6. Importance of Quality Fibre

This section outlines and discusses the importance of specific fibre quality attributes, and how changes in these attributes affect textile production. Textile production in this context refers to spinners, who spin yarn and the fabric manufacturers; knitters and weavers, who make and finish the fabric. Finishing the fabric refers to scouring, bleaching, dyeing and the addition of any functional finishes, e.g. stain resistant, permanent press finishes, to the fabric. Many fibre properties are considered and measured where possible by the spinner and fabric manufacturer in order to control product quality. For the spinner the following properties are considered important:

- Length, Length Uniformity, Short Fibre Content
- Micronaire (Linear Density/Fibre Maturity)
- Strength
- Trash (including the type of trash)
- Moisture
- Fibre entanglements known as neps (fibre and seed coat fragments)
- Stickiness
- Colour and grade
- Contamination
- Neps

These fibre properties however, vary in importance according to the spinning system used and the product to be made. Table 6.1 lists the most important fibre properties required by each system to process high quality yarns.

Table 6.1: Important considerations of fibre properties for different spinning processes

Importance rank	Ring Spinning	Rotor Spinning	Air-Jet Spinning
1	Length	Strength	Length
2	Strength	Low Linear Density	Low Trash
3	Low Linear Density	Length	Low Linear Density
4	-	Trash	Strength

For the fabric manufacturer the quality of the fibre is largely characterised by the quality of yarn they buy or are provided with, where good quality fibre translates to good quality yarn. However, the following fibre properties also have significance when appraising the finished fabric quality. These include:

- Micronaire (maturity)
- Trash
- Contamination
- Short Fibre Content (SFC)
- Neps
- Colour and grade

The above properties contribute to knowledge of the general 'spinning ability' and 'dyeing ability' properties. Indeed indices and equations incorporating various fibre properties are commonly used to predict spinning and dyeing ability. However there are fibre properties not yet routinely measured, which could contribute to a more accurate prediction of the spinning and dyeing properties of cotton fibres. These properties might include such things as fibre elongation, fibre cross-sectional shape, surface and inter-fibre friction, the make up of a cotton fibre's surface wax, the crystalline structure of cotton's cellulose, and the level of microbial activity or infection (known as 'Cavitoma').

Consequences of poor fibre quality are presented in Table 6.2 and are discussed in more detail below. In subsequent chapters practices to reduce poor quality are discussed.

(Warwick Stiller: CSIRO)

