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Susceptible time window and endurable duration of cotton fiber development to high temperature stress

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Abstract

The development of the cotton fiber is very sensitive to temperature variation, and high temperature stress often causes reduced fiber yield and fiber quality. Short-term high temperature stress often occurs during cotton production, but little is known about the specific timing and duration of stress that affects fiber development. To make this clear, pot experiments were carried in 2014 and 2015 in a climate chamber using cotton cultivars HY370WR (less sensitive variety) and Sumian 15 (heat sensitive variety), which present different temperature sensitivities. Changes of the most important fiber quality indices (i.e., fiber length, fiber strength and marcironaire) and three very important fiber development components (i.e., cellulose, sucrose and callose) were analyzed to define the time window and critical duration to the high temperature stress at 34°C (max38°C/min30°C). When developing bolls were subjected to 5 days of high temperature stress at different days post-anthesis (DPA), the changes (Δ%) of fiber length, strength and micronire, as a function of imposed time followed square polynomial eq. as $y=a+bx+cx^2$, and the time around 15 DPA was the most sensitive period for fiber quality development in response to heat stress. When 15 DPA bolls were heat-stressed for different durations (2, 3, 4, 5, 6, 7 days), the changes (Δ%) of fiber length, strength and micronire, as a function of stress duration followed logistic equations $y=\frac{A_1-A_2}{1+(x/x_0)^p}+A_2$. Referred to that 5, 10 and 15% are usually used as criteria to decide whether techniques are effective or changes are significant in crop culture practice and reguard to the fiber quality indices change range, we suggested that 5% changes of the major fiber quality indices (fiber length, fiber strength and micronaire) and 10% changes of fiber development components (cellulose, sucrose and callose) could be taken as criteria to judge whether fiber development and fiber quality have been significantly affected by high temperature stress. The key time window for cotton fiber development in response to the high temperature stress was 13–19 DPA, and the critical duration was about 5 days.

Keywords: cotton (*Gossypium hirsutum* L.), fiber quality, high temperature stress, susceptible time window, stress endurable duration

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1. Introduction

It takes 45 to 60 days for a cotton boll to mature, which depends on the daily effective accumulation temperature (Basra and Malik 1984; Salnikov *et al*. 2003; Dai *et al*. 2015). Cotton boll development is very sensitive to temperature

(Haigler *et al*. 2001; Pettigrew 2001; Gou *et al*. 2007; Singh *et al*. 2007), and temperature stress usually causes large declines in fiber yield and fiber quality (Oosterhuis 1999; Reddy *et al*. 1999; Haigler 2007; Murtaza *et al*. 2007). As global temperatures are warming, extreme climate events will occur more often (Parry *et al*. 2007); thus, short-term high temperature stress will occur more and more frequently during the cotton growing season. Therefore, it is necessary to identify the stages of fiber development that are sensitive to high temperature stress.

There are several indices that determine fiber quality, and different fiber quality indices have different sensitivities to environment factors (John and Keller 1996; Bradow and Davidonis 2000; Gokani and Thaker 2002; Bowman and Gutiérrez 2003; Gou *et al*. 2007). The main fiber quality indices are fiber length, fiber strength and micronaire (a measure of the air permeabilty of compressed cotton fibers, and it is often used as an indication of fiber fineness and maturity).

The optimal mean daily temperature (MDT) for fiber development is 26°C (Reddy *et al*. 1991; Oosterhuis 1999; Haigler *et al*. 2005; Murtaza and Shah 2007; Dai *et al*. 2015). When MDT is higher than 30°C or the maximum temperature is more than 35°C (Reddy *et al*. 1991; Pettigrew 2001), fiber quality development will be restrained severely, depending on the duration of stress (Reddy *et al*. 1995; Oosterhuis 1999; Murtaza and Shah 2007). Fiber length is adversely affected when the mean night temperature is higher than 21°C (Pettigrew 2008). Fiber strength is the most sensitive fiber index to temperature, and it would be affected significantly (Pettigrew 2001). Micronaire deteriorated when temperature regimes were over 33/28°C (Reddy *et al*. 1999; Pettigrew 2001). Therefore, fiber quality development is very sensitive to high temperature. However, former studies did not report the stage difference in fiber development while organisms usually behave differently to environment stress in different stage. Thus, our objective was to study the key time window and the critical duration for fiber length, fiber strength and micronaire development in response to high temperature stress.

