Modified use of the CSIRO Sirolan-Tensor wool fibre strength tester, for measuring cotton fibre strength attributes.

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Aim

To adapt the CSIRO Sirolan-Tensor to measure strength attributes of cotton fibres.

Project summary

The CSIRO Sirolan-Tensor was employed to measure fibre bundle strength attributes of Australian cotton varieties. The instrument was selected because of the potential to adapt it to operate under different temperature and humidity conditions, thus having future potential to give insight into the glass transition temperature of cotton. Four *Gossypium hirsutum* varieties, Sicot 71BR, Sicala 350B, CHQX12B and CHQX377, and a *G. barbadense* variety Pima CPX42, were examined. Sirolan-Tensor fibre bundle breaking tenacity was on average 49, 41 and 32 % (at 1.0, 3.2 and 5.0 mm gauge lengths respectively) less than the breaking tenacity measured via the industry standard high volume instrument (HVI), and there was a strong linear relationship between Sirolan-Tensor and HVI breaking tenacity (R^2 >0.98 for all three gauge lengths). Fibres were also assessed at four length groupings, short (20-25 mm), medium (25-30 mm), long (30-35 mm) and extra long (35-40 mm), with longer average length fibre bundles exhibiting greater breaking tenacity. Fibres with higher average maturity ratio values as measured with the CSIRO Siromat cotton fibre maturity tester had greater breaking tenacity.

Background

Cotton fibres are single-celled outgrowths from individual epidermal cells on the outer integument of the ovules or seeds in the cotton fruit (Hsieh and Wang, 2000). Currently High Volume Instrument (HVI) lines are employed to measure fibre quality attributes that relate to the spinability of cotton, including fibre length, length uniformity, strength, elongation, micronaire, colour as reflectance (Rd) and yellowness (+b), and trash content (Bradow and Davidonis, 2000).

The breaking strength of cotton fibres is an important attribute in determining the strength of yarn and wear of fabric manufactured from those fibres (Kalyanaraman, 1984; Taylor, 1992) and also reflects how robust cotton fibres are during pos-harvest processing. In strength testing, a bundle of fibres is combed parallel and secured between two clamps, and a force to try to separate the clamps is applied and gradually increased until the fibre bundle breaks. Fibre tensile strength is calculated from the ratio of the breaking load to bundle mass. Fibre strength is reported as breaking tenacity or grams of breaking load per tex, where tex is the fibre linear density in grams per kilometer (Bradow and Davidonis, 2000). Tensile properties of cotton fibres are dependent on genotype, environmental or growth conditions and competition for nutritional resources (Liu et al., 2005).

The CSIRO Sirolan-Tensor (Figure 1) was designed, and is routinely employed, to accurately determine strength properties of wool fibres. The aim of the research reported herein was to adapt this instrument to measure strength properties of cotton fibres. This instrument was selected because of the potential to use it to gain understanding of the glass transition temperature of cotton, and how this physical condition interacts with, and assists in optimizing, the mechanically intensive and potentially damaging processing of cotton lint (e.g. ginning and spinning).

The glass transition temperature is the temperature, below which the physical properties of amorphous materials vary in a manner similar to those of a crystalline phase and above which amorphous materials behave like liquids. A material's glass transition temperature, T_g, is the temperature below which molecules have little relative mobility (http://en.wikipedia.org/, 17th January 2007). Cotton is a cellulosic polymer being 70% crystalline and 30% amorphous. The amorphous material will effect the mechanical properties of cotton, particularly when fibres are bent, twisted or stretched. The properties of the amorphous portion will be effected by the presence of absorbed water, effected by relative humidity. The T_g decreases as water content increases (Phillips, pers comm).

Figure 1. CSIRO Sirolan-Tensor wool strength tester

Testing the strength of cotton above, below and at this temperature, whilst also assessing the co-effecting factor of relative humidity, would be an interesting future area of research. For example, prior preliminary work has shown that a 1% increase in relative humidity and the accompanying increase in fibre moisture content will increase the strength of cotton by 0.2 to 0.3 g tex^{-1} (Bradow and Davidonis, 2000). The Sirolan-Tensor is a potential candidate for such research; the instrument is small enough to be easily operated in a laboratory based variable climate cabinet, or a climate controlled shroud could be assembled to cover the fibre-breaking apparatus of the instrument (Figure 2).