Table 6.2: Consequences of poor fibre Quality

Fibre Trait	Trait Description	Ideal Range	Consequences of poor fibre quality – cotton price	Consequences of poor fibre quality – spinning
Length	Fibre length varies with variety. Length and length distribution are also affected by stress during fibre development, and mechanical processes at and after harvest.	UHML in excess of 1.125 inch or 36/32nds. For premium fibre 1.250 or 40/32nds.	Significant price discounts below 33/32nds.	Fibre length determines the settings of spinning machines. Longer fibres can be spun at higher processing speeds and allow for lower twist levels and increased yarn strength.
Short fibre content	Short fibre content (SFC) is the proportion by weight of fibre shorter than 0.5 inch or 12.7 mm.	< 8%	No premiums or discounts apply.	The presence of short fibre in cotton causes increases in processing waste, fly generation and uneven and weaker yarns.
Uniformity	Length uniformity or uniformity index (UI), is the ratio between the mean length and the UHML expressed as a percentage.	> 80%	Small price discounts at values less than 78. No premiums apply.	Variations in length can lead to an increase in waste, deterioration in processing performance and yarn quality.
Micronaire	Micronaire is a combination of fibre linear density and fibre maturity. The test measures the resistance offered by a weighed plug of fibres in a chamber of fixed volume to a metered airflow.	Micronaire values between 3.8 and 4.5 are desirable. Maturity ratio >0.85 and linear density < 220 mtex Premium range is considered to be 3.8 to 4.2 with a linear density < 180 mtex.	Significant price discounts below 3.5 and above 5.0.	Linear density determines the number of fibres needed in a yarn cross-section, and hence the yarn count that can be spun. Cotton with a low Micronaire may have immature fibre. High Micronaire is considered coarse (high linear density) and provides fewer fibres in cross section.
Strength	The strength of cotton fibres is usually defined as the breaking force required for a bundle of fibres of a given weight and fineness.	> 29 grams/tex, small premiums for values above 29 /tex. For premium fibre > 34 grams/tex.	Discounts appear for values below 27 g/tex.	The ability of cotton to withstand tensile force is fundamentally important in spinning. Yarn and fabric strength correlates with fibre strength.
Grade	Grade describes the colour and 'preparation' of cotton. Under this system colour has traditionally been related to physical cotton standards although it is now measured with a colorimeter.	> MID 31, small premiums for good grades.	Significant discounts for poor grades.	Aside from cases of severe staining the colour of cotton and the level of 'preparation' have no direct bearing on processing ability. Significant differences in colour can lead to dyeing problems.
Trash / dust	Trash refers to plant parts incorporated during harvests, which are then broken down into smaller pieces during ginning.	Low trash levels of < 5%	High levels of trash and the occurrence of grass and bark incur large price discounts.	Whilst large trash particles are easily removed in the spinning mill too much trash results in increased waste. High dust levels affect open end spinning efficiency and product quality. Bark and grass are difficult to separate from cotton fibre in the mill because of their fibrous nature.
Stickiness	Contamination of cotton from the exudates of the silverleaf whitefly and the cotton aphid.	Low / none	High levels of contamination incur significant price discounts and can lead to rejection by the buyer.	Sugar contamination leads to the build-up of sticky residues on textile machinery, which affects yarn evenness and results in process stoppages.
Seed - coat fragments	In dry crop conditions seed-coat fragments may contribute to the formation of a (seed-coat) nep.	Low / none	Moderate price discounts.	Seed-coat fragments do not absorb dye and appear as 'flecks' on finished fabrics.
Neps	Neps are fibre entanglements that have a hard central knot. Harvesting and ginning affect the amount of nep.	< 250 neps/gram. For premium fibre < 200	Moderate price discounts.	Neps typically absorb less dye and reflect light differently and appear as light coloured 'flecks' on finished fabrics.
Contamination	Contamination of cotton by foreign materials such as woven plastic, plastic film, jute / hessian, leaves, feathers, paper leather, sand, dust, rust, metal, grease and oil, rubber and tar.	Low / none	A reputation for contamination has a negative impact on sales and future exports.	Contamination can lead to the downgrading of yarn, fabric or garments to second quality or even the total rejection of an entire batch.

Fibre length, Length Uniformity, and Short Fibre Content (SFC)

Longer fibres allow finer and stronger yarn to be spun as the twist inserted into longer fibres traverses and entwines over a longer length of yarn. Fibre length determines the draft settings of machines in a spinning mill. Longer fibres also mean that less twist needs to be inserted into yarn, which in turn means production speeds can be increased. Spinning production is determined by the spinning speed of the spindle, rotor and air current and the amount of twist required in the yarn. Hence longer fibre allows lower twist levels to be used, increases yarn strength, improves yarn regularity and allows finer yarn counts to be spun. Fibre length must stay consistent as variations in length can cause severe problems and lead to an increase in waste, deterioration in processing performance and yarn quality.

Fibre length is a genetic trait that varies considerably across different cotton species and varieties. Length and length distribution are also affected by agronomic and environmental factors during fibre development, and mechanical processes at and after harvest. Gin damage to fibre length is known to be dependent upon variety, seed moisture, temperature (applied in gin) and the condition of fibre delivered to the gin (e.g. weathered fibre). The distribution pattern of fibre length in hand-harvested and hand-ginned samples is markedly different from samples that have been mechanically harvested and ginned; two processes that result in the breakage of fibres.

Fibre length can be determined using fibre arrays or fibre staple length diagrams (Figure 6.1a) produced using a comb-sorter apparatus. These diagrams can be used to define upper fibre staple lengths such as the upper-quartile length (UQL), which is the length of the shortest fibre in the upper one-fourth of the length distribution, and other fibre length parameters such as mean length and SFC. Comb-sorter apparatus use a series of hinged combs separated at 1/8 inch intervals, to align, separate and allow the withdrawal and description of weight-length or number-length groups from a sample.

