A Comprehensive Guide to the Classification of Upland Cotton

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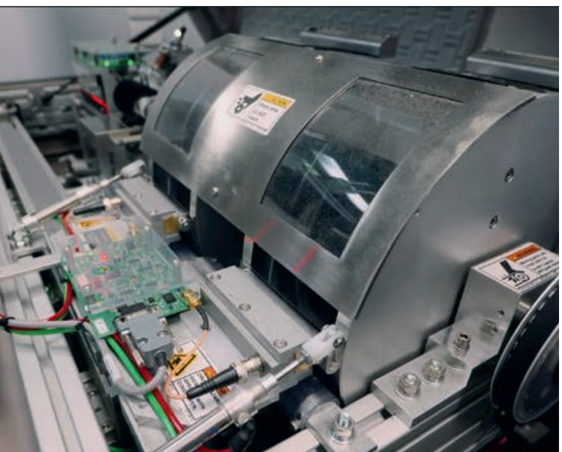

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Foreword


René van der Sluijs

In today's highly competitive and incredibly diverse global textile market, product quality has become of paramount importance. With 'value for money' a driving force for growers, both yield and fibre quality is important to maximise their return. For cotton spinners to produce yarns that can be converted into high quality woven and knitted fabrics with little or no difficulty, emphasis continues to be placed on fibre quality, and the maintenance of this quality throughout the entire cotton processing pipeline. To achieve production efficiency, a spinner requires information on fibre properties to control processing performance, operating costs, and the resultant yarn and fabric quality. Cotton is spun on a number of spinning systems with the most important physical fibre properties being fibre length & uniformity, short fibre content, micronaire, strength, trash, and extraneous matter. Colour is also recognised by the cotton trade and spinning industry, with other properties such as contamination, stickiness, neps, and seed-coat fragments also considered important with elongation, fineness and maturity gaining traction.

This guide aims to provide an overview on cotton classification and covers details on factors that can impact fibre quality, how fibre quality properties are measured and what the requirements are in terms of laboratory layout and practices. It also provides a brief overview of classing in Australia.

This guide was developed by CottonInfo Fibre Quality Technical Lead, René van der Sluijs, Principal Consultant at Textile Technical Services. René brings more than 40 years of experience across the cotton supply chain, from field to fabric, with extensive expertise in fibre quality and yarn manufacturing.

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Introduction

Traditionally, and still for much of the world's cotton crop today, fibre properties are assessed using physical cotton standards. This qualitative (manual/physical/visual) classification system evaluates characteristics such as colour, leaf content, preparation (the smoothness or roughness of the sample), and the presence of extraneous matter. However, with the increasing demands of modern spinning, the cost of raw material (contributing up to 70% of the total yarn manufacturing costs), and the increasingly competitive global market, there was a need to determine rapidly and accurately those cotton fibre quality parameters that affect processing performance and quality in a cost-effective way.

This led to the initial development of classical methods of direct (if time-consuming) measurement, followed by a number of rapid methods, many of which utilise indirect measurements of fibre properties. This ultimately led to the development of completely automated and fast methods which culminated in high-volume automatic testing systems. These systems, termed High Volume Instruments (HVI™) and also referred to as Standard Instrument for Testing Cotton (SITC) provide objectively measured information to either supplement or replace the traditional method of cotton classification. Other instruments such as the Advanced Fiber Information System (AFIS from Uster Technologies AG), Textechno Favimat (Herbert Stein GmbH & Co.KG) and Cottonscope (Fibemetrics Pty Ltd) are also used by breeders and spinners to further quantify fibre properties.

Irrespective of whether cotton is classified manually or by instrument there are a number of technical and operational challenges that need to be addressed. These include, but are not limited to, sampling, layout and design of the facility, atmospheric conditions, conditioning of samples, maintenance, and condition of instruments, testing procedures and protocols, calibration and verification of the instruments, participation in local and international Round Trials as well as training, experience, and management of the personnel. They all play a pivotal role in providing results that are dependable, consistent, reliable, repeatable, accepted and trusted by the cotton trade as a whole.

Ensuring that cotton is classed to a globally approved standard results in a predictable product that can compete with man-made fibres, and price premiums for growers.

Factors affecting fibre properties

General

As cotton is grown in a large number of countries it is unsurprising that the quality and quantity of the fibre produced varies greatly. Variation is largely due to variety selection, environmental conditions and management practices including harvesting and ginning methods. Indeed, fibre quality is at its best after the boll has opened and prior to any subsequent weathering, harvesting, and ginning. That said, there is really no such thing as inherently 'high' or 'low' quality cotton. Instead, cotton quality is best viewed in terms of suitability, whether it meets the required performance characteristics, specifications, price expectations, and intended end use.

In terms of the contribution of fibre properties to the price, on average, colour has the biggest contribution (30%). Spinners are prepared to pay up to 1% more for cotton that is 1% whiter and up to 1% more for cotton that is 1% less yellow, i.e. brighter. Colour is followed in importance by cleanliness/trash at 23%, micronaire at 22%, length at 20%, and strength at 5%.

Colour

The colour of commercially grown cotton varies from white to creamy to yellow and is mainly determined by the cultivar and growing conditions, including temperature, rainfall, frost, insects, and fungi - see Figure 1.

Staining, through contact with soil, grass or other parts of the cotton plant, moisture during harvest and ageing during prolonged storage can also deteriorate the colour of cotton.

Cotton colour has little effect on the processing performance and quality during spinning and fabric manufacture, provided that the colour has not been compromised by microbial decay, which may also have an effect on the length and strength of the fibre. However, as textile mills process cottons of different grades and origins, the control of fibre colour is essential, as colour differences may affect dyeing and finishing results - see Figure 2.

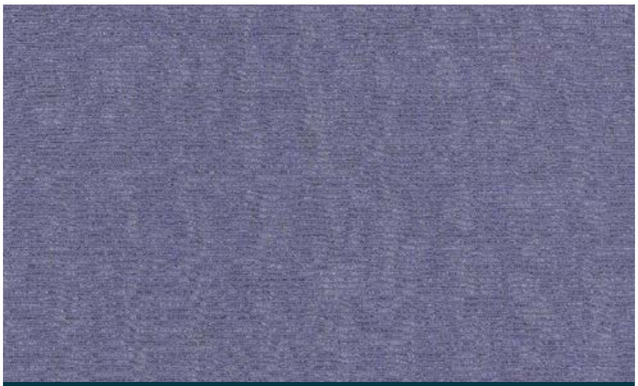

FIGURE 2 Dyed fabric with colour differences

The process of bleaching, prior to dyeing, is often able to reduce, or even eliminate, colour differences present in the raw cotton.

Trash

As raw materials make up more than half the cost of yarn production, the utilisation in terms of input vs output is important and should be closely monitored and controlled.

The trash found in cotton typically refers to parts of the cotton plant such leaf fragments, pieces of stem, bract, seed-coat fragments (parts of the seed-coat that have been broken off during mechanical processing) and motes (immature seed with short immature fibre attached), which are incorporated into the seed-cotton during harvesting and largely remain with the cotton through to the spinning mill. Trash also includes grass and bark as well as dirt and sand, which are generally referred to as extraneous matter.

The amount of trash present in seed-cotton is very much dependent on the variety, crop management (including nutrition and defoliation), harvesting method and set up

FIGURE 1 Bale laydown in spinning mill

as well as the ambient air conditions (temperature and relative humidity) of the field. The amount of trash in seed-cotton can vary from 1 to 5% for cotton harvested by hand, to between 5 and 10% for spindle and between 10 and 30% for stripper harvested cotton. For this reason, gins that process mechanically harvested cotton require more cleaning and drying equipment to remove this trash.

