Measuring the variation along the length of cotton fibres

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IN a recent (small) study sponsored by Cotton Incorporated, CSIRO A&F's Natural Fibres Team investigated the ability of the Cottonscope instrument to measure the cross-sectional variation along cotton fibre lengths.

From a structural perspective the cotton fibre is a singularly discrete, elongated plant cell with no junctions or inter-cellular boundaries. Its form in nature is essentially unchanged from the field to the spinning mill where its cross-section properties, as for any textile fibre, are central in determining the properties of the yarn and fabric made from it.

Because a cotton fibre is a plant cell, the geometry of its cross-section includes a cell wall and a hollow cavity called the lumen. The dimensions of these features will naturally vary along the length of the fibre, although under the influence of the genetics of the plant and the environment under which the cell develops.

But a cotton fibre's cross-sectional shape, which is hollowed, irregular and highly variable between individual fibres, brings challenges in measurement (see Figure 1). In contrast, the equivalent properties of man-made fibres that compete with cotton (e.g. polyester), are more easily described because of their uniform symmetry.

Growth of the fibre

A fibre's growth from the cotton seed epidermis is initiated at pollination and its extension in length starts within one day of flowering or anthesis – the period is often referred to in days post-anthesis (DPA). Figure 2 shows seed epidermis cells beginning their extension into fibres at one DPA. The width of the cells at this point is thought to be pre-determined by genetics because the average perimeter tends to reflect a 'known' fineness value for a given cultivar. But a more recent hypothesis is that the perimeter could vary under different environmental conditions during fibre wall development, and that the rate of response to changes in environment is determined by genetics.

Figure 3 shows the fibre initials at three DPA. Noticeable is the dramatic elongation in the cell, the already large variation in dimensions between neighbouring fibres and significantly, the variation along the length of individual fibres. In almost all developing fibres a taper is evident in the cell perimeter or width from the base near the seed to the apical tip.

While this is 'interesting' from a plant physiology/development perspective, from a material perspective it represents a variation that collectively might provide a fault line or weak point in the assembled material, i.e., the yarn or fabric. A place where a fibre break might occur resulting in higher collective short fibre and yarn hairiness values, or where the yarn can be weaker and prone to breakage.

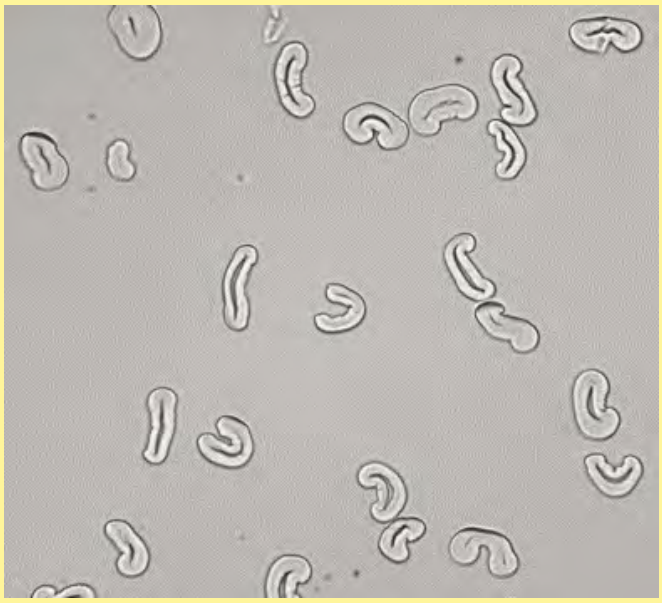
Over the next 50+ days the epidermal cell that becomes a cotton fibre undergoes:

- Elongation (up to >2.5 cm in some cotton species) via primary wall synthesis;
- Transitional wall thickening; and then,
- Secondary wall thickening where the secondary cell wall of the fibre is laid down in a series of concentric growth rings or lamellae.

The exact period of elongation and secondary thickening depends on factors such as variety (genetics), growing temperature, light level and water turgor. But the effects of genetics and environment are difficult to quarantine unless:

- Appropriate controls on the plant's physiological responses are applied to, for example, water, temperature, radiation and fertilisation; and,

FIGURE 1: Cross-sections of cotton fibres embedded in methyl-butyl methacrylate resin showing variation in fibre cell wall and lumen