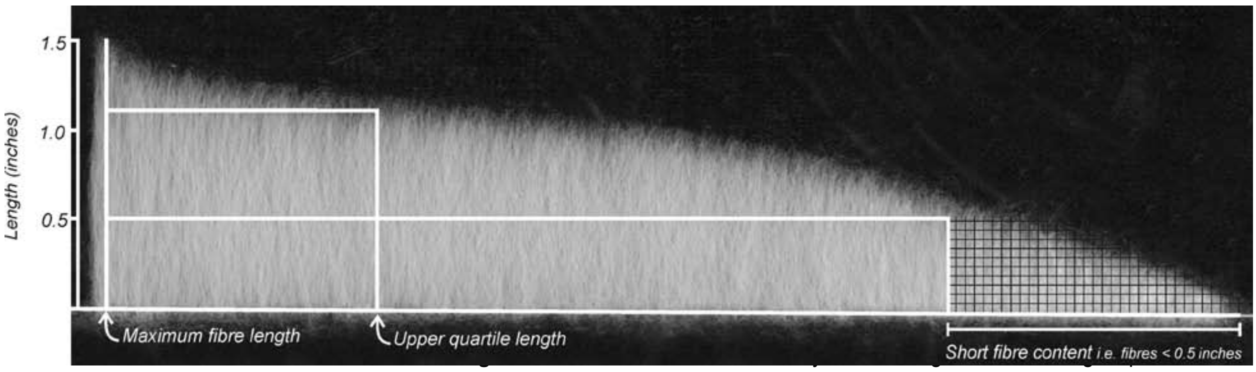
Whilst in theory comb-sorter methods are accurate they are unacceptably expensive in terms of operator cost and give results that are too imprecise for routine testing for commercial trading purposes. To rectify this issue a Fibrograph instrument was developed and later incorporated into HVI lines. Test specimens for this instrument are fibre beards prepared manually or automatically. Fibre length from HVI is usually defined as the upper-half mean length (UHML) or 2.5% span length (2.5% SL) from a Fibrogram beard. Both measures roughly coincide with the manual classer's assessment of staple length.

The HVI test fibre beard sample is held in a comb that is inserted into the instrument and scanned by a light source. The variation in fibre density (related to light intensity) of the different lengths of fibre is recorded and reproduced in the form of a length-frequency curve called the Fibrogram (Figure 6.1b). Interpretation of the Fibrogram takes into account the comb gauge length i.e., the depth of the comb at which fibres are held (0.25 inch).

Two different kinds of fibre length measurement can be generated from a Fibrogram; mean lengths and span lengths. Mean lengths, e.g. the upper half mean length (UHML), which is the mean length of the longer half (50%) of the fibre by weight, and the mean length (ML) are more commonly used since they describe the mean of all or a set portion of fibres represented in the Fibrogram. Span lengths (SL), which came about as a result of a technical shortcoming in the ability of the first digital Fibrograph to graphically run a tangent to the Fibrogram, represent fibre extension distances, e.g. the 2.5%SL represents the distance the longest 2.5% of fibres extended from the comb.

Fibre length is typically reported as 100ths of an inch or 32nds of an inch. Length reported in 100ths of an inch can be converted to 32nds by multiplying the value by 32 and rounding to the nearest whole number (conversion table in Fibre History Chapter). Length Uniformity is expressed either as the uniformity index or uniformity ratio. Both terms are ratios of measurements from the Fibrogram, where uniformity index refers to the ratio between the mean length and the upper half-mean length and the uniformity ratio refers to the ratio of the 50% span length to the 2.5% span length (see Figure 6.1b).

Excessive short fibre increases waste in the mill, lowers yarn strength and can cause yarn imperfections. The most common definition of SFC is the proportion by mass of fibre shorter than one half inch. Short fibre content is not measured directly by any instrument employed in HVI lines. Instead SFC or short fibre index (SFI) is estimated indirectly using the Fibrogram measurements of UHML and ML or 2.5% span length and 50% span length as the main variables in prediction equations.



sample. Note long maximum length and proportion of short fibre. (Photo: CSIRO).