Grade plays a crucial role in determining the price paid for cotton, which often forces gins to over-clean the cotton. This is done to achieve a better grade which results in a higher price being paid for the cotton lint and therefore a better return for the grower. Unfortunately, this is often to the detriment of the physical fibre quality, as this can adversely affect fibre length and uniformity, increase nep and short fibre content which will affect the textile performance and value of the cotton. Ginning represents, in essence, a compromise between fibre quality parameters (leaf grade, length, length uniformity etc.).

Besides the number of particles, the size of trash particles in ginned lint is also of considerable concern to spinners. In general, spinners prefer the trash particles to be large, although they impact grade significantly, so that the particles can easily be removed with standard cleaning equipment at the mill. Small trash particles, commonly referred to as “pepper trash”, are more difficult to remove.

Micronaire

Micronaire, a combination of fineness and maturity, has a substantial influence on processing performance in terms of ends down, processing waste, yarn and fabric quality, dyed fabric appearance as well as end-use. In order to spin a reasonable quality ring-spun yarn, a spinner needs at least 80 fibres in the yarn cross section, more than 100 fibres in rotor (open-end) yarn cross-section and more than 75 fibres in an air-jet spun yarn – see Figure 3. To produce light weight fabrics, fine count yarns are required, which means that fine (and long) fibres are required to obtain the minimum number of fibres in the cross-section.

Excessive micronaire variation can lead to streakiness or barré due to differences in dye absorbency and retention and hence the levels within a laydown or blend should not vary excessively (+/- 0.2 units). Surveys conducted worldwide of spinning mills, found that 78% of the respondents rated micronaire as a major cause of defects and deficiencies during yarn manufacturing.

Micronaire is one of the most challenging fibre quality parameters to manage as it is subject to penalties for being either too high or too low. Table 1 provides information of worldwide classification and description for interpreting micronaire values. The table shows that the base grade falls in the range of 3.5 to 4.9 with the premium range 3.7 to 4.2. Any cotton with micronaire below base grade will be severely discounted as it is considered to be immature whereas cotton above base grade is not as severely discounted as it can be used to produce lower quality coarse yarns.

TABLE 1 Micronaire classification

Micronaire range	Group	Description
≥5.3	G7	Very coarse
5.2 – 5.0	G6	Coarse
4.9 - 3.5	G5	Base grade
3.4 – 3.3	G4	Immature
3.2 – 3.0	G3	Very immature
2.9 – 2.7	G2	Very immature
2.6 – 2.5	G1	Very immature
≤ 2.4	G0	Very immature

One of the single most important decisions a grower makes in terms of yield and quality is the selection of variety which accounts for 25% of variation in micronaire. Most variation (51%) in micronaire can be attributed to weather and management, with temperature accounting for 21% of the variability in micronaire.

Micronaire is a combination of maturity (the degree of the secondary wall development) and fineness (linear density), with low micronaire cotton severely discounted. However, low micronaire does not necessarily imply that the fibre is immature, it could also be mature and fine which would be valuable to fine count spinners. This is particularly true for Extra Long Staple (ELS) cottons which are generally finer than Upland cotton.

There are direct methods to determine maturity and fineness, but they are extremely labour intensive, costly, and subjective. As a consequence, instruments have been developed to separate maturity and fineness, but these are currently too slow to be accepted by the industry and are mainly used for research purposes.

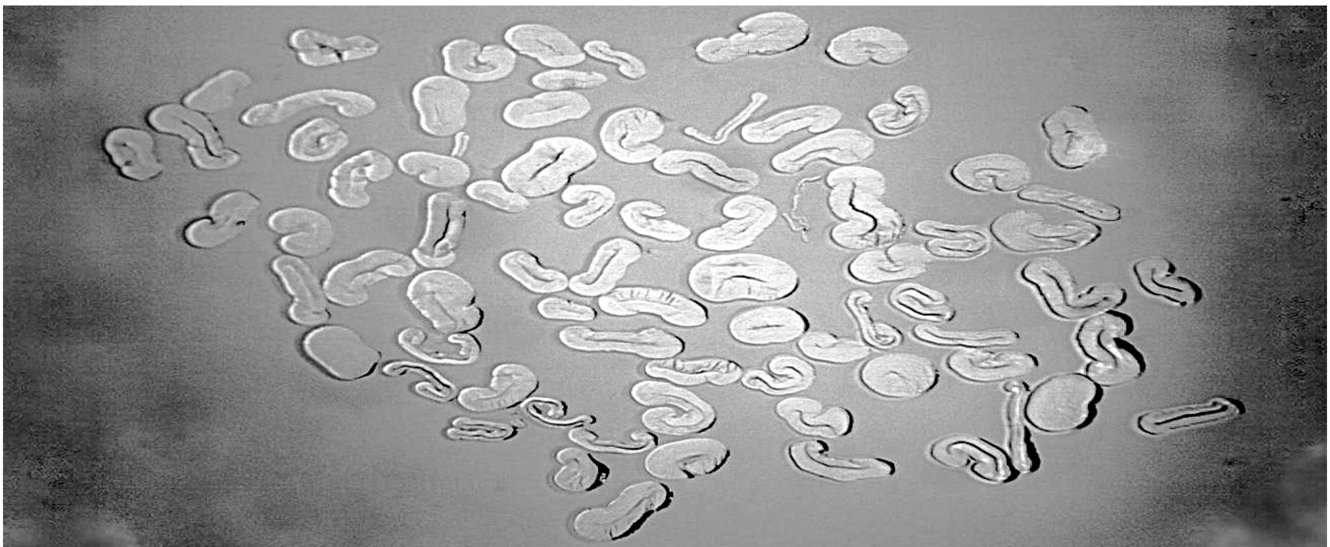

FIGURE 3 Fibres in yarn cross section

Length & length uniformity

Fibre length will determine the spinning system that can be used (i.e., ring, rotor, or air-jet), the specifications in terms of drafting roller distances, yarn count, and twist, as well as processing speeds. Excessive fibre length variation and an associated increase in short fibre content (generally accepted as fibres shorter than 12.7 mm or 0.5 inch) will result in increased waste and adversely affect processing performance (i.e., ends down, fly and comber waste). Yarn quality will be reduced, in terms of yarn strength, hairiness, and evenness (specifically in ring-spun yarn), and results in lower fabric quality, including handle and lustre.

Fibre lengths of Upland cotton range from as low as 15 mm (0.59 inch) to medium to long ≥ 29 mm (1.17 inch) to long staple ≥ 32 mm (1.26 inch) - see the Upland conversion chart in Table 2.

TABLE 2 Upland length conversion chart

Length (32nds)		Length (Inches)	Length (mm)
26	13/16	0.80 – 0.85	20.64
28	7/8	0.86 – 0.89	22.23
29	29/32	0.90 – 0.92	23.02
30	15/16	0.93 – 0.95	23.81
31	31/32	0.96 – 0.98	24.61
32	1.00	0.99 – 1.01	25.40
33	1.1/32	1.02 – 1.04	26.24
34	1.1/16	1.05 – 1.07	26.99
35	1.3/32	1.08 – 1.10	27.78
36	1.1/8	1.11 – 1.13	28.58
37	1.5/32	1.14 – 1.17	29.37
38	1.3/16	1.18 – 1.20	30.16
39	1.7/32	1.21 – 1.23	30.96
40	1.1/4	1.24 – 1.26	31.75
41	1.9/32	1.27 – 1.29	32.54
42	1.5/16	1.30 – 1.32	33.34
43	1.11/32	1.33 – 1.35	34.13
44 & +	1.3/8	1.36 & +	34.93

Length uniformity is the ratio between the mean length (ML), and the upper half mean length (UHML) of the fibres and expressed as a percentage. If all the fibres in a bale were the same length, ML and UHML would be similar, and the uniformity would be 100%. However, due to natural variation and processing, length uniformity is always less than 100% - see Table 3. As indicated above, length uniformity is perhaps even more important than fibre length, as variations in length can affect the evenness and strength of the yarn as well as processing performance.

