Breeding fibre for the future

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Background

This paper aims to present the breeder's understanding of fibre and variety characteristics for the next decade. We need to think on that time scale because that is how long it takes us to produce a new variety. In addition, ginning and spinning investments need to consider times of that magnitude to get value from new equipment which may have higher fibre quality targets.

What will spinners require? The last two seasons have highlighted shifts in market preference for fibre properties. Base levels for many fibre properties have narrowed, with preference for micronaire between 3.8 and 4.5 (and higher discounts for micronaire above 5.0); fibre length preference is now above 1.125 inches, particularly for some end uses. Fibre strength preference is now above 28 g/tex. These shifts are in addition to the preference for reduced neps, more uniformity in all properties, less trash and no contamination.

Our breeding program will utilize these criteria in selection at all stages. For segregating material in the early stages of breeding we will exclude lines more aggressively on HVI fibre data. At the end of our breeding timeline, there may be lines ready for release which will be terminated because fibre properties are marginal.

History

CSIRO has a long tradition of reacting to spinning market requirements and developing varieties with improved fibre properties to ensure ready marketing. Norm Thomson presented data at the 1993 Plant Breeding conference to show progress with different fibre properties, particularly with fibre strength. This data showed fibre strength was not associated with yield. In the late 1980s to early 1990s, there were CSIRO varieties available such as Sicala 34 which attracted a premium on the basis of long, strong and mature fibre. Further variety development occurred where all varieties had increased yield with good fibre - and premiums disappeared.

The dilemma with micronaire

The micronaire instrument measures air flow through a set weight of lint. It is not an accurate measure of fibre maturity when comparing different varieties - the same reading will be obtained from fine mature fibres as with coarse immature fibres. Micronaire would only be an appropriate instrument if the world had only one variety.

Fibre maturity is important for fibre strength and also for obtaining good and uniform dying of fibres. An immature fibre will take up dye less than a mature fibre and these differences are responsible for variability which can have a major negative impact on yarn value. Within a variety, management and climate affect fibre maturity – the most common effect is reduced fibre maturity from stress or cool conditions during fibre thickening in late boll fill. There have been problems with high micronaire in the past two seasons. Fibre fineness is important for spinning. Of particular interest, with other factors being equal, fine fibres enable more fibres in a cross section of thread during spinning and this improves yarn strength – this is the problem with high micronaire. Fineness tends to be a variety characteristic. The dilemma with micronaire measurement is that low values are termed as immature and high values as coarse (not fine), but the micronaire instrument really cannot distinguish the difference between these two traits.

Neps are entangled pieces of fibre which form lumps when spun into yarn. Small fragments of trash or seed coat cause some neps, but many neps are caused by immature fibres: our measurements have indicated that neps are associated with low fibre length uniformity, fine fibres as well as by immature fibres. As such, neps can be considered to be associated with the same problem as immature fibres: poor conditions during boll filling and also possibly from immature bolls being defoliated and opening too early.

There are ways of measuring fineness and maturity and in the CSIRO breeding program we use an older Shirley FMT3 instrument: our aim is to select for fine but mature fibres – this combination is eagerly sought after for high-speed fine count spinning (Faerber, 2000). However the measurement is slow, complicated and cumbersome. There is a need for new instruments to measure fineness and maturity. Development for these is occurring in a number of places, including CSIRO Division of Textiles and Fibre Technology in Geelong (Naylor and Sambell, 1998).

Ginning

Gins are becoming larger to improve cost and speed. There is debate on the extent of fibre damage that can occur in a gin. Refer to the poster by Grant Roberts at this conference where different heat and cleaning steps have changed length, strength, neps and trash. Of relevance to breeding is seed size: heavy selection for lint% to improve gin turnout will eventually reduce seed size and seed coat fragments may occur from seed caught in grid bars. For our breeding selection process we have set a nominal minimum seed size, however some management and climate factors will reduce seed size.

Spinning

Spinning equipment is also running faster for cost benefits. A faster spinning process will require greater fibre strength to withstand the extra stress on fibres. Different spinning methods also need a range of properties. Traditionally ring spinning (how most Australian cotton is spun) requires better fibre properties, especially length, when compared with rotor spinning. Alternatives such as Murata Vortex spinning also require long and uniform fibre length and high strength (Gordon, 2002) and Compact spinning may be able to process shorter fibre (Krifa et al, 2002).

Transgenic approaches to fibre quality improvement

While the strategies for breeding for improved fibre properties are relatively clear cut - crossing selected individuals and screening for those with a particular combinations of genes that result in fibres with the desired physical or chemical properties, we do not really understand enough about how these properties are determined at the level of the functioning of specific genes or combinations of genes. CSIRO and other international researchers are beginning to put a lot of effort into the discovery of genes involved in the development of the cotton fibre with the hope that one day these genes could be manipulated in transgenic cotton plants to generate fibres with pre-determined and even novel characteristics.