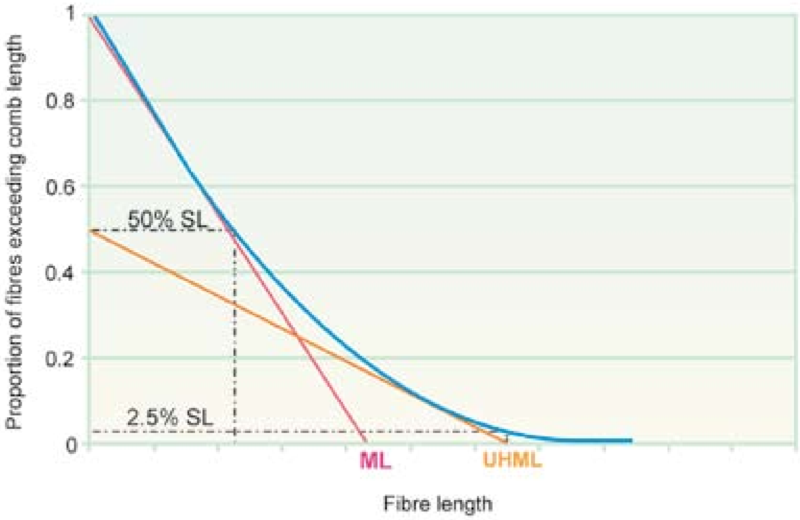


Figure 6.1b: – Typical Fibrogram showing length measurement locations on the fibre length diagram produced by the Fibrograph.

Fibre Strength

Yarn strength is directly related to fibre strength, particularly in rotor spun yarns (see Table 6.1). Cottons with good strength can be spun faster and usually result in fewer problems during processing than weaker cottons. In turn strong yarn improves fabric strength and durability.

Fibre and yarn strength represent the maximum resistance to stretching forces developed during a tensile test in which a fibre, fibre bundle or yarn is broken. The maximum resistance to these forces is called the breaking load and is measured in terms of grams (or pounds) force. To account for differences of fibres with different linear densities and for the number of fibres present in a bundle, the breaking load is adjusted by the number of fibres in the bundle, which is determined by the linear density of the fibre and the weight of fibre in the bundle. This adjustment produces the value of tenacity, which is measured in terms of grams force/tex and allows direct comparison of the strength of different fibres and yarns.

There are also other issues that need consideration when measuring the strength of fibre bundles (Figure 6.2). One issue relates to the length, known as the gauge length, between the jaw clamps that hold the fibre bundle. A sample with a high number of short fibres (high SFC) means that many of the fibres may not reach across the gauge length (typically 1/8 inch) to be clamped, resulting in a lower bundle strength measurement. Another important issue relates to the moisture content of the fibres in the bundle. It is well known that fibre with high moisture content has a higher strength than ‘dry’ fibre. It is for this reason that fibre moisture is equilibrated to standard conditions (20°C and 65% relative humidity) before testing. Fibre tenacity can be increased in excess of 10% by increasing fibre moisture from 5% to 6.5%.

The effect of fibre maturity or immaturity on fibre bundle strength tests is also sometimes a point of contention. Whilst a single mature fibre is inherently stronger than a single immature fibre by virtue of its crystalline cellulose structure, this relativity is often not clearly seen in HVI bundle strength tests. Research has shown that reasonably immature fibre can still produce good fibre bundle tenacity values and corresponding yarn tenacity values. The effects seen in this circumstance can probably be attributed to one or a combination of the following factors. One is inaccurate assessment of fibre linear density and bundle weight by the HVI and therefore improper adjustment of the fibre bundle/yarn strength value, and the other is the positive effect of immature fibre having more fibre ends and surface area contributing to the bundle strength result.

Figure 6.2: Photo of a fibre array comb for the HVI Fibrograph (length) and strength tester. (Photo: Warwick Stiller, CSIRO).

Elongation

Cotton fibre is flexible and can be stretched. The increase in length or deformation of the fibre before it breaks as a result of stretching is called elongation. Expressed as a % increase over its original length.

Neps

Neps occur in all ginned cotton but hardly in unpicked seed-cotton. Neps are fibre entanglements that have a hard central knot that is detectable (Figure 6.3). Harvesting, ginning (particularly lint cleaning), opening, cleaning, carding and combing in the mill are mechanical processes that affect the amount of nep found in cotton. The propensity for cotton to nep is dependent upon its fibre properties, particularly its linear density and fibre maturity, and the level of biological contamination, e.g. seed coat fragments, bark and stickiness. Studies have shown generally that over 90% of fibres in a nep are immature.