TABLE 3 Interpretation of length uniformity (%) values

Descriptive designation	Length uniformity (%)
Very low	< 77
Low	77-79
Average	80-82
High	83-85
Very high	≥85

Length uniformity is also related to short fibre content, fibres less than 0.5 inch or 12.7 mm which the HVI reports as short fibre Index (%). Cotton with low uniformity values is likely to have high SFI%. SFI% is of concern to textile manufacturers because it relates directly to the amount of waste extracted including during combing (noil) and also has a detrimental effect on the quality of yarn and fabric - see Table 4.

TABLE 4 Interpretation of short fibre content (%) Values

Descriptive designation	Short fibre index (%)
High	≥ 8.0
Average	8.0-6.0
Low	≤ 6.0

Fibre length is largely a genetic trait and 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 harvesting and ginning. Gin damage to fibre length is known to be dependent upon variety, seed cotton moisture, trash content, moisture during ginning, number of lint cleaners and production rate.

It is also worth mentioning that fibre length distribution presents a serious challenge in most other natural fibres, such as wool and mohair, but seldom in man-made fibres.

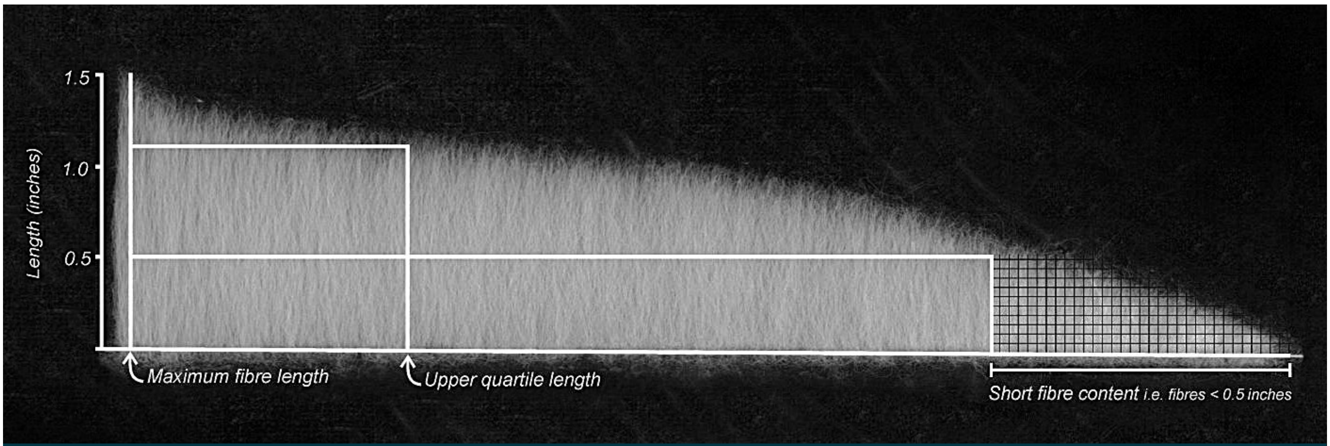

FIGURE 4 Fibre array with different length measurements

Strength

The ability of cotton to withstand tensile force is fundamentally important in the processing of cotton. Yarn strength correlates highly with fibre strength, fibre length and micronaire. It is an important factor in resisting damage through the gin, particularly through the lint cleaner. Table 5 provides general classifications of strength values. Fibre strength is highly dependent on the genetics, although environmental conditions can also have a small effect.

TABLE 5 Interpretation of strength values

Descriptive designation	Strength (grams per tex)
Weak	≤ 23.0
Intermediate	24.0 – 25.0
Average	26.0 – 28.0
Strong	29.0 – 30.0
Very strong	≥ 31.0

As part of the strength measurement elongation is also measured, although the value of this parameter in the market is less understood. No premium or discount is paid on the basis of this property and only a small number of high-end spinning mills as well as plant breeders are starting to pay attention to this property. Table 6 provides general classifications of elongation values.

TABLE 6 Interpretation of elongation values

Descriptive designation	Elongation %
Very low	≤ 5.0
Low	5.0 – 5.8
Medium	5.9 – 6.7
High	6.8 – 7.6
Very high	≥7.7

Contamination

Any foreign matter found entwined within or stained onto cotton fibre, yarn or fabric is considered contamination. Contamination arises from foreign matter being incorporated into the bale as a result of human interaction during harvesting, ginning, and baling, and even extending into the mill.

Anecdotal data suggests that the major source of contamination in all cotton bales continues to be organic matter, such as leaves, feathers, paper, and leather. The next most prevalent contaminants are pieces of fabric and string made from cotton, woven plastic, plastic film and jute/hessian, followed by sand and dust and then by oily substances/chemicals and inorganic matter, such as rust and metal. The incidence of plastic contaminants has the potential to be a major problem in countries which have introduced harvesters with on-board module building capabilities which produce round modules covered with plastic wrap.

The degree of contamination varies widely from region to region and is related to different farming, harvesting and ginning practices - with no cotton 100% contaminant free. It is also noted that cotton that is mechanically harvested generally has less contamination than that harvested by hand as there is less interaction between humans and the cotton during harvesting.

Cotton passes through a large number of processes in a spinning mill on its way to being converted into yarn. While larger pieces of contaminant are more likely to be removed, each mechanical process reduces the size of most contaminants into a large number of fragments, particles, or fibres. These smaller pieces and fragments can remain undetected through the mill and only become noticeable quite late in the conversion process, e.g., as yarn, in an end-break, or more costly, when finished fabric or garment is inspected before sale – see Figure 5. When contamination is discovered by the retailer or consumer the cost to the manufacturer becomes very high, in terms of the particular order and longer-term reputation. The loss of reputation can cause irreparable harm to all the relationships back down the supply chain to the growers.

