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Consequences of immature fiber on the processing performance of Upland cotton

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ABSTRACT

Immature cotton fiber will negatively impact textile processing. Three field experiments were undertaken that applied chemical harvest aids to upland cotton (*Gossypium hirsutum* L.) crops at varying times with the intention of manipulating the maturity of bolls and fibers. The aim was to quantify the effects of these treatments on the textile performance of the harvested cotton and relate these differences to the status of the crop at the time of treatment application. Although earlier treatments produced less mature fiber that was lower in linear density, yarn and fabric strength was not affected. However less mature cotton from a cooler growing season produced stronger yarns (by 3 cN tex^{-1}) and fabric (by 0.39 N $(g\,m^{-2})^{-1}$) which was partly attributed to the smaller ribbon width of this fiber affecting more fiber packing density and inter-fiber friction. Yarns made from this immature cotton also contained more neps. Micronaire and linear density were equally well related, and more strongly related than maturity ratio, to dyed fabric color dimensions, which were greatly influenced by treatments. Percent immature bolls at the time of harvest aid application related well to changes in the degree of fabric blueness ($R^2 = 0.89$). Knowing the status of a crop in the final stages of production will help cotton producers and the supply chain to predict some of the processing performance aspects of harvested fiber.

1. Introduction

Cotton fiber development consists of a number of distinct phases including the deposition of cellulose in the secondary cell wall. This degree of cell wall thickening is referred to as fiber maturity, with mature fibers having more thickening so that the hollow space in the fiber, the lumen, is small. Immature fibers have less cell wall thickening with a larger lumen and are undesirable because they reflect light differently and do not uptake dye as effectively as mature fibers and will appear a lighter hue (Smith, 1991). Immature fiber will also entangle more easily and form neps (knots) which contribute to processing inefficiencies and appear as 'white specks' or flecks on finished fabric. Delays in boll and fiber maturity are caused by less than optimal crop growing conditions including cold temperatures (Liakatas et al., 1998), excessive nutrition (Cassman et al., 1990) and other crop management decisions (Roberts and Constable, 2003) including the early application of harvest aids (Snipes and Baskin, 1994).

Fiber maturity will influence the fineness of fibers. 'Fineness' refers to two interrelated conditions, firstly as a term for fiber weight per unit length or linear density, and secondly it pertains to fiber diameter or ribbon width. Typically fibers with smaller diameters will be lower in linear density and therefore are regarded as finer. Fineness contributes to yarn strength because stronger yarns contain either more finer fibers (smaller diameter or width) in a given volume resulting in greater packing density and inter-fiber friction, or there will be a greater total number of fibers of lower linear density in the yarn cross section (Goswami et al., 1977; Sullivan, 1942). While fiber maturity will affect linear density, maturity also has potential to additionally affect fiber fineness or coarseness because the degree of cell wall thickening may influence the external dimensions of fibers. For example a flatter immature collapsed fiber may have a smaller ribbon width compared to a fuller more mature fiber.

This paper details findings extending on from those reported by Bange et al. (2010) in which the timing of harvest aids were systematically varied on maturing cotton crops to influence the proportion of immature fiber and neps in the crop. These quality attributes were related to different measures of crop status at the time of treatment application, and recommendations for refining management strategies for harvest aid timing were suggested to optimize yield and quality. The work herein reports on the effects of the same experimental treatments but with emphasis on the processing performance of the treated cotton fiber. The aim of this work includes ascertaining which plant status and fiber quality measures best reflect changes in yarn and fabric performance, as well as quantifying the effects of harvest aid timing on these textile attributes.

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Table 1
Impact of harvest aid timing treatments on fiber quality attributes micronaire, maturity ratio, linear density and ribbon width, for all experiments.