There have been several attempts already at improving cotton fibres using transgenics, as yet without a great deal of success, but this has been by applying scientific intuition or hunches about what genes are likely to be important in the production of cotton fibres rather than a direct knowledge of their roles. Researchers at the Agrecetus company in the US, for example, knowing that plant hormones are important for cell growth and elongation, tried to alter the levels of these hormones in fibres and were successful of increasing the levels of both cytokinins and auxins, but this had no observable effect on fibre properties (John, 1999). Putting extra copies of a gene for peroxidase – one of the enzymes that cross-links the chains of cellulose in the cotton fibres has resulted in apparently stronger fibres but this extra strength did follow through to improved germplasm in field experiments and highlights the difficulties of reliably measuring in small numbers of plants fibre properties that are influenced by both environmental conditions and varietal backgrounds. Other examples of enhancing the expression of genes normally expressed in fibres like expansins, or microfibril cross linking proteins are reportedly giving 10-15% increases in key fibre properties under small scale glasshouse conditions (Mishra et al., 2001), but it remains to be seen if these are heritable and will be translated into products.

As we gain more knowledge about the genes and metabolic pathways involved in cotton fibre development we can apply more targeted approaches to manipulating fibres. CSIRO and US researchers are manipulating key genes for enzymes involved in mobilising sugars in cotton that are the necessary precursors for the production of cellulose. Simple sugars are thought to provide the turgor pressure necessary to cause the fibre cells to swell up and elongate so a number of strategies for increasing the proportion of sugars that go to the fibre cells are being explored. Haigler et al, (2001) report that over-expressing sucrose phosphate synthase results in a greater deposition of cellulose inside the developing fibre and this resulted in an increase in seed cotton yield under field conditions. CSIRO researchers have concentrated on the enzyme sucrose synthase that controls the rate of sugar import into fibres (Ruan et al., 2000) and using transgenic plants have shown that this enzyme is absolutely essential for fibre development. Experiments are now underway to modify the expression of this gene in both the developing embryo and fibre to see if the balance can be shifted in the sugar flow to favour fibre elongation.

Completely novel fibres have been the focus of some research, for example, with attempts to produce naturally blue and black cottons using genes for pigment production from bacteria. The very specialised nature of the cotton fibre and its metabolism dedicated to cellulose production has hindered success in this area and insufficient pigment has been produced to warrant further research and development (Calgene Inc, unpublished data). Chinese researchers have reportedly produced a novel type of cotton fibre in transgenic plants expressing the gene for rabbit keratin resulting in whiter, longer, more lustrous fibres (as yet unpublished) and in a similar vein US researchers have used bacterial genes to produce small quantities of a biodegradable plastic in fibres (John, 1999) resulting in slightly enhanced thermal properties.

Researchers are only now starting to use the more encompassing genomics or whole genome approaches to systematically investigate what genes are really important at the different stages of fibre production from when they begin to form on the seed, during their rapid elongation and during the secondary cell wall filling or maturation stages that all determine fibre yield and fibre quality. So-called cotton DNA chips are being manufactured containing many thousands of cotton genes which can be used to follow changes in gene expression at different times in development, in different cotton mutants with altered fibres or even in different breeding lines with different fibre quality characteristics (see paper by Wu et al., in these proceedings). These approaches should identify new target genes for manipulation in transgenic cotton as well as genes that may provide useful molecular markers to enhance the breeding of high quality cotton varieties using conventional breeding.

Yield and quality

There is a considerable volume of literature in many crops which would indicate a common result of yield and quality being linked: in other words high yield may be achieved at the expense of quality. Cotton is no exception, particularly for some fibre properties: it is common for better fibre uniformity and fineness to be associated with lower yields. At the other extreme, high micronaire can be associated with higher yield because factors encouraging fibre thickening at season's end will also benefit yield.

We have precedents from our own data to use as examples. Figure 1 shows a negative association between fibre length and yield in a breeding population in two successive generations from multiple testing sites. This data is from the family which produced the line subsequently released as Sicot 80 (large symbol); a variety with good fibre length - this example of the difference between sister lines from the same cross emphasises the need to have good fibre properties to start with. We were able to choose from the high-yielding end of this family in the choice of the final variety. In this data there were no significant associations between fibre strength or micronaire with yield. Figure 2 shows a positive association between micronaire and yield. The associations are not very strong and it is possible to choose lines which deviate from the regression with high yield and desirable micronaire. The line marked as a large symbol is in an advanced stage of breeding and evaluation.

Figure 1. An example of a negative relationship between yield and fibre length in one breeding population. (A) Fifteen F4 lines tested at three locations in 1997/98; (B) Nine F5 lines tested at six sites in 1998/99.