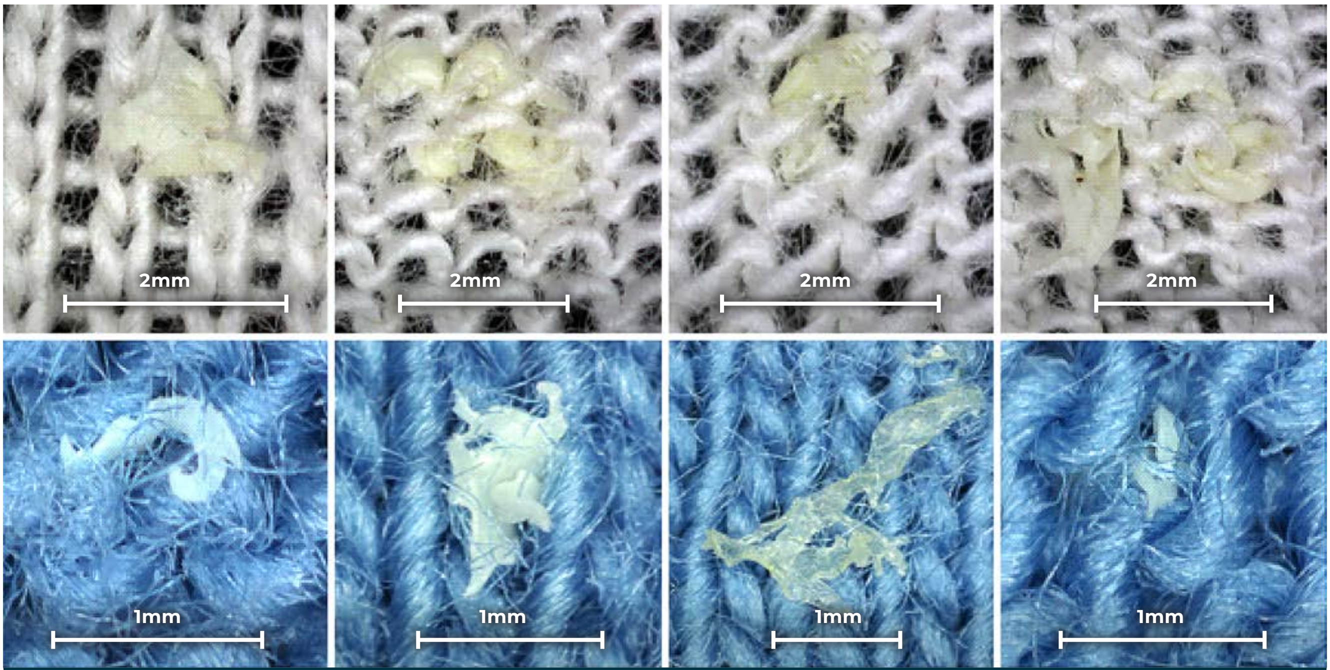

FIGURE 5 Examples of plastic wrap found in undyed and dyed knitted fabric

Contamination represents a significant cost to spinning mills and as such it is important to detect and eliminate contamination as early in the process as possible. This has led to the development and implementation of a range of methods and behaviours to detect and remove contamination from the mill process. The first step, and the most logical, is to prevent/avoid or minimise the amount of contamination entering the production process. This can be achieved by educational programs to growers, harvesters and ginners that provide information on preventing contamination of seed-cotton and lint in the field and at the gin. These programs need to be regularly updated and presented to ensure high awareness. The key message in these campaigns is that negative reputations around contamination can lead to huge losses to the country/region concerned.

Stickiness

Cotton stickiness can present a major problem, in terms of textile processing performance and cost and product quality. Because of a reputation for stickiness, some countries have difficulty selling their cotton, and incur discounts of up to 50%. In fact, sticky cottons caused by honeydew contamination for example, are impossible to process on their own into yarn of acceptable quality. Furthermore, the costs for controlling stickiness in the field can be extremely high.

The most common and problematic causes of stickiness are those due to excess sugars related to insect secretions, notably aphids, whitefly, and mealy bugs. These secretions, referred to as honeydew, are responsible for 80 to 90% of stickiness problems. In addition, a black sooty mould can also grow on honeydew, darkening the lint and adversely affecting grade. Physiological or plant related stickiness originates from highly immature cottons (which can contain up to about 0.9% sugars) and plant sap, but also from crushed seeds, seed fragments, and fine leaf particles, as well as excessive levels of cotton wax.

The main problem related to cotton stickiness is that of the sticky deposit, or residue, adhering to any machine part or surface encountered by the cotton along the processing pipeline, causing an accumulation of fibres (and even dust or grit), during the ginning and spinning process and even during classing – see Figure 6.

FIGURE 6 Sticky cotton causing disruptions during processing

In extreme cases, stickiness can also affect harvesting with the spindle type harvester, as sticky deposits will accumulate and clog the spindles causing blockages.

During ginning, sticky deposits can clog saws and also disrupt the baling process due to accumulation of lint on the lint slide of the battery condenser. These disruptions can reduce gin production resulting in longer and more expensive ginning seasons, due to higher labour costs and additional spare parts, as saws and blades will need to be replaced more regularly.

Sticky deposits can also cause issues during cotton classification, with deposits on HVI combs and glass, leading to incorrect and inaccurate fibre measurements.

The incidence of stickiness varies considerably and is very much dependent on the growing conditions during the season as well as farming practices.

Factors that affect stickiness include:

- Farm hygiene and biosecurity;
- Nitrogen fertiliser rates;
- Late irrigation;
- Timing of planting and field selection;
- Limiting availability of attractive crops;
- The integrated pest management practices adopted in terms of maintaining beneficial insect numbers;
- Harvest aid chemicals for mechanical harvesting; and,
- Variety selection.

One of the major problems associated with the prevention and treatment of stickiness, is that, due to its isolated and random nature, it is very difficult to effectively detect sticky cottons, until the problem manifests itself during the processing of the cotton.

Neps

A nep can be described as a tightly tangled knot-like mass of unorganised fibres. It has been stated that nep formation is inherent in short staple spinning, irrespective of fibre type and that neps in yarn are an unavoidable phenomenon, which can be controlled but not totally eliminated.

Neps are formed by the mechanical stresses applied to the fibre all along the processing chain from harvesting but particularly during ginning (lint cleaning) and opening and cleaning in the spinning mill – see Figure 7. The quality and value of a finished garment is affected by the number of imperfections contained in the fabric. Neps adversely affect the appearance of cotton yarns and subsequently the fabric made from them. Neps are usually associated with lower yarn strength, higher ends down in spinning and less uniform yarn. Neps result in short, thick places in the yarn, resulting in an uneven fabric appearance and

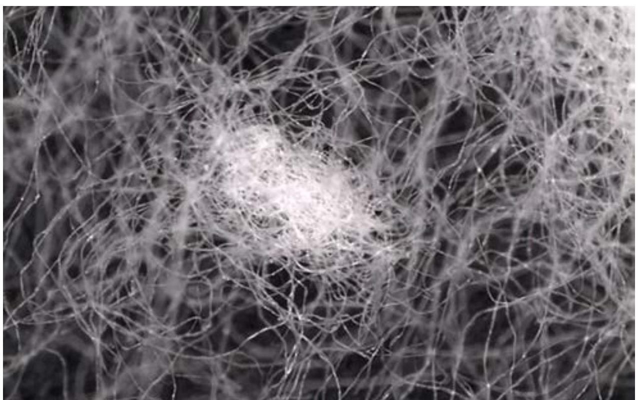

FIGURE 7 Image of a fibrous nep

weak places in yarns causing a loss in spinning efficiency as well as resulting in stoppages and fabric defects during weaving and knitting.

The appearance of dyed or printed fabrics is negatively influenced by the presence of neps, which often comprise immature fibres. Immature fibres absorb dye and reflect light differently to mature fibres due to relatively thin secondary cell walls and lack of cellulose. They appear as white spots or flecks on finished fabrics and although noticeable when fabrics are dyed lighter colours, are particularly noticeable on fabrics dyed to dark shades. Their appearance can cause fabrics to be downgraded or rejected, as there are no practical means of covering or removing the imperfections once present in the fabric. There are currently no industry standards for an acceptable number of neps per cm_2 of finished fabric nor is there a consensus on nep size or classification. A generally accepted rule of thumb is that the nep content in short and medium staple cotton lint should not exceed 250 neps/gram, but preferably ≤ 200 neps/gram.

Fibre properties that have an effect on the formation of neps include fineness (micronaire), maturity, length (including short fibre content), and strength, with micronaire and maturity having a large influence on nep formation. 'Finer' micronaire cotton fibres tend to form neps more easily than coarser fibres, because the former are more easily bent, buckled, and entangled during mechanical manipulation because of their relatively low longitudinal rigidity.