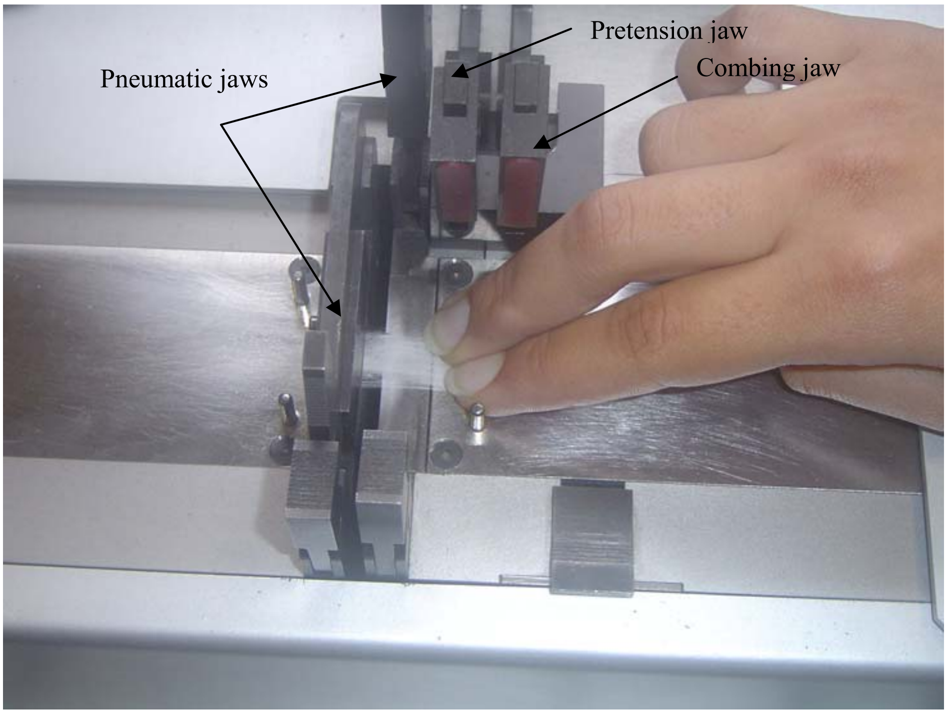

Figure 2. Sample holder jaws of the CSIRO Sirolan-Tensor

Fibre length varies significantly on a single seed with longer fibres occurring at the chalazal end of the seed and shorter fibres occurring at the micropylar end. Variations in fibre length are attributed to genotype and environmental changes occurring around the time of floral anthesis may limit fibre initiation or retard the onset of fibre elongation. Fibre length is directly related to yarn fineness, strength and spinning efficiency (Bradow and Davidonis, 2000).

Fibre maturity is the degree of fibre cell-wall thickening relative to the diameter of fineness of the fibre. A mature fibre is a fibre in which two times the cell wall thickness equals or exceeds the diameter of the fibre cell lumen, the space enclosed by the fibre cell walls. Fibre maturity properties, which are dependent on deposition of photosynthate in the fibre cell wall, are affected by environmental influences. Variations in fibre maturity are related to the seed position; the degree of secondary wall thickening is lowest in seeds at the apex of the locule and highest at the peduncle or basal end (Bradow and Davidonis, 2000). The CSIRO Siromat cotton fibre maturity tester is based on polarized light microscopy, a technique that has been used to investigate the crystalline structures of inorganic and inert organic materials. The technique has been used extensively in the identification of fibres that exhibit birefringent properties.

In this study, strength attributes of five CSIRO cotton varieties were assessed using the Siorlan-Tensor at different gauge lengths. Fibre bundles were selected on length, and the average maturity ratio of tested fibres was determined using the Siromat cotton fibre maturity tester.