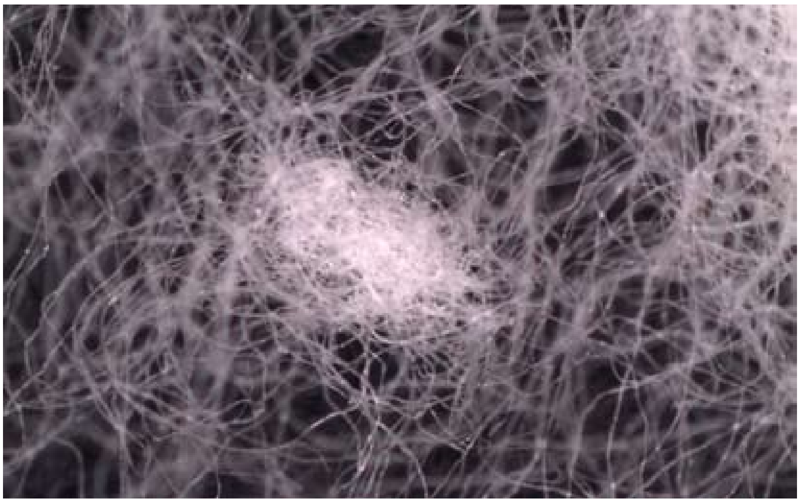


Figure 6.3: A nep is an entanglement of fibres resulting from mechanical processing. More neps can occur if cotton is immature. (Photo: CSIRO).

Trash

Trash in seed-cotton is a grower and ginner problem, whilst trash in baled lint is a spinner problem however, the solutions for the grower and ginner are not always the best solutions for the spinner. In the gin more cleaning can mean more fibre breakages leading to increased short fibre content, and more neps. With an increasing number of impurities (i.e. trash), such as husk, leaf, stalk and seed-coat fragments, the tendency towards inferior yarn quality can increase if the installed opening and cleaning line in a mill is unable to cope with it. Removing trash is a direct cost to a spinning mill and can cause deterioration in spinning performance and yarn quality. It is thus imperative for a spinning mill to know what the cleaning efficiency of its cleaning line is to ensure that it can cope with the trash content in the cotton lint, especially for rotor and air jet spinning.

Stickiness

Sticky cotton is a major concern for spinning mills. Physiological plant sugars in immature fibres, contaminants from crushed seed and seed coat fragments, grease, oil and pesticide residues are all potential sources of stickiness. However, these are insignificant compared with contamination of cotton from the exudates of the silverleaf whitefly (*Bemisia tabaci* B-biotype) and the cotton aphid (*Aphis gossypii*). The sugar exudates from these insects lead to significant problems in the spinning mill including a build-up of residues on textile machinery, which results in irregularities and stoppages in sliver and yarn production. Even at low to moderately contaminated levels, sugar residues build up, decreasing productivity and quality, and forcing the spinner to increase the frequency of cleaning schedules. A reputation for stickiness has a negative impact on sales, exports and price for cotton from regions suspected of having stickiness. Stickiness is discussed in more detail in the chapter 'Open Boll to Harvest'.

Colour or grade

Colour is a primary indicator of grade. Discolouration is due a to range of influences including trash and dust content, rain damage, insect secretions, UV radiation exposure, heat and microbial decay. Colour in cotton is defined in terms of its reflectance (Rd) and yellowness (+b), which are measured by a photoelectric cell. Historically grade is a subjective interpretation of fibre colour, preparation and trash content against 'official' standards.

Fibre Linear Density

Fibre linear density (often referred to as fineness) determines the minimum yarn linear density or yarn count that can be spun from a particular fibre or growth. This is based on the minimum number of fibres required to physically hold a twisted yarn assembly together. The linear density of fibres increases with both larger fibre perimeter

Figure 6.4: The cross section of a cotton yarn showing the packing and interaction of individual fibres. In this yarn cross-section seventy eight individual fibres are distinguishable. (Photo: CSIRO).

and greater fibre maturity. This ‘spin-limit’ minimum will depend on different spinning systems and the level of twist inserted into the fibre assembly. In general, for ring spinning the minimum number of cotton fibres required in the yarn cross-section is around 80 (Figure 6.4), for rotor spinning the number is 100 fibres and for air-jet spinning the number is 75 fibres.