Seed-coat fragments

It has been stated that practically all ginned lint contains seed-coat fragments (SCF), and that the main source is the chalazal end, which is generally not fully developed or is structurally weak, with fibres in this area possibly immature due to varietal and environmental factors, and torn off with a piece of seed instead of being broken off. This leads to the creation of SCF when the fibre is separated from the seed, which consists mainly of pieces of the chalazal or rounded end of the seed, as well as motes (whole immature seeds) broken off during ginning – see Figure 8.

The number of SCF in ginned cotton can vary by as much as 50%, with the major factors contributing to their occurrence including cotton variety, crop year and timing of harvest. Not only do SCF cause spinning end breakages, but they also cause a deterioration in yarn appearance, and an increase in production costs, being virtually impossible to extract from the bulk of raw cotton, except at the combing process, because of the tuft of fibres attached to the seed-coat. As a result, they are generally incorporated into the yarns as a nep. SCF appear as dark specks on the surface of dyed fabrics and are generally surrounded by immature fibres of lighter colour, which reduces the quality of the final product.

There seems to be a general consensus that SCF content in short and medium staple cotton lint should not exceed 20 neps/gram, but preferably ≤15 neps/gram.

FIGURE 8 Image of a seed-coat fragment nep

Classing in Australia

There are currently four classing facilities in the country. They are ProClass, located in Goondiwindi, Australian Classing Services, in Wee Waa, Top End Classing in Kununurra, and Australian Food and Fibre in Sydney. These classing facilities currently have a total of 24 HVI instruments, of which 17 are 1000M and 7 are ClassingQPro instruments (Uster Technologies AG, Knoxville, USA).

Up until 2024 all classing facilities were members of the Cotton Classers Association of Australia (CCAA), which had developed a Best Management Practise Handbook for Classing which has been in place since 2004. With the dissolution of the CCAA, as a result of the reduced number of classers in Australia, classers are now part of the Australian Cotton Shippers Association (ACSA) Classing & Quality Committee which is working to ensure cotton classing in Australia continues to maintain the highest possible standards. As part of this, the Best Management Practise Handbook for Classing is currently being reviewed and will be referred to as Minimum Standards for Australian Cotton Classing. In addition to this, local standard classing facilities are working towards world's best practice by participating in International Round Trials and certification by ICA Bremen.

Classing samples are collected from both sides of the bale and wrapped in numerical order in a plastic roll, with the relevant bale tags, either placed on top of the sample or between the two samples taken. Rolls have a maximum of 60 samples and to comply with health and safety protocols should not weigh more than 13 kg. The plastic used is either virgin or reused plastic and it is estimated that the plastic used for each roll has a minimum length of 4.3 metres and weighs 500 grams. To assist with recycling, gins use clingwrap to secure the rolls rather than masking tape. All the gins in Australia utilise a sample table to wrap the samples securely.

Due to the relative consistency of Australian fibre quality, not every bale is tested with the industry currently testing, as a minimum, every third sample, ensuring that at least one sample is tested per round module. The average is then applied to all non-tested samples, with the samples tested retaining their individual results. The Australian industry has been module averaging for many years with two methods agreed upon after an extensive study in 2005 and adoption in 2006. The two methods are - applying the average to all non-tested bales, with bales tested retaining their results or applying the average value to all bales. The number of samples tested is increased if there is a variability in certain or all fibre properties.

Layout and design of a classing facility

Layout

Where possible the facility should be located within a separate building, with no windows and outside doors to aid in providing consistent environmental conditions. Air locks for doors leading into the facility from unconditioned areas are highly recommended.

Space

There should be sufficient space available in the facility for the instruments, personnel, and storage. Instruments should be easily accessible with enough space for doors and panels to be opened for cleaning, servicing, and maintenance. Personnel should be able to move freely, in a safe manner, and there should be enough space to store samples and other miscellaneous items required by the facility.

Wall & ceiling colour

For manual classing, a neutral, and consistent wall and ceiling colour is crucial. A pure white or a very soft, cool white is ideal for the ceiling to maximise visibility and avoid any colour cast on the cotton fibre samples. Choose a neutral paint for the walls with a matt or low-sheen finish to prevent distracting reflections. It is recommended to use grey for the walls in accordance with the Munsell Natural Value Scale. Classing tables should be black.

Lighting

Specific artificial daylight conditions are required in a classing room to assess cotton's colour grade accurately and uniformly. It mimics natural daylight to allow a trained cotton classer to make a valid colour assessment by comparing the sample to a cotton standard. Rows of lights must be installed to provide not less than 100 foot-candles or 860 lux of illumination at the working surface of the classing table. Further information can be obtained from 'Standard Practice for Lighting Cotton Classing Rooms for Cotton Grading,' ASTM D1684-07(2020).

Electrical

Consistent and reliable power supply is crucial for any facility to operate efficiently and to protect HVI instruments and personnel. Surge protection measures are key as is the additional safeguard of adding uninterruptable power supply (UPS) units to each instrument to protect them from power surges and outages.

Compressed air

HVI instruments need a consistent and uninterrupted supply of compressed air for testing samples. Compressors should be large enough to provide the required compressed air (minimum of 7 to 8 bar) to conduct testing and be maintained and serviced on a regular basis. Furthermore, to prevent oil from contaminating the instruments, which can be catastrophic and influence test results, a suitable filter should be installed to drain off any oil and moisture prior to the air being distributed to the instruments.

Personnel

All personnel must be competent to perform their designated tasks and duties based on their training, skills, and experience.

Test methods

A standard test method provides detailed directions on performing specific tests. For reference purposes it is recommended to have up to date copies of all the standard test methods either in hardcopy or online and easily accessible.

Sampling

A sample should be extracted from each side of a bale preferably at the gin but in some extenuating circumstances at the warehouse. The sample should be at least 120 mm wide, 220 mm long and 140 mm high with a weight of approximately 200 grams – see Figure 9. This is especially important for colour and trash measurement on HVI instruments where the sample window must be fully covered by the specimen to obtain an accurate measurement. If cotton samples are too small to cover the entire sample window, the colour and trash measurements should not be reported. Cut or trimmed, dirty and damaged and uneven samples should not be tested for classing purposes. Leafy and very low-grade samples should be tested with care.

Samples must not have bolt holes originating from the press and must have an identification tag and be packaged appropriately to preserve the identity and integrity of the individual sample.

Sample retention is influenced by clients and the space available for storing samples at the classing facility or testing laboratory.

Atmospheric conditions/ conditioning

As the physical properties of cotton can be influenced by their moisture content it is important that samples are brought to and tested at approved atmospheric conditions. An integrated Air Management System (AMS) with sufficient capacity to maintain the required conditions should be installed. The atmospheric conditions for the classification of cotton as per 'Standard Practice for Conditioning and Testing Textiles,' ASTM D1776/D1776M-20(2024), are Temperature of 21°C +/- 1°C and Relative Humidity of 65% +/- 2%. It is recommended that the testing facility is conditioned permanently 24/7 during the classing season or at least when testing is conducted on a continuous basis. The temperature and humidity should be monitored continuously by independent electronic sensors that have sufficient accuracy and sensitivity, suitable to detect and record short term fluctuations at least every two minutes or more frequently.

Records of the temperature and relative humidity readings should be kept for at least a year.

The number of sensors required depends on the length, height, and width of the facility and as a rule of thumb should be at least one sensor per 50 m^3 hanging from the roof at 1.5 to 2.5 metres from the floor and away from walls to ensure adequate airflow- see Figure 10.