Physiological indices can reflect the state of developing cotton cells (Reddy *et al*. 1997a, b). The main component of the mature cotton fiber is cellulose (>85%), and cellulose accumulation has a close relation with fiber quality. The optimal temperature for cellulose synthesis is about 25–30°C, and when the temperature is out of this range, the cellulose synthesis rate decreases (Roberts *et al*. 1992). Sucrose is the initial substrate of cellulose synthesis (Tian *et al*. 2013), and its concentration affects cellulose synthesis directly (Tamoi *et al*. 2005). Cotton photosynthetic ability drops when MDT is higher than 32°C (Feller *et al*. 1998; Crafts-Brandner and Salvucci 2000), which reduces the synthesis of sucrose. Callose synthesis consumes uridine diphosphate glucose (UDPG) as does cellulose synthesis; so an increase of callose synthesis under stress will adversely affect the synthesis of cellulose and then adversely affect fiber quality (Tucker *et al*. 2001). In summary, changes of cellulose, sucrose and callose affect the development of cotton fibers. While there are many reports of high temperature stress on cotton plant growth, final fiber quality changes and the yield components (Ullah *et al*. 2016), little is known about the key physiological windows and the critical duration with respect to fiber development in high temperature stress. Therefore, we evaluated the effect of timing and duration of moderate high temperatures on fiber quality and components using two cotton varieties with differing stress tolerance.

2. Materials and methods

2.1. Experiment design

The experiment was carried out at Nanjing Agricultural University, Nanjing (118°50′E, 32°02′N), Jiangsu Province, China in 2014 and 2015. The soil used was yellow-brown loam, plowed layer. Soil pH was 7.0; organic matter content was 9.8 g kg^{-1}, total nitrogen content was 1.0 g kg^{-1}; available nitrogen content was 58.4 mg kg^{-1}; available phosphorus content was 43.1 mg kg^{-1}; and available potassium content was 105.6 mg kg^{-1}. The cotton varieties PHY370WR (high temperature tolerant cultivar, middle maturity, non-transgenic) and Sumian 15 (high temperature sensitive cultivar, middle maturity, non-transgenic), which have different high temperature tolerance, were used as materials. Seeds were sown on April 15th in both years, and seedlings with three leaves were transplanted to pots on May 10th. The pots were 37 cm in diameter and 32 cm in height. Cotton plants were grown in a roof-open-controlled (the roof could be closed and opened fully or partially as needed) greenhouse. Flowers on the 1st and 2nd nodes in the 6th–8th fruit branches were labeled on the flowering days.

Treatment for the heat stress susceptible time window study 120 cotton plants with lots of bolls (around 25) at 7, 10, 12, 15, 17, 20, 22, 25, 27, and 30 days post-anthesis (DPA) were moved to the temperature-controlled climate chamber (each chamber was 2 m in wide, 4 m in long and 1.7 m in high, totally 4 chambers were applied) and gradual heat the chamber to set temperature in 2 h. After 5 d of high temperature stress, cotton plants were returned to the greenhouse for further growth. The temperature of the greenhouse was indicated in Fig. 1-A, and the temperature of the chamber for heat stress was indicated in Fig. 1-B.

Treatment for the heat stress endurable duration study A total of 120 cotton plants with bolls (around 25) were moved at 15 DPA to the temperature-controlled climate chamber at middle night (24:00). After 2, 3, 4, 5, 6, and 7