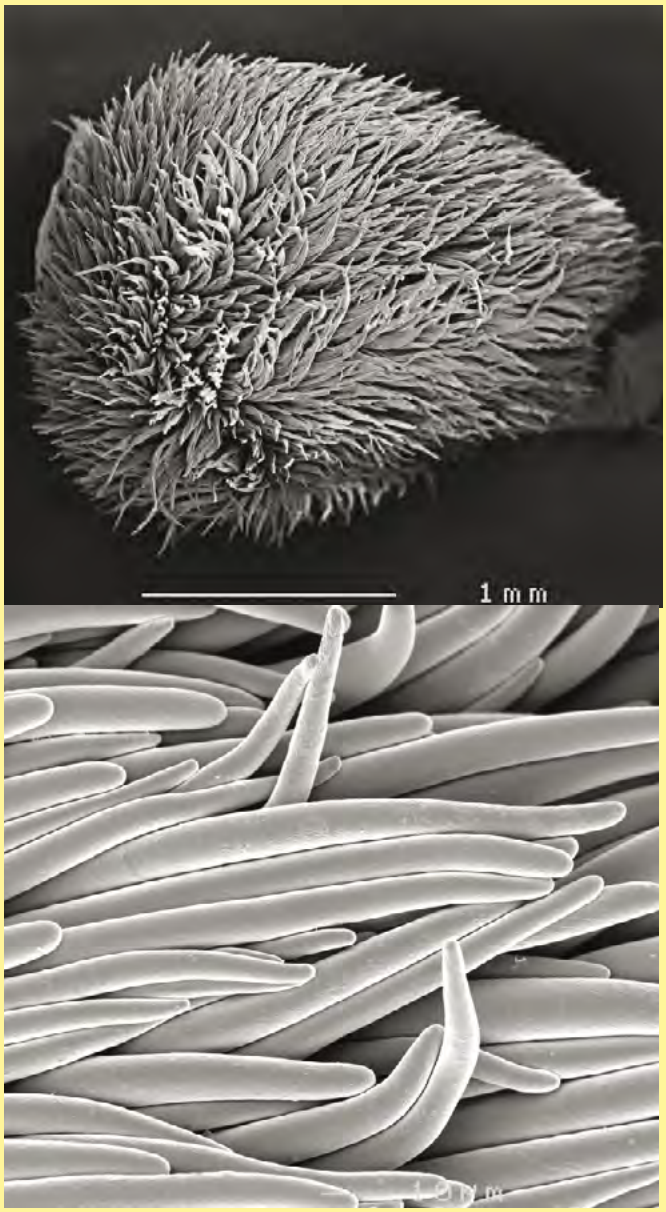


(PHOTO: Margaret Pate, CSIRO)

FIGURE 2: Fibre 'epidermis' cells beginning their elongation and development at one DPA

(PHOTO: Rosemary White, CSIRO)

FIGURE 3: Fibre 'epidermis' cells at three DPA on seed and closeup



(PHOTOS: Rosemary White, CSIRO)

■ There is a method to measure the geometric and material response in the fibre.

In this short study, a set of opened boll samples from the same experimental crop (planted at CSIRO's Australian Cotton Research Institute for the 2019–20 season) was investigated. The samples came from the same crop year and variety (Sicot 74BRF), grown in adjacent rows under the same conditions but sown at three different times – early, standard and late.

Fibre snippets for Cottonscope measurement were prepared from quartile length sections while fibres were still attached to the seed (see Figure 4). The fibre still attached to the seed was 'combed' gently by hand and then 0.9 mm snippets cut progressively from tip (1) to the fibre base (4) at the seed epidermis, with snippets from each quartile length section segregated. The examination looked at fineness, fibre width and maturity along the quartile lengths of the fibre at the different times of sowing.

Cottonscope measurements were subject to a nested analysis

of variance (ANOVA) wherein the quartile position and (three) replicate measurements were nested within the three times of sowing. Figures 5, 6 and 7 show Cottonscope measurements and the ANOVA effects for linear density measured in mtex or milligrams per km, width measured in microns and maturity measured as the maturity ratio.

Evident from this preliminary analysis are large time-of-sowing (ToS) effects on linear density (fineness), fibre width and maturity ratio (MR). There were also significant fibre wall tapering effects between the base and the tip for this variety and environment. These effects amounted to:

- Over 30 mtex difference in fineness;
- Over 0.75 µm difference in fibre width; and,
- Over 0.05 difference in maturity ratio.

Interesting is that an early time of sowing resulted in a 'finer' but more mature (heavier) fibre. The decrease in MR at the base (quartile 4) is because immature linter fibres (short immature fibres) were included in the measurement. These linters do not extend more than 5 mm in length.

In conclusion, these measurements raise questions about the genetic and environmental influences on tapering along the fibre length and the consequences for processing (ginning and spinning).