FIGURE 10 Sensors hanging from roof

These sensors need to be checked and calibrated externally by either a qualified body or by the instrument manufacturer on an annual basis.

Areas where only manual classing is conducted do not require controlled atmospheric conditions.

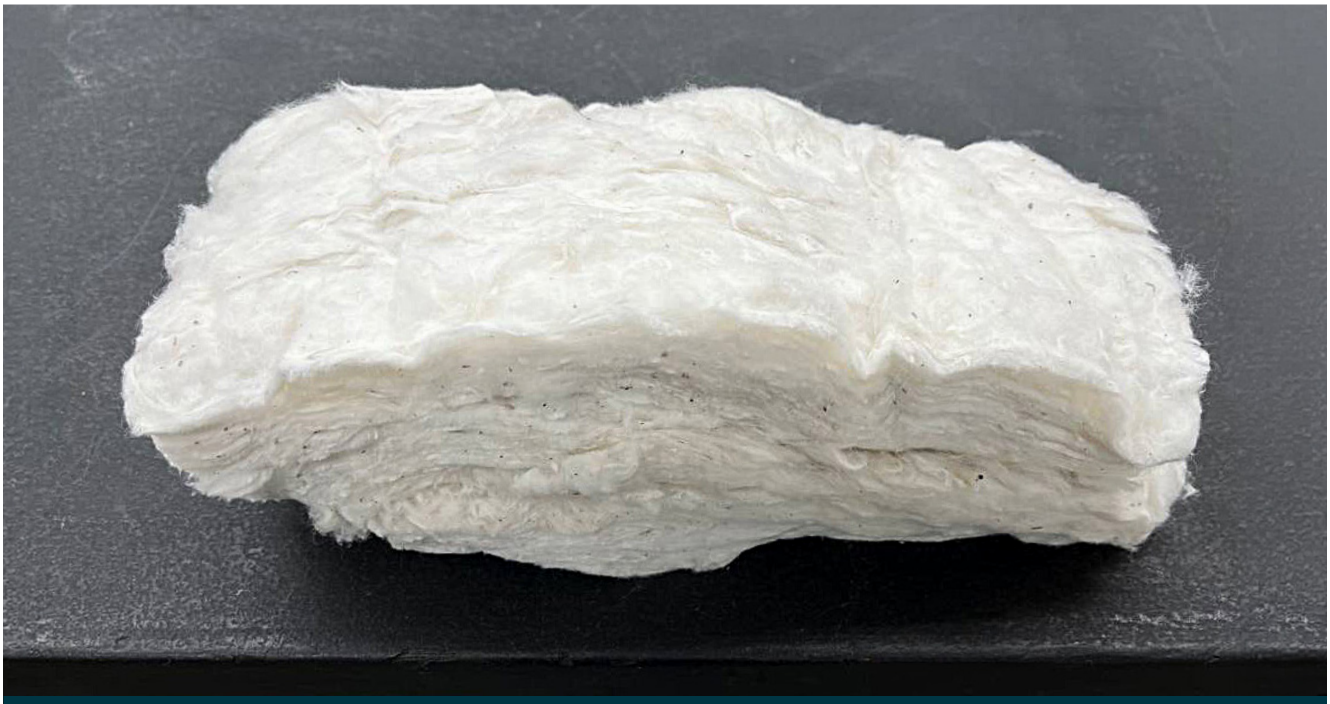

FIGURE 9 Example of sample size required for accurate classification

Sample conditioning

As per 'Standard Test Methods for Measurement of Physical Properties of Raw Cotton by Cotton Classification Instruments,' ASTM D5867-12(2020), the moisture content of samples should be between 6.75% and 8.25% (dry weight basis) prior to the commencement of testing. Samples should always be conditioned from the dry side as cotton has hysteresis which affects the equilibrium amount of water absorbed. If samples have a high moisture content, they may need to be preconditioned to a relatively dry moisture content prior to sample conditioning. It is recommended that samples are periodically checked to determine the moisture content upon arrival with externally checked and calibrated handheld moisture meters (for example a Delmhorst C2000 cotton moisture meter or equivalent).

Cotton samples can be conditioned by either passive or rapid/active conditioning. In both instances samples and calibration material must be conditioned in open-wire shelves, plastic or cardboard mesh baskets, or mesh wire racks - see Figure 11.

FIGURE 11 Example of sample tray and rack

Conditioning of samples in sacks, wrappers or other coverings is not accepted as air needs to penetrate the samples from all sides. There should be sufficient space between the racks with a distance of at least 20 cm.

For passive conditioning samples must be conditioned for a minimum of 12 hours but preferably 24 hours where practically possible. Rapid conditioning units, which are generally situated in the same conditioned room, can also be used as an alternative to passive conditioning. Rapid conditioning is achieved by drawing air through the samples for at least 15 minutes until equilibrium with the surrounding atmosphere is reached. The total conditioning time is usually less than one hour. In both cases the moisture content should be periodically verified, with externally checked and calibrated handheld moisture meters. If the samples are not within the accepted moisture range of 6.75% and 8.25%, they must be reconditioned. Records need to be kept indicating the date, time, and moisture content.

The HVI instrument also measures moisture at the comb by detecting the electrical resistance between the comb's teeth and the clamping jaws. Care should be taken to ensure dust build up on the comb is avoided or cleaned. Although this is not an accurate measurement, as there is no means of calibrating the sensor, it can be used for comparison and to monitor drift or sudden changes.

No moisture correction should be applied to test results. However, if any moisture correction has been applied it must be reported with the results, bearing in mind that research has demonstrated that moisture correction is unreliable.

Visual/manual classing

Universal upland colour and leaf grade cotton standards

A large proportion of cotton is still bought and sold on the basis of a cotton classer's subjective assessment of grade relative to a prepared physical sample of the said grade. In awarding a classing grade, the classer will assess the sample's colour, visible trash (leaf grade), and preparation (degree of smoothness or roughness of the cotton sample) relative to the appearance of a physical grade. The physical sample grades were established by the United States Department of Agriculture – Agricultural Marketing Service (USDA-AMS) in the early 1900s to eliminate price differences between markets, provide a means of settling disputes and to make the grower more aware of the value of their product. USDA-AMS physical grade boxes and the qualities they represent are globally accepted and routinely used to trade cotton worldwide. The only exception being that some cotton is sold on physical grades and shipper types represented by actual samples, which are used for reference purposes against the shipped cotton.

The colour grading of Upland cotton considers both major and minor differences in colour. Major colour differences occur between the five classes of 'white,' 'light spotted,' 'spotted,' 'tinged' and 'yellow' stained cotton, chiefly due to increasing degrees of yellowness across the five classes. Within each of these classes the reflectance or whiteness of the fibre is assessed across another eight levels from 'Good Middling' through to 'Below Grade.' There are 25 official physical colour grades for Upland cotton and five grades for below grade colour- see Table 7.

TABLE 7 Official colour grades of upland cotton

Designation		White	Light spotted	Spotted	Tinged	Yellow stained
Good Middling	GM	11	12	13	-	-
Strict Middling	SM	21	22	23	24	25
Middling	M	31	32	33	34	35
Strict Low Middling	SLM	41	42	43	44	-
Low Middling	LM	51	52	53	54	-
Strict Good Ordinary	SGO	61	62	63	-	-
Good Ordinary	GO	71	-	-	-	-
Below Grade	BG	81	82	83	84	85

These colour and trash grades referred to as Universal Upland Colour and Leaf Grade Cotton Standards are placed in boxes with six samples representing the range of each colour grade and the size and amount of leaf. Samples of each box are photographed and attached to the lid of the box for comparison – see Figure 12. As colour changes over time these boxes are dated and need to be replaced annually. The samples should not be handled or touched as this may affect the colour and leaf particles may be impacted.