Methodology

Cotton production

CSIRO cotton varieties were used in experiments, including four upland (*Gossypium hirsutum*) varieties and one Pima (*G. barbadense*) variety. These varieties are the latest premium quality varieties produced from the CSIRO breeding program and exhibit good fibre quality traits (Table 1). Upland varieties included the currently released Sicot 71BR and Sicala 350B, and two unreleased varieties CHQX12B and CHQX377. Pima was the unreleased variety Pima CPX42.

Table 1. High volume instrument data for five CSIRO varieties. Mean and standard error values (n = 2 bales).

Variety	Length (mm)	se	Uniformity index (%)	se	Short fibre index (%)	se	Strength (g/tex)	se	Elongation (%)	se	Micronaire (µg/inch)	se
Sicot 71BR	29.3	0.63	83.1	0.05	8.9	0.75	29.8	0.65	6.1	0.25	4.50	0.10
Sicala 350B	32.4	0.64	84.8	1.60	7.6	0.85	31.5	1.35	5.5	0.00	4.25	0.05
CHQX12B	31.9	0.13	84.1	0.05	8.2	0.05	32.0	0.95	4.1	0.15	4.35	0.05
CHQX377	31.0	0.25	85.5	0.25	7.1	0.50	34.0	0.90	5.3	0.05	4.35	0.05
PIMA CPX 42	34.9	0.13	86.4	0.10	6.3	0.75	49.0	1.00	3.8	0.05	3.65	0.05

The five varieties were grown together under normal industry standard, conventionally managed, and irrigated conditions at the Australian Cotton Research Institute (ACRI) (Narrabri, New South Wales) during the 2005 / 2006 season. Upland varieties were saw ginned at Cotton Seed Distributors in Wee Waa, New South Wales. Pima cotton was roller ginned at the ACRI.

Sample preparation and Sirolan-Tensor measurements

Cotton samples were conditioned for at least 48 hours under standard conditions (20^{o}C +/- 2^{o}C and 65% relative humidity +/- 3%), and all tensile tests were carried out under standard conditions.

Five samples of fibres based on length were examined for each cotton variety, including an average length bundle that was hand selected. Four groups were prepared using a Shirley comb-sorter: short (20 -25mm), medium (25 – 30 mm), long (30 – 35 mm) and extra long (35 – 40 mm).

Combed tufts were placed under the pneumatic jaws of the Sirolan-Tensor and tests were carried out without the use of the combing jaw or the pretension jaw (Figure 2). For average length samples, tensile testing was conducted at each of three gauge lengths, 1.0 mm, 3.2 mm and 5.0 mm. Specific combed length samples were tested at 1.0 mm gauge length. Ten tensile tests were carried out for each sample.

For each of the remaining tensile tested specimens, 2 to 3 mg was sub-sampled for maturity testing via the Siromat cotton maturity tester. Fibres were cut into 1 mm snippets and then spread in an annular pattern on a 5 cm x 7 cm glass slide using an OFDA fibre spreader. Castor oil was used as the mounting medium, with a 5 cm x 7 cm slide used as a cover slip. The digital camera settings (U balance, V balance and shutter speed) and the microscope lamp intensity was adjusted to match a prescribed background (magenta colour) in terms of red, green and blue ratios. Background colours were checked after each slide during testing to minimize drift in instrument readings. Four replicate slides were tested for each sample.

Results and discussion

Sirolan-Tensor breaking tenacity for the five experimental varieties reflected HVI results, with Pima having the strongest fibres, and the new unreleased conventional variety tending to be stronger than the other upland varieties (Figure 3A). Sirolan-Tensor fibre bundle breaking tenacity was on average 49, 41 and 32 % (at 1.0, 3.2 and 5.0 mm gauge lengths respectively) less than HVI breaking tenacity, and there was a strong linear relationship between Sirolan-Tensor and HVI breaking tenacity (R^2 >0.98 for all three gauge lengths) (Figure 4). Fibre breaking elongation results did not reflect those obtained via HVI analysis ($R^2 < 0.20$ for the three gauge lengths, data not shown), and this is attributed to samples being broken without the use of the pre-tension jaws on the tensor instrument. Pre-tension jaws were not used because the cotton fibre bundles were considerably shorter than typical wool fibre bundles that the instrument was made for. The lack of a consistent amount of pre-tension for each sample confounded the elongation before break measurement.

