ALTERATIONS OF LEAF PHOTOSYNTHESIS AND FIBER CELLULOSE SYNTHESIS BY COOL NIGHT TEMPERATURES

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Abstract

Cool nights reduce photosynthetic efficiency, especially in the short-term, resulting in lower sucrose levels during the day and reduced ability to export sucrose. Cool nights also inhibit the use of sucrose that is available in the fiber for cellulose synthesis.

Introduction

Our goals are to improve the efficiency of cotton photosynthesis and fiber maturation under cool night temperatures so that producers on the Texas Southern High Plains (and other similar regions) can produce a high quality, high yield cotton crop in the shortest growing season ever likely to occur. The cotton growing season is limited in temperate regions to the months between adequate warming of soil to allow planting and the first killing frost. Furthermore, cool nights (below about 24°C = 75°F) during the season greatly limit the efficiency of photosynthesis and the time that is truly effective for fiber maturation. To achieve our goal, we must know where rate-limiting steps occur in photosynthesis and cellulose synthesis so that particular genes can be manipulated by genetic engineering. (Cellulose synthesis is required for at least 90% of the secondary wall thickening required to produce a mature fiber.) Therefore, we have used several experimental approaches as described below, all using *Gossypium hirsutum* L.

Discussion

Photosynthetic Experiments

Warner and coworkers (1995) report that cotton exhibits reduced photosynthesis (A) accompanied by adjustments in starch pools but maintains sucrose pools when grown long-term at 20°C (=68°F) rather than 28°C (=82°F) nights. However, the short term effects of cool night temperatures on A have not been studied nor is the mechanism limiting A known. Cotton plants (cv Coker 312) were grown in growth chambers (30°/28°C day/night cycle; light intensity 650 µmol photons m^{-2} s^{-1}) and then transferred to 30°/19°C or 30°/15°C, or alternatively, they were grown constantly at 30°/28°C, 30°/19°C or 30°/15°C with the same light conditions. (C/F conversions are as follows: 30°C = 86°F; 28°C = 82°F; 19°C = 66°F; 15°C = 60°F). Determinations were made of maximum photosynthetic rates, stomatal conductance (g_s), internal CO_2 concentration (C_i), and levels of leaf sucrose and hexose (glucose and fructose).

The photosynthetic studies indicated that maximum rates of A were lower for plants grown with cool nights throughout the photoperiod compared with plants grown at 30°/28°C. Transferred plants had lower A values than the 30°/28° C plants after the first cool night, but after 8 days some partial recovery of A had occurred. Both g_s and C_i were substantially reduced for the first 2 days after transfer, indicating a strong limitation to A in the short term. By day 8, g_s had nearly recovered in plants transferred to 30°/19°C. However, in plants transferred to 30°/15°C, although there was some recovery of g_s, the C_i remained low even 8 days after transfer.

Leaf hexose (glucose and fructose) levels during the photoperiod were similar for plants grown with warm and cool nights. However, sucrose levels were 19 and 28% lower for 30°/19°C and 30°/15°C plants, respectively, than the warm grown plants. A 57% and 133% increase in pre-dawn sucrose was observed in plants transferred to 30°/19°C and 30°/15°C, respectively, suggesting a restriction in sucrose translocation. A preliminary $^{14}CO_2$ incorporation study indicated that this restriction may extend into the following day, but a low A may be responsible for sucrose levels remaining near those of warm-grown plants during the day.

Cellulose Synthesis Experiments

Sucrose in fibers is essential for cellulose synthesis because it is cleaved by sucrose synthase to generate uridine diphosphoglucose (UDPG) that is channeled to the cellulose synthase in a closely coupled reaction (Amor et al., 1995). We carried out pulse/chase experiments by feeding ^{14}C-glucose to cultured cotton ovules (methods according to Roberts et al., 1992) with fibers at the secondary wall stage of to determine if a particular block point in the cellulose biosynthetic pathway could be revealed. ('Pulse' refers to an initial time of feeding the radioactive substrate, and 'chase' refers to a subsequent period of feeding only unlabeled substrate. Glucose is the preferred substrate for cultured ovules since sucrose causes extensive callus production.) We monitored the incorporation of ^{14}C into CO_2 (indicating respiratory activity to produce energy), crystalline cellulose, and into metabolites in the fiber, including glucose, sucrose, fructose, and an intermediate pool including glucose-6-P, glucose-1-P, fructose-6-P, and UDPG. Metabolites were separated by HPLC using a Waters Sugar Pak 1¨ cation ion exchange column and ^{14}C incorporation into each metabolite or metabolite pool was determined by a flow scintillator.

Results are reported here for Paymaster HS-200, a new cultivar with partially improved cool tolerance in cellulose synthesis that is more productive on the Southern High

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Plains. It is important to note that HS-200 and all other cultivars that we tested can still be substantially improved in cool tolerance of cellulose synthesis; at 15°C (= 60°F), it makes crystalline cellulose at only 24% of its control rate (Haigler et al., 1994). The data shown suggest that: (1) crystalline cellulose (required for fiber maturation) is made most efficiently from actively imported substrate, whereas CO_2 (indicating energy production) is made from actively imported and stored substrate; and (2) cool temperatures hinder cellulose biosynthesis in cultured cotton fibers after sucrose is present.

Summary

Cool nights reduce cotton A by reducing g_s especially in the short term. Associated with lower values of A are lower sucrose levels during the photoperiod. Additionally, warm grown plants exposed to a cool night may have a reduced capability to export sucrose from the source leaf. Even after sucrose is present in the fiber, cool nights inhibit its use for cellulose synthesis to accomplish fiber maturation.

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