FIGURE 12 USDA universal upland colour and leaf standards

Measurement of fibre properties

Staple length

An experienced cotton classer pulls and aligns a small tuft of fibres by hand with the length measured using a ruler, chart or is estimated by the classer. This process is repeated to get an average length.

Colour & leaf grade

A trained classer takes the sample of cotton and visually inspects the sample to evaluate:

1. **Colour:** Assessing the brightness and whiteness of the fibre, and the absence of greyness or dullness. The classer compares the sample against official grade standards and assigns a grade. An example being 31 or 21 or M (Middling) or SM (Strict Middling).
2. **Leaf:** The amount of foreign matter, such as leaves and stems, present in the sample. Upland leaf grades, determined by a human classer, are identified by the numbers 1 (low) through to 7 (high) and there is also a 'below grade' (8) grade. Colour and leaf are reported in combination. For example. 31-2.
3. **Preparation:** The smoothness or roughness of the cotton sample. This is considered an arbitrary and outdated categorisation as the appearance of a sample is very much dependent on harvesting and ginning methods. This can produce differences in appearance and preparation and are not necessary a reflection of the fibre quality. Case in point being the difference in appearance of roller and saw ginned cotton.

FIGURE 13 Manual classing

Extraneous matter

This is described as any substance in a cotton sample that is not cotton fibre or leaf material. This includes bark, grass, seed coat fragments, spindle twist, dust, oil, and plastic. The classer inspects the sample and makes a notation of the type and amount of extraneous matter. The amount of extraneous matter in the cotton is reported as level 1 or level 2, with level 2 indicating the heavier contamination. The code numbers identifying the presence and level of extraneous matter in a sample are represented in Table 8.

TABLE 8 Extraneous matter codes

Code	Description	Level
01	Preparation	1
02	Preparation	2
11	Bark	1
12	Bark	2
21	Grass	1
22	Grass	2
31	Seed - coat fragments	1
32	Seed - coat fragments	2
41	Oil	1
42	Oil	2
51	Spindle twist	1
52	Spindle twist	2
61	Seed coat	1
62	Seed coat	2
71	Plastic	1
72	Plastic	2

* 1=light, 2 = heavy

Instrument testing

Principle of testing

Testing by HVI instruments is quick (≥ 90 samples/hour) and easy to conduct. HVI instruments have three modules:

- One to test length/strength by means of fibre bundle testing, where several thousand fibres are measured to determine the average value;
- One to test colour/trash; and,
- Another for micronaire – see Figure 14.

Colour

Due to the subjective nature and inconsistency of manual classing, the need for objective measurement led USDA-AMS in the 1970s to consider the feasibility of colour and trash measurement by instrument. With the development of colorimeter technology and the incorporation of colorimeters into HVI instruments, the classification of colour and trash by instrumentation became feasible. Objective measurement of cotton fibre colour is defined in terms of the Nickerson-Hunter model, which describe colour in terms of greyness (Rd) and yellowness (+b) – see Figure 16.

Refinements in instrumentation and calibration techniques have led to the adoption of HVI measured colour grades for all US cotton since 2000 and trash in 2011, with the world industry playing catch up since that time. The Australian cotton industry has been slow to embrace the change to colour and trash measurement by HVI, but in 2024 moved to classing colour and trash solely by HVI.

Colour is measured by placing a lint sample on a glass pane with the instrument measuring the colour using a two-filter colorimeter that measures Rd and +b. Results are then compared to established standard values to determine the official colour grade (Figure 16). As indicated earlier the sample must cover the entire glass pane with the pressure of the of colour hand at a minimum of 75 kg +/- 2 kg to ensure that the sample is pressed flat to avoid shadowing, with the colour hand pads replaced annually and the glass pane replaced if discoloured or scratched.

FIGURE 15 Measurement of colour

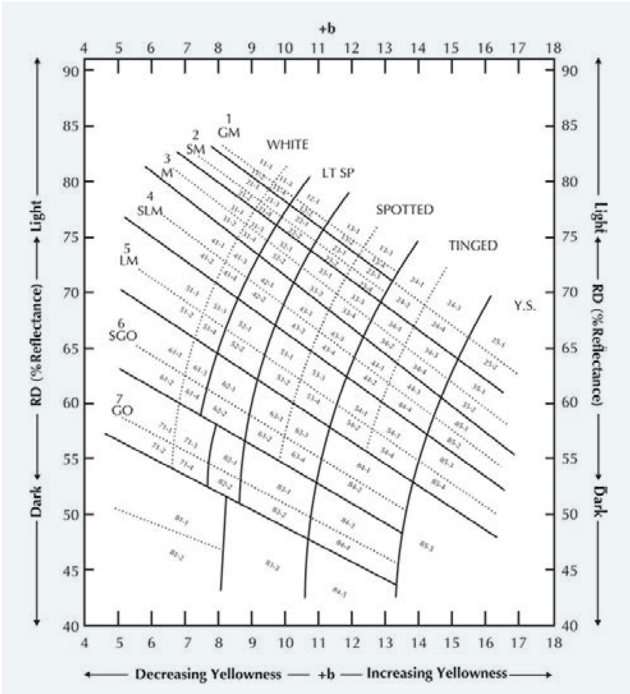

FIGURE 16 HVI colour grades for upland cotton

FIGURE 14 Cotton classification by HVI instrument

Using the Nickerson-Hunter model, the Rd and +b values will determine the colour grade (CG) and the quadrant. For example, 31-1; which means 31 colour falling in the first quadrant. The majority of the Australian crop generally falls in either the first or second quadrants with fairly high Rd values ≥ 76 and low +b values of ≤ 8.0.

Trash

Trash and colour are measured at the same time. Trash is defined as:

1. **Trash count** - The number of trash particles in the sample
2. **Trash area** - The percentage of the total measured sample area that is covered by trash particles.
3. **Trash grade** - Trash count and % area converted to trash grade.

Table 9 provides the rough relationship between the trash % area from the HVI and manual leaf grades determined during the manual classing process.

TABLE 9 Relationship between trash % area and manual leaf grade

Classer's leaf grade	Trash area %
1	≤0.13
2	≤0.20
3	≤0.34
4	≤ 0.51
5	≤ 0.72
6	≤1.00
7	≤1.20
8	>1.57

The colour and trash values are combined. For example, 31-1-2 relates to 31 colour falling in the first quadrant with a trash grade of 2.

Micronaire

Micronaire is measured by placing a lint sample of a fixed weight (10 gram+/- 0.5 g, more flexible for the new HVI instruments with automated micronaire measurement) into a chamber and measuring the permeability (resistance) of the cotton to compressed air – see Figure 17. Cottons with high micronaire are coarse, with fewer fibres per unit weight resulting in less fibre surface area allowing air to pass through with less resistance. Low micronaire cottons, on the other hand, are fine and have more fibres per unit weight, providing more surface area resulting in more resistance to airflow.

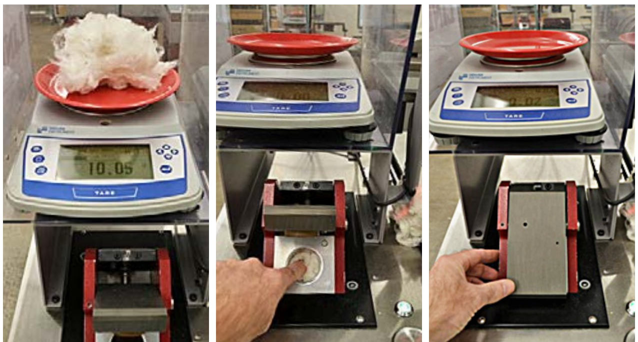

FIGURE 17 Micronaire measurement

In order to further automate and speed up testing the micronaire module has been relocated and automated. USDA-AMS has been installing these newer ClassingQPro (AutoMic) instruments since 2012, with Australia installing the first of these instruments in 2023.

