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RESEARCH ARTICLE

Effects of planting dates and shading on carbohydrate content, yield, and fiber quality in cotton with respect to fruiting positions

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Abstract

Two cotton (*Gossypium hirsutum* L.) cultivars, Kemian 1 (cool temperature-tolerant) and Sumian 15 (cool temperature-sensitive) were used to study the effects of cool temperature on carbohydrates, yield, and fiber quality in cotton bolls located at different fruiting positions (FP). Cool temperatures were created using late planting and low light. The experiment was conducted in 2010 and 2011 using two planting dates (OPD, the optimized planting date, 25 April; LPD, the late planting date, 10 June) and two shading levels of crop relative light rate (CRLR, 100 and 60%). Compared with fruiting position 1 (FP1), cotton yield and yield components (fiber quality, leaf sucrose and starch content, and fiber cellulose) were all decreased on FP3 under all treatments. Compared with OPD-CRLR 100%, other treatments (OPD-CRLR 60%, LPD-CRLR 100%, and LPD-CRLR 60%) had significantly decreased lint yield at both FPs of both cultivars, but especially at FP3 and in Sumian 15; this decrease was mainly caused by a large decline in boll number. All fiber quality indices decreased under late planting and shading except fiber length at FP1 with OPD-CRLR 60%, and a greater reduction was observed at FP3 and in Sumian 15. Sucrose content of the subtending leaf and fiber increased under LPD compared to OPD, whereas it decreased under CRLR 60% compared to CRLR 100%, which led to decreased fiber cellulose content. Therefore, shading primarily decreased the "source" sucrose content in the subtending leaf whereas late planting diminished translocation of sucrose towards cotton fiber. Notably, as planting date was delayed and light was decreased, more carbohydrates were distributed to leaf and bolls at FP1 than those at FP3, resulting in higher yield and better fiber quality at FP1, and a higher proportion of bolls and carbohydrates allocated at FP3 of Kemian 1 compared to that of Sumian 15. In conclusion, cotton yield and fiber quality were reduced less at FP1 compared to those at FP3 under low temperature and low light conditions. Thus, reduced cotton yield and fiber quality loss can be minimized by selecting low temperature tolerant cultivars under both low temperature and light conditions.

Keywords: cotton, planting date and shading, fruiting position, yield, fiber quality

1. Introduction

The indeterminate growth habit of cotton causes formation of bolls at different fruiting positions (FP) to grow at different times under various environmental conditions (Bondada and Oosterhuis 2001). Many studies have documented

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that the FP1 contributed more to the total cotton yield and produced better fiber than bolls at any other positions of the same sympodial branch (Jenkins *et al*. 1990b; Pettigrew 1995; Heitholt 1997; Davidonis *et al*. 2004). However, the contribution of FPs differs between cultivars and under different environmental conditions. Under optimal conditions, the distal FPs (FP3 and above) could sustain a 58.8% retention rate of cotton bolls in high cotton yield fields (7 657 kg ha^{-1}, 24 240 plants ha^{-1}) (Gu *et al*. 2010). In contrast, the distal FP (FP3) produced less cotton bolls with weaker fiber under normal conditions, but the rate of reduction was less in low temperature-tolerant cultivars (Ma *et al*. 2014). Thus, cotton yield and fiber quality on distal FPs might be more plastic under various environmental conditions, which could minimize reduced yield and fiber quality in adverse conditions. Studies about the underlying physiological changes in distal FPs and their relationship with inner FPs could be used to identify genotypes that are resistant to adverse conditions or to develop new varieties for better productivity under environmental stress.