The linear density of raw cotton used to manufacture a yarn can therefore have a big impact on yarn evenness. For coarser fibres with higher linear densities there is a higher probability of there not being enough fibres in a yarn cross section to support the yarn structure (a thin place) as illustrated below (Figure 6.5). A thin place in a yarn is a weak place, which has potential to break during either the spinning process itself or later during fabric manufacture. This can have a significant impact on the efficiency of the spinning process and the effect of uneven yarn can sometimes be observed in light weight tee shirts or vests where close examination highlights a slightly uneven appearance of the knit structure. So there is considerable pressure on the spinner to ensure that the yarn manufactured and supplied is as even as possible so breakages do not occur.

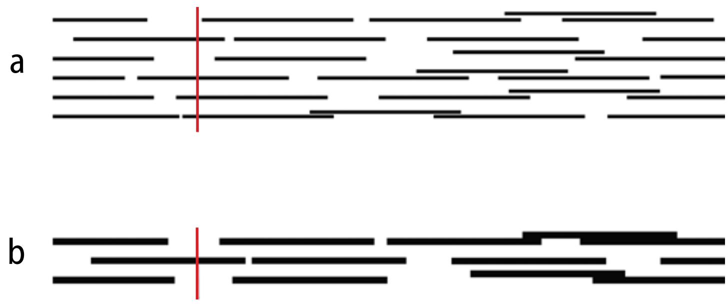


Figure 6.5: Schematic simple representations of the arrangement of fibres within a yarn. (a) a yarn made with fine fibres (lower linear density) (b) a yarn with a similar linear density made from coarser fibres (higher linear density). The red line indicates less fibres in the cross section leading to a thin/weak spot.

In the example, illustrated in Figure 6.5, imagine if the spinner chose to make the same yarn from a coarser cotton fibre. In this case, fewer rows of the heavier fibres are required to make up the required mass for the yarn as shown schematically in Figure 6.5b. With coarse fibres along with the natural variation in the number of fibres in the yarn cross-section there are opportunities for more ‘thin’ places in the yarn cross section (see vertical line in Figure 6.5b).

These effects are well known to the spinner and hence he chooses fibre quality with some care. The linear density of synthetic fibres is routinely available and fibre diameter (micron) is used by the wool industry. Spinners carefully use this data to choose appropriate raw materials for spinning either synthetic or wool yarns. In the case of cotton, unfortunately fibre linear density is not available to the trade, which instead relies on the Micronaire value as a proxy for fibre linear density. The Micronaire has limitations as it is unable to properly distinguish premium fine mature cotton from immature, coarser cotton (smaller fibre perimeters and lower linear density).

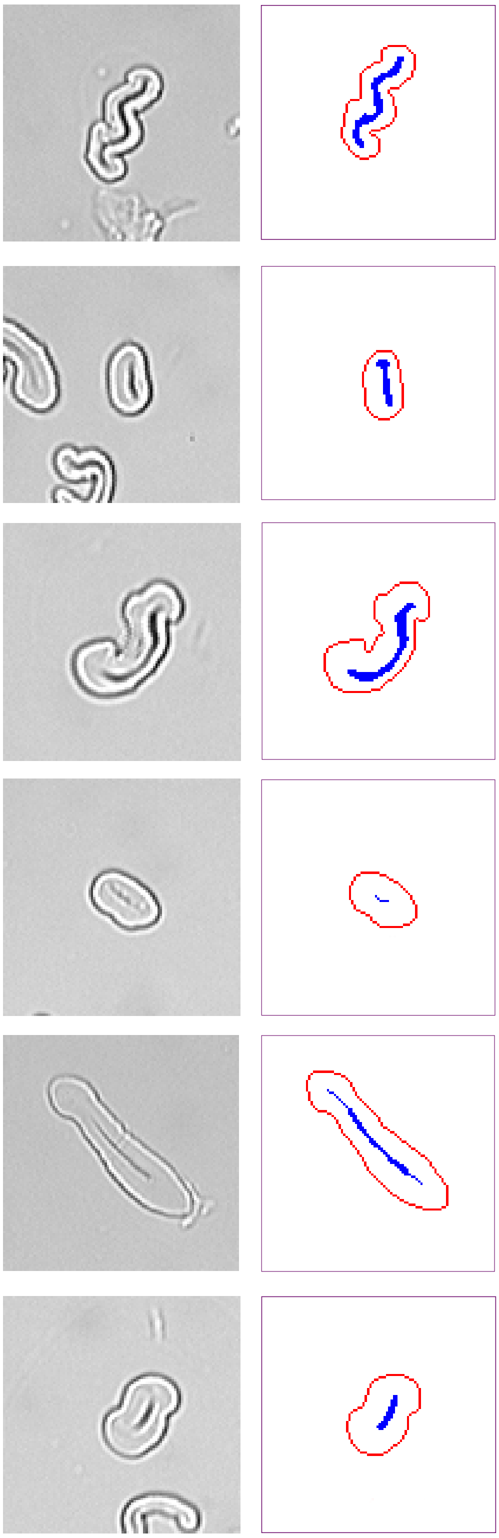
Limitations of the Micronaire measurement