It was found that as the gauge length increased, the corresponding tenacity decreased (Figure 3A). This can be explained by the weak-link effect. A fibre specimen always breaks at the weakest point along its length. Since the probability of appearance of the weakest point increases with length of a specimen, the fibre tenacity decreases with increasing the testing gauge length (Duckett, Krowicki and Cheng, 1975).

Fibre bundles with greater average length were stronger. The presence of fibres shorter than the sum of the width of both pneumatic jaws and the 1mm gauge length (12.2 mm) (Figure 2) would be less effectively held by the breaking apparatus of the instrument, with bundle strength of such fibres being less, and thus bundles with higher average length being stronger (Table 2).

Table 2. Sirolan-Tensor fibre bundle breaking tenacity (cN/tex) at 1.0 mm gauge length, of four fibre length categories for five CSIRO cotton varieties.

Length	Sicot 71BR	Sicala 350B	CHQX12B	CHQX377	Pima CPX42
20-25mm	14.41	16.18	13.17	18.65	23.93
25-30mm	16.33	17.90	16.73	18.98	24.17
30-35mm	16.73	18.67	17.95	20.06	24.91
35-40mm	-	18.57	-	-	26.56
ANOVA P	*0.02*	*0.01*	*<0.01*	*0.09*	*0.03*
LSD (5%)	*1.56*	*1.34*	*1.71*	*n.s.*	*1.75*

Shorter fibres are more likely to have had less cellulosic deposition and will thus be weaker. Indeed, for the five varieties examined, there was a strong linear relationship between fibre maturity and fibre strength (Figure 5), with longer fibres tending to be more mature (data not shown).