Harvest aid treatment	% immature bolls	Micronaire	Maturity ratio	Linear density mtex	Ribbon width μm
Exp. 1					
1	67.5	4.1	0.88	172	14.8
2	41.0	4.2	0.91	181	14.8
3	23.4	4.6	0.98	194	14.9
4	22.2	4.6	0.91	191	15.0
5	21.1	4.3	0.95	183	14.8
6	12.5	4.7	0.91	195	15.0
7	6.1	4.6	0.95	196	15.1
8	0.0	4.6	0.95	193	15.0
Average		4.4	0.93	188	14.9
LSD (0.05)		0.4*	0.10	12**	0.2
Exp. 2					
1	64.9	4.2	0.82	179	14.7
2	56.6	4.6	0.85	188	14.7
3	50.1	4.7	0.90	196	14.9
4	36.1	4.9	0.95	202	14.9
5	19.8	5.2	0.91	207	15.1
6	10.2	5.1	0.95	205	14.9
7	10.1	5.0	0.99	210	15.0
8	0.0	4.9	0.90	201	14.9
Average		4.8	0.91	198	14.9
LSD (0.05)		0.4***	0.10*	11***	0.3
Exp. 3					
1	88.2	3.0	0.53	159	14.6
2	81.0	2.9	0.69	152	14.7
3	72.4	3.3	0.63	173	14.8
4	72.2	3.6	0.65	178	14.7
5	40.4	3.7	0.75	182	14.8
6	20.0	3.8	0.75	191	14.7
Average		3.4	0.67	172	14.7
LSD (0.05)		0.3***	0.15*	9***	0.2
LSD (0.05) Exps.		0.4***	0.06***	12**	0.1*

* ANOVA was significant at the 0.05 level.
** ANOVA was significant at the 0.01 level.
*** ANOVA was significant at the 0.001 level.

The hypothesis that fiber maturity affects fiber fineness and thus yarn strength is also briefly examined.

2. Materials and methods

2.1. Cultural details, treatments, and measures of plant status and fiber quality

Full experimental details are described in Bange et al. (2010). Briefly, field experiments were conducted at the Australian Cotton Research Institute at Narrabri, NSW, Australia (30°S 150°E) in which a single mixture of harvest aids, designed to cause leaf shed and to increase the rate of boll opening, was applied to cotton crops with different proportions of open bolls. Experiments were conducted in the 2006, 2007 and 2008 harvest seasons, designated as experiment (Exp.) 1, 2 and 3, respectively. Treatments were an application of a mixture of leaf defoliant and a boll opener; being Dropp Liquid® (Bayer CropScience), Prep 720® (Bayer CropScience) and D-C Tron® (Caltex) applied at approximately 5 d intervals in Exps. 1 and 2, and at 7 d intervals in Exp. 3 from high to low percent immature bolls. Percent immature bolls at initial harvest aid application ranged from 65 to 90% (Table 1). In Exps. 1 and 2 Bollgard II Roundup Ready (Monsanto Co., St. Louis, MO) upland (*Gossypium hirsutum* L.) cultivar Sicot 71BR (CSIRO, Australia) was used while Exp. 3 used the non-transgenic upland cultivar Sicot 71 (CSIRO, Australia; Reid, 2003), the recurrent parent of Sicot 71BR. All experiments used a randomized complete block design with four replications.

On the day of each respective treatment application, crop status measurements were taken, including a count of the number of mature and immature bolls to determine the percentage of immature bolls. Immature bolls were determined by assessing the color of the seed coats contained within the bolls; bolls with seed coats that were not dark were deemed immature (Brecke et al., 2001). Bange et al. (2010) discussed several measures of crop status (additionally % open bolls, % immature fiber mass, and nodes above cracked boll) and reported good relationships between them for this study. Percent immature bolls are presented herein because it was seen to best represent the differences in quality at harvest, and although not definitely proven, is thought to potentially be a more reliable plant status measure when crops are non-uniform in their maturity and when they contain fruiting gaps.

The micronaire of machine harvested fiber samples that had been ginned without lint cleaning, was determined using an Uster Technologies High Volume Instrument model 900. Additional samples were subjected to one passage of a SDL 'Shirley' Analyser Mk2 (to remove some trash and help homogenize samples), and then tested for maturity ratio using the CSIRO polarized light microscopy instrument SiroMat (Gordon and Phair, 2005; Long et al., 2010b), gravimetrically determined linear density (mtex) using the CSIRO Cottonscan instrument (Naylor and Purmalis, 2005; Abbott et al., 2010), and fiber diameter (ribbon width) (μm) using the CSIRO photometric laser based instrument Sirolan-Laserscan (Lynch and Michie, 1976; Lunney and Irvine, 1979; Charlton, 1995).

2.2. Yarn manufacture

Four 42 g samples of machine harvested ginned fiber were taken from each experimental unit. Each sample was separately carded twice and drawn once using a 'Shirley' miniature spinning plant card and draw frame (Platt brothers, England). The four miniature