Micronaire is a measure of the rate at which air flows under pressure through a plug of lint of known weight compressed into a chamber of fixed volume. The rate of air flow depends on the resistance offered by the total surface area of the fibres which is related to the linear density as well as the thickness of the fibre walls. A reduction in linear density, wall thickness or fibre perimeter decreases the Micronaire reading as there is more fibres in a plug of cotton that is tested increasing air resistance.

It is important to remember that both yarn count (how fine) and yarn quality (how even and strong) are the main reasons why fibre linear density is so important, and thus why spinners prefer to purchase fibres with a specified linear density (see chapter on textile production). Currently, the commercial trade relies on Micronaire readings to indicate the linear density of cotton, despite it being well known that the Micronaire readings represent a combination of fibre linear density and fibre maturity, and as a result is not a particularly accurate measure of either important parameter.

For the spinner there are two potential problems in managing quality using the Micronaire value. Low Micronaire may indicate the presence of immature fibre and high Micronaire values may indicate that the cotton is coarse. Instances can occur where Micronaire readings are similar and fibre traits of fibre maturity and linear density (and wall thickness) can be entirely different (see Figure 6.6). All situations are problematic for the spinner.

Microscope image **Analysed image**



Micronaire: 3.1
Linear density: 150 mtex
Theta: 0.41
Perimeter: 56 µm
Wall area: 102 µm²

Micronaire: 3.1
Linear density: 81 mtex
Theta: 0.76
Perimeter: 30 µm
Wall area: 56 µm²

Micronaire: 4.3
Linear density: 216 mtex
Theta: 0.43
Perimeter: 65 µm
Wall area: 145 µm²

Micronaire: 4.3
Linear density: 108 mtex
Theta: 0.86
Perimeter: 33 µm
Wall area: 73 µm²

Micronaire: 5.3
Linear density: 279 mtex
Theta: 0.45
Perimeter: 72 µm
Wall area: 187 µm²

Micronaire: 5.3
Linear density: 160 mtex
Theta: 0.78
Perimeter: 42 µm
Wall area: 107 µm²

Figure 6.6: Cross section of fibres that have similar Micronaire values (same surface area to weight ratios). For instance, one fibre type achieves a Micronaire of 4.2 because it has a smaller fibre perimeter (meaning more fibres are present in the plug used for sampling) and has more fibre wall thickening (fibre maturity), overall resulting in a smaller fibre linear density. The other fibre achieves the same Micronaire as it has a larger fibre perimeter but has poorer fibre wall thickening (immature) resulting in a larger fibre linear density. (Photo: CSIRO).

Figures 6.6 and 6.7 show the relationship between the fibre quality attributes of Micronaire, fibre linear density and fibre maturity. Note that it is not possible to accurately estimate fibre linear density from the Micronaire value alone. However, without an accurate measure of fibre linear density the spinning industry is forced to adopt a risk minimisation strategy by choosing cottons within a relatively narrow Micronaire band. Within these bands the spinner can be reasonably assured that the linear density and fibre maturity of the fibre will translate into good quality yarn. In the international cotton fibre market, Micronaire values less than 3.4 and greater than 5.0 are considered to be in the Discount Range; the range 3.5 to 4.9 is regarded as Base Grade whilst 3.7 to 4.2 is considered to be the Premium Range.

