


Fig. 1. Membrane leakage percent difference for main-stem leaves for both the control and temperature stress plants from the final autoclaved tissues. Lower relative values indicate greater initial leakage from the leaves sampled. Capitalized letters indicate no significant difference at $\alpha = 0.05$ level for control values; whereas lowercase letters indicate no significant difference at $\alpha = 0.05$ level for the heat-stressed leaves.

Fig. 2. Electron transport rate (ETR) of leaf photosystems for both the control and temperature stressed plants. Capitalized letters indicate no significant difference at $\alpha = 0.05$ level for control values; whereas lowercase letters indicate no significant difference at $\alpha = 0.05$ level for the heat-stressed leaves.