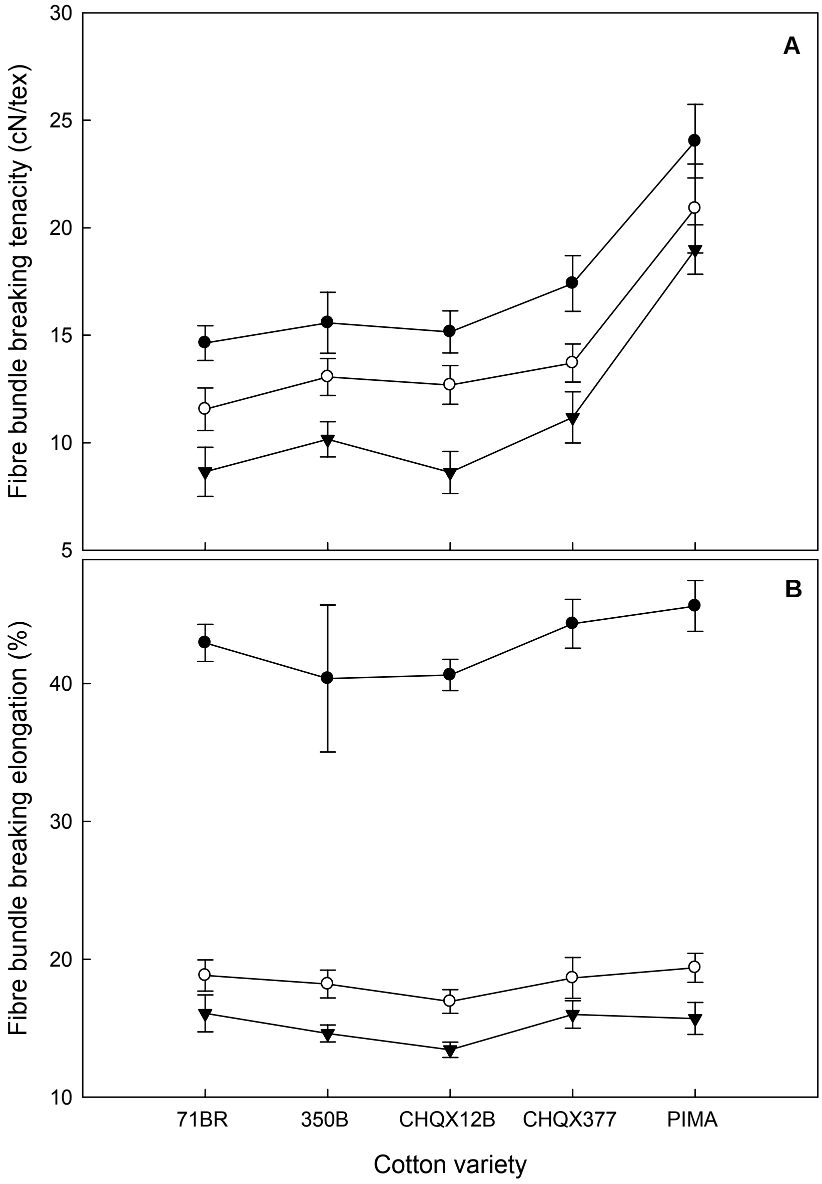

Figure 3. Sirolan-Tensor fibre bundle breaking tenacity (A) and breaking elongation (B) made at 1.0mm (●), 3.2mm (○) and 5.0mm (▼) gauge lengths, for five CSIRO cotton varieties. Values are mean ± standard deviation.

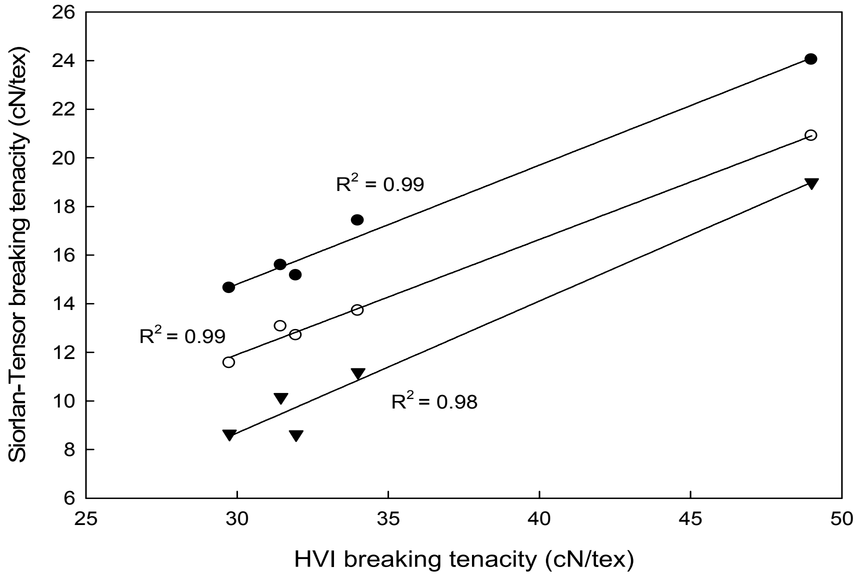

Figure 4. The linear relationship between Sirolan-Tensor fibre bundle breaking tenacity and high volume instrument fibre bundle breaking tenacity, for five CSIRO cotton varieties.