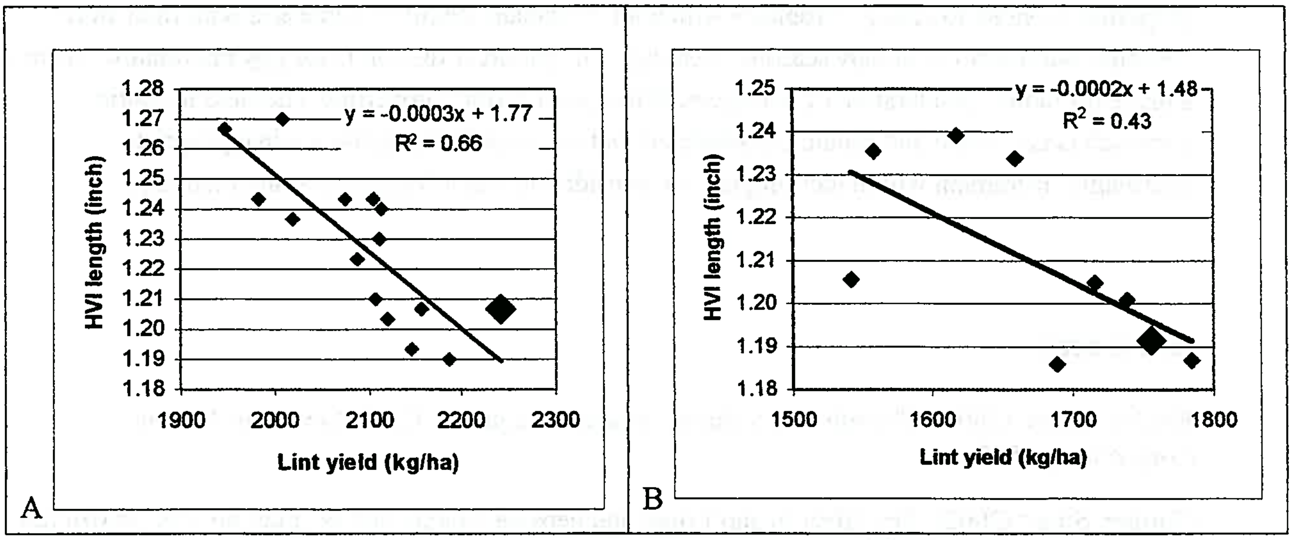
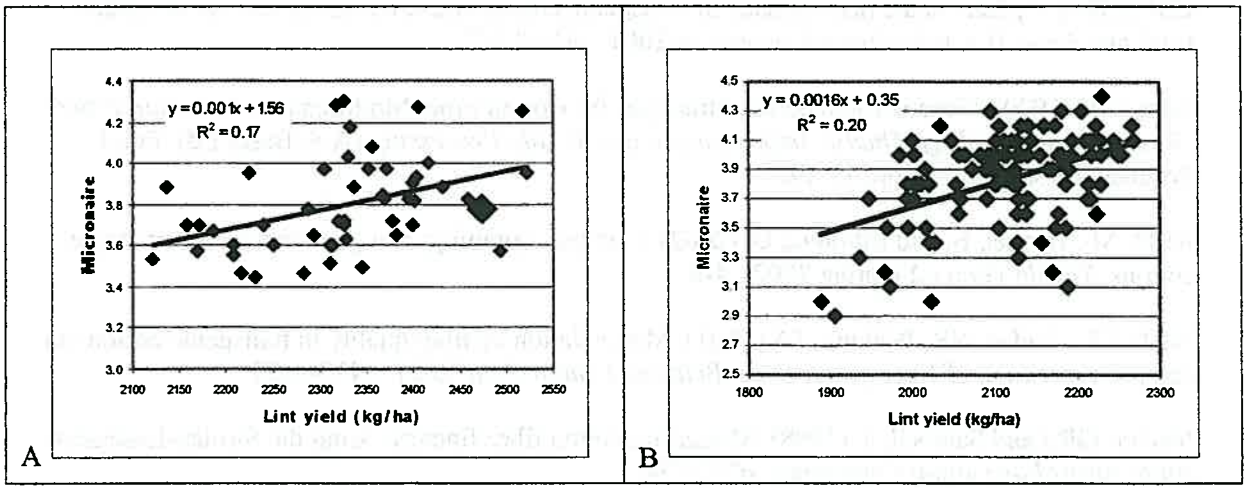


Figure 2. An example of a positive relationship between yield and micronaire in two separate breeding populations at one site in 1997/98. (A) Family 94001; (B) Family 93020.



There will be many circumstances where these relationships are not as strong. However, fibre quality has many traits and during breeding it is necessary to combine the desired fibre length, fibre strength, micronaire, fibre maturity with high yield and disease resistance. The breeding exercise becomes a numbers game: for example, if 20% of lines in a family are expected to have each of the six desired traits just listed, then only 0.0064% (0.2x0.2x0.2x0.2x0.2x0.2) of a segregating population will be the perfect line in combining all objectives. A breeder would need a population of 1563 plants to find one plant with that combination. These days we are starting from a higher base with some properties, but this example highlights the numbers game and we conclude that, even if yield and quality are not always negatively associated, breeding and selection for one will complicate selection for the other.

Conclusions

We have already highlighted how weather, management and conditions can affect some fibre properties separate to variety. Problems with high micronaire could be addressed with finer fibre varieties, but in cool or cloudy seasons, these types might incur discounts for low micronaire. There is a place for more consideration of management to optimise fibre properties. The field to fabric approach is very good and should be continued, but continued reliance on the inappropriate micronaire instrument will hinder progress on considering true fibre fineness and maturity.

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