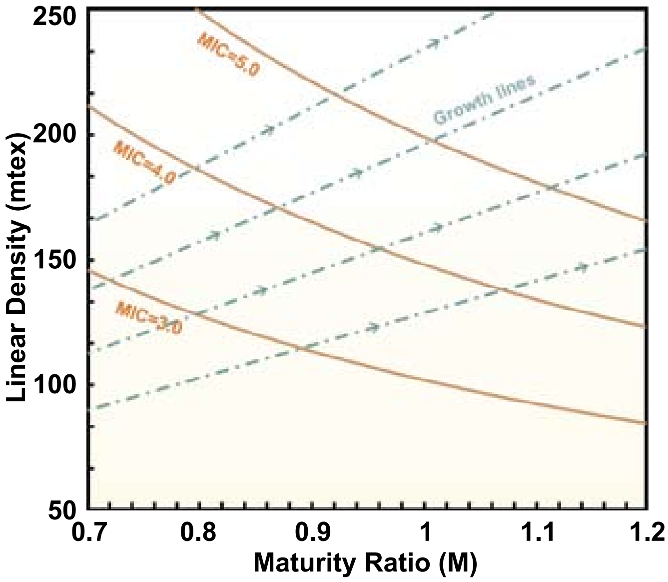


Figure 6.7: The relationship between fibre linear density, maturity ratio, and Micronaire (MIC). Note that during growth a fibre will progress diagonally across this graph as illustrated schematically by the dotted lines, with the increasing wall thickening resulting in fibre linear density, fibre maturity ratio and Micronaire all increasing. The different growth lines can represent varietal differences. (Adapted from Thibodeaux 1998).

Whilst there are a number of methods for measuring fibre maturity and linear density until recently no one method has been able to do so accurately and with the speed requirement for classing purposes. The development of the Cottonscan™ (fibre linear density) and SiroMat (fibre maturity) instruments by CSIRO is aimed at creating fast and accurate instrument test methods for breeders, merchants and spinners alike to manage fibre linear density and fibre maturity (Figure 6.8).

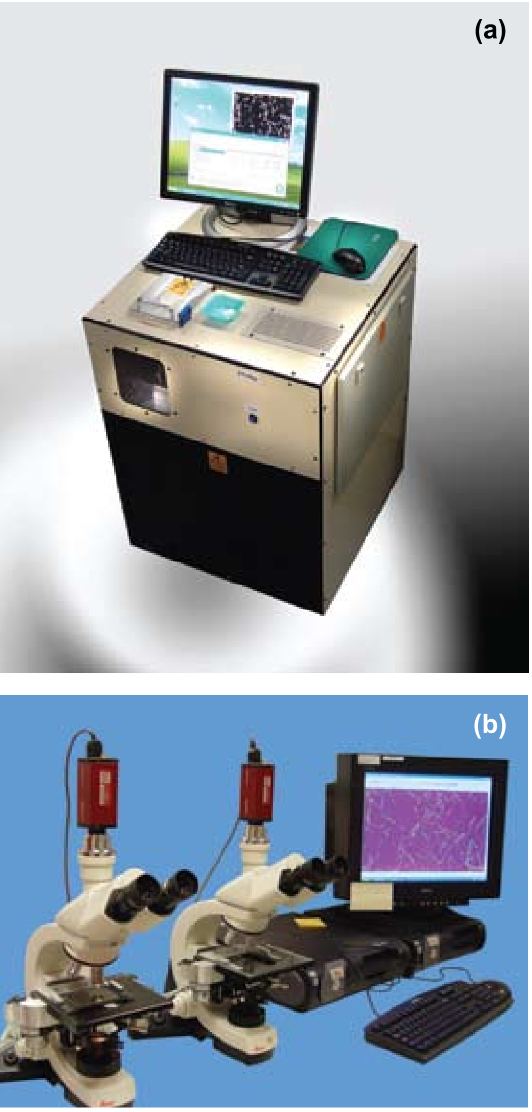


Figure 6.8: New instrumentation has been developed that offers significant opportunities to measure fibre linear density (a - Cottonscan™) and fibre maturity ratio (b - SiroMat) directly and quickly as an alternative to the indirect measurement of these properties using Micronaire. (Photos: CSIRO).

Further Reading

ASTM D4604, Standard Test Method for Measurement of Cotton Fibers by High Volume Instruments (HVI)

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