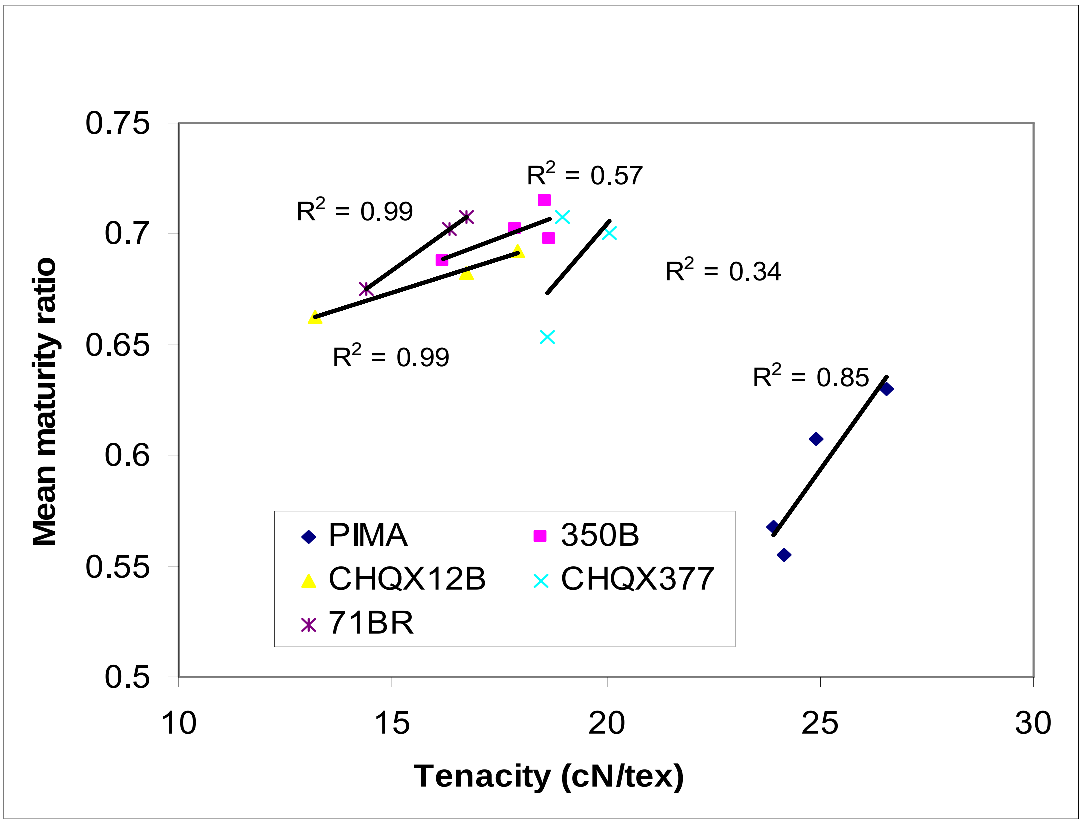

Figure 5. The linear relationship between mean fibre maturity ratio and fibre bundle breaking tenacity for each of five CSIRO cotton varieties.

Conclusion

The CSIRO Sirolan-Tensor was employed to measure fibre bundle strength attributes of Australian cotton varieties. Sirolan-Tensor breaking tenacity for the five experimental varieties reflected HVI results, with Pima having the strongest fibres, and the new unreleased conventional variety (CHQX377) tending to be stronger than the other upland varieties. Sirolan-Tensor fibre bundle breaking tenacity was on average 49, 41 and 32 % (at 1.0, 3.2 and 5.0 mm gauge lengths respectively) less than HVI breaking tenacity, and there was a strong linear relationship between Sirolan-Tensor and HVI breaking tenacity ($R^2 > 0.98$ for all three gauge lengths). Longer average length fibre bundles exhibiting greater breaking tenacity, and fibres with higher average maturity ratio values as measured with the CSIRO Siromat cotton fibre maturity tester, had greater breaking tenacity. In conclusion, the CSIRO Sirolan-Tensor instrument could be easily modified to make tenacity measurements of cotton at different temperature and relative humidity conditions, with such future work giving insight into the glass transition temperature of cotton.

References

Bradow, J. M. and Davidonis, G. H. (2000). Quantitation of Fiber Quality and the Cotton Production-Processing Interface: A Physiologist's Perspective. *The Journal of Cotton Science* **4**, 34-64.

Duckett, K. E., Krowicki, R. S. and Cheng, C. C. (1975). Some Observations on Single-fiber and Flat-bundle Tensile Tests, and on the Application of Weak-link Theory to the Determination of a True Zero-Gauge Tensile Test Length of Single Cotton Fibers. *Applied Polymer Symposium* **27**, 359-368.

Kalyanaraman, A. R. (1985). An Investigation to Identify Factors that Confer High Strength Properties to Normal Cottons: The Relationship Between Orientation Factors (X-ray, Optical) and Tensile Strength. *Carbohydrate Polymers* **5**, 215-222.

Liu, J., Yang, H. and Hsieh, Y. (2005). Distribution of Single Fiber Tensile Properties of Four Cotton Genotypes. *Textile Res. J.* **75**(2),117-122.

Taylor, R. A. (1986). High Speed Measurements of Strength and Elongation. *Textile Res J.* **56**, 92-101.

http://en.wikipedia.org/, 17th January 2007