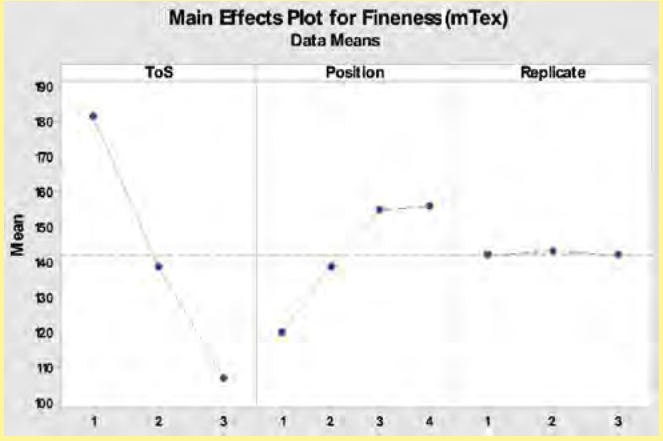
The variation along the length of cotton fibres has been noted by other researchers. But without a quick direct method for measurement, understanding the genetic and environmental triggers and the extent of variation in fibre ripening (thickening) has been limited.

The taper of the fibre ribbon width and the variation around the taper within fibre samples from the same crop, row, plant and even boll observed here suggests there is actually no distinct cell wall thickening phase applicable to the plant as a whole but rather each fibre develops, like the rest of the plant, in an indeterminant but progressive fashion that is affected by combinations of genetics, time, turgor pressure, sunlight and subsequently carbohydrate flow. Understanding the combination of factors at play in determining fibre ripening will be key in negating the issues associated with fibre immaturity, fibre breakage and other quality issues.

Provision of boll samples examined in this study by Sandra Williams and her team is gratefully acknowledged.

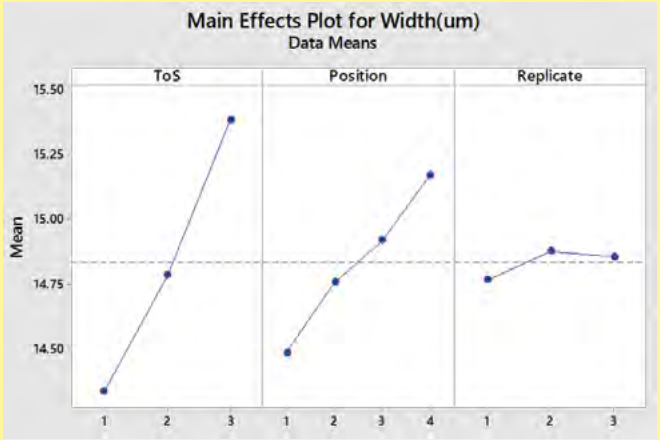
FIGURE FIGURE 4: Seed-cotton fibre locks (Sicot 74BRF ToS 2). Fibre specimens cut along combed sections (top and bottom quartiles shown) of the seed-cotton were isolated in their quartile measurements from tip to base.

FIGURE 5: Linear density (mg/km) effects along the length of quartile sections of fibres



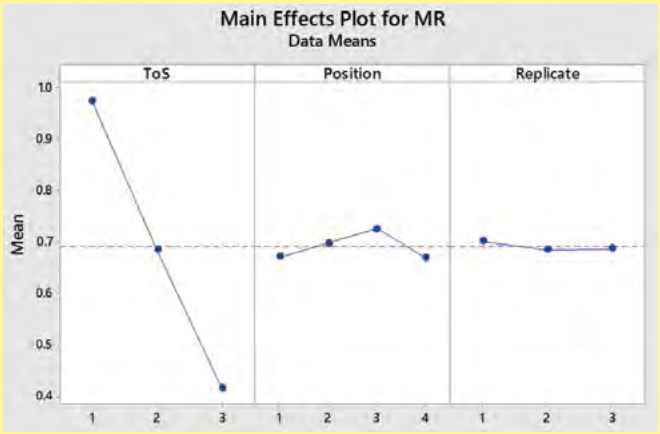
ToS 1 = early, 2 = standard and 3 = late. Position 1 = tip Q1, 2 = Q2, 3 = Q3 and 4 = base Q4. Replicates as numbered.

FIGURE 6: Fibre width (10^{-6} m) effects along the length of quartile sections of fibres



ToS 1 = early, 2 = standard and 3 = late. Position 1 = tip Q1, 2 = Q2, 3 = Q3 and 4 = base Q4. Replicates as numbered.

FIGURE 7: Fibre maturity ratio effects along the length of quartile sections of fibres



ToS 1 = early, 2 = standard and 3 = late. Position 1 = tip Q1, 2 = Q2, 3 = Q3 and 4 = base Q4. Replicates as numbered.