The above-mentioned changes are related to source-sink (leaf-boll) interactions. In cotton, the development of a boll and its subtending leaf are closely associated (Wullschleger and Oosterhuis 1990). In a mature cotton boll, most of the carbon originate from the subtending leaf (Ashley 1972; Grindlay 1997). Efficient production of carbohydrates (mainly sucrose and starch) in leaves and translocation of carbohydrates towards bolls is essential for maintaining cotton yield and fiber quality (Jiang *et al*. 2006; Ahmadi *et al*. 2009). In mature fiber cells, cellulose constitutes more than 90% of the dry weight (Delmer and Amor 1995), which means that the process of cotton fiber formation is primarily a process of cellulose synthesis. Sucrose, transported from the subtending leaf, is the initial carbon source for cellulose synthesis and supplies UDP-glucose as the immediate substrate for cellulose polymerization (Delmer and Haigler 2002; Williamson *et al*. 2002). Sucrose content in cotton fiber and subtending leaf are highly correlated with the cellulose accumulation and final fiber quality (Wang *et al*. 2009; Gao *et al*. 2012), and all of these factors are influenced by genetic and environmental factors.

Both low temperature and light deficiency are vital environmental constraints for cotton production (Yeates *et al*. 2010; Lv *et al*. 2013). These two important constraints can occur singly or combined in cotton-growing areas of the Yangtze River Valley and the Yellow River Valley in China under multiple cropping systems due to late harvesting of preceding full-season winter crops (Chen *et al*. 2014b). Previous studies have shown that low temperatures as a result of late planting significantly increased fiber sucrose content, and also decreased sucrose transformation rate and cellulose content, which consequently reduced lint yield and decreased fiber quality due to carbohydrate deficiency (Dong *et al*. 2006, 2010; Shu *et al*. 2009; Cao *et al*. 2011; Lu *et al*. 2017). In some studies, low light decreased lint yield (SassenrathCole *et al*. 1996; Dusserre *et al*. 2002; Lv *et al*. 2013; Echer and Rosolem 2015), increased fiber length, and lowered strength of fiber and micronaire (Pettigrew 1995, 2001). In other studies, results suggested that low light decreased or did not significantly affect fiber length (Zhao and Oosterhuis 2000; Wang *et al*. 2005). Moreover, recent research showed that both low temperature and low light had severe effects on carbohydrate content in both cotton leaf and fiber, which decreased cotton yield and fiber quality (Liu *et al*. 2015b; Hu *et al*. 2016).

Many studies have described low temperature and light effects on cotton fiber and/or the subtending leaf (Chen *et al*. 2014a, b; Liu *et al*. 2015b; Hu *et al*. 2016). However, it is still not fully understood how low temperature, reduced light, and their interaction affect cotton source-sink relationships at different FPs. Therefore, an experiment with a variety of planting dates and shading treatments was designed to determine the effects of low temperature and light on cotton yield, fiber quality, and carbohydrate content in leaves and fibers of two different FPs in low temperature-tolerant and low temperature-sensitive cultivars. The goals of this experiment were to elucidate differences between physiological mechanisms of cotton fiber development in different FPs in response to temperature-light stress.

2. Materials and methods

2.1. Experimental design

A two-year field experiment was conducted at Pailou Experimental Station, Nanjing Agricultural University (118°50´E, 32°02´N), Jiangsu Province, China, in 2010 and 2011. Two cotton cultivars were used: Kemian 1 (low temperature-tolerant) and Sumian 15 (low temperature-sensitive), which are both widely grown in the Yangtze River Valley (Shu *et al*. 2009; Liu *et al*. 2013). Soil was clay, mixed, thermic, typic Alfisols (udalfs; FAO Luvisol) based on a soil profile depth of 0–20 cm. Before planting cotton, nutrient contents of soil were: 17.5 and 18.5 g kg^{-1} organic matter, 1.1 and 1.0 g kg^{-1} total N, 62.3 and 80.5 mg kg^{-1} available N, 17.6 and 18.8 mg kg^{-1} available P, and 98.3 and 110.5 mg kg^{-1} available K in 2010 and 2011, respectively.

According to previous research, 25 April and 10 June are the optimal and late planting dates, respectively, in the Yangtze River Valley (Jiang *et al*. 2006; Liu *et al*. 2015b). Thus, two planting dates, 25 April and 10 June, and two shading treatments, CRLR 100% (control, with no shading) and CRLR 60% (photosynthetically active radiation was reduced to about 60% of control by covering plants with