Length

In the HVI test a 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 – see Figure 18. Interpretation of the Fibrogram considers the comb gauge length i.e., the depth of the comb at which fibres are held (0.25 inch). Although there are two different types of fibre length measurement generated from a Fibrogram; only 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. The Uniformity Index % is an expression of the consistency of the fibre length and is the ratio of ML to UHML.

FIGURE 18 Length measurement

Strength

Strength is measured physically by clamping a fibre bundle between two pairs of clamps at a known distance. The second pair of clamps pulls away from the first pair at a constant speed until the fibre bundle breaks- see Figure 19. The distance it travels, extending the fibre bundle before breakage, is reported as elongation. Although elongation does currently not form part of cotton classification it is growing in importance as it affects fibre handling and processing. The issues with the measurement of elongation are related to accuracy, precision and the lack of elongation calibration cottons. The recent development of elongation calibration cottons for high-speed tensile testing has renewed interest in characterising cotton for strength and elongation.

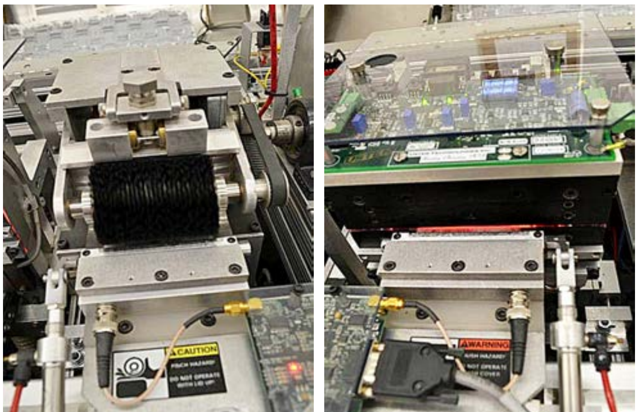

FIGURE 19 Strength measurement

Operation/testing

The HVI manufacturer's instruction manual and recommendations for operation should be followed. HVI instruments are capable of testing and producing results across a number of parameters according to 'Standard Test Methods for Measurement of Physical Properties of Raw Cotton by Cotton Classification Instruments,' ASTM D5867-12(2020) used by the cotton trade. These include fibre length, length uniformity, strength, micronaire, colour, both reflectance (Rd) and yellowness (+b) and trash in terms of trash count, % area and leaf grade. The test method specifies that at least two tests should be conducted for fibre length, strength, colour, and trash and one for micronaire.

Other parameters such as short fibre index %, elongation % and maturity may also be reported.

Maintenance and condition of instruments

It is recommended that all instruments should be checked and serviced prior to the beginning of a testing season or alternatively every year. This should ideally be performed by a representative of the instrument manufacturer, or a highly skilled contractor. In addition to this, the instruments should be cleaned on a regular basis during the season. Every instrument should have a logbook to record any issues for evaluation during and after the season.

All instruments should have the latest version of software installed and should be verified prior to the start of the season according to 'Standard Practice for Qualification of Cotton Classification Instruments for Cotton Marketing,' ASTM D7410-07(2020).

The balance for the determination of sample weight in the measurement of micronaire should be calibrated annually by either a representative of the instrument manufacturer or a qualification body. Alternately, sample weights used for verification should be calibrated by a qualification body.

Calibration and verification of instruments

General

Calibration contributes to the accuracy and confidence in HVI measurements but is not a substitute for maintaining the equipment in good operating condition or maintaining properly adjusted and controlled atmospheric conditions. Once calibrated, verification checks should be conducted to determine whether the instrument is still within tolerance. Recalibration is only required when calibration check results are outside of the defined tolerances, or there are consistent deviations as determined by independent checks or in Round Trials, changes of the calibration material, conditions and instrument repair or maintenance.

Calibration and verification cottons must be stored in the conditioned room for a minimum of 72 hours to ensure consistent moisture equilibrium.

Calibration material

All calibration material must be obtained from USDA-AMS. Universal HVI Calibration Cotton Standards (U-HVI-CCS) are samples from bales of ginned cotton lint with established standard values for length, length uniformity, and strength. For Upland cotton, Universal Short-Weak and Long-Strong calibration cottons are required. These calibration cottons are packed in boxes that weigh approximately 2.27 kg each and have an expiration date that must be adhered to.

Universal HVI Micronaire Calibration Cotton Standards are samples from bales of ginned and carded cotton lint with established standard values for micronaire. Two standard samples are required, one low micronaire (2.5 to 3.5) and one high (5.0 to 5.6) and irrespective of what low and high micronaire cottons are used they should differ by at least 1.5 micronaire. These calibration cottons are packed in rolls which weigh approximately 0.45 kg each and have no expiration date.

An alternative way to calibrate micronaire is by using the USDA orifice calibration method. This method involves the use of high and low mechanical air orifices, in place of calibration cottons, to ensure accurate chamber volume. As these orifices are capable of only calibrating the air systems, calibration cottons should still be used after this method to verify test values.

Calibration cottons need to be replaced when they have been used frequently ("overused") and have an appearance of being matted or ropey, or if there is any suspicion that they have been contaminated in some way.

Calibration tiles are designed for the calibration of colour in terms of reflectance (Rd) and yellowness (+b). A set comprises five ceramic tiles (central, white, brown, yellow and grey) covering a range of established standard values for Rd and +b. Colour tile sets are instrument and illumination specific (Xenon or LED), the instrument and illumination type must be specified when ordering. The surface of the colour tiles must be clean to ensure accurate calibration. An effective procedure for cleaning the tiles is to spray a diluted non-abrasive liquid detergent on the tile surface, followed by wiping with a clean cloth or tissue. Detergents containing bleach, abrasive or other harsh cleaning agents should not be used. Colour tiles must be returned to USDA-AMS every two years for re-evaluation to ensure accurate colorimeter calibration. Alternatively, they can be replaced.

There is also one calibration tile for the measurement of trash percent area and trash particle count. This tile comprises an image of patterned dots mounted under glass which has established standard values for trash percent area and trash particle count. The trash tile is also instrument and illumination specific.

The set of colour and trash tiles is packed in a storage box which weighs 1.81 kg.

FIGURE 20 USDA calibration standards

Internal verification material

In addition to Universal Calibration Standards, there is an option to use internal (in-house) check material for verification of test results, but not for calibration. The advantage of using this material is the reduced use of expensive calibration standards and the use of check testing material that are similar to those that are generally tested. Internal verification cotton should be established from homogeneous bales of even running cotton that has been saw-ginned. The mean and standard deviation is established by conducting at least 60 tests over several days from different parts of the bale.

Calibration & calibration check tolerances

The acceptable tolerance for calibration of the average test results are as follows:

- Micronaire within +/- 0.10 units
- Length +/- 0.013 inch or 0.33mm
- Length Uniformity (UI) +/- 1%
- Strength +/- 1 g/tex
- Colour Rd +/- 0.4 units
- Colour +b +/- 0.4 units
- Trash Area +/- 0.05 %

The acceptable tolerance for calibration checks of the average test results are as follows:

- Micronaire within +/- 0.10 units
- Length +/- 0.013 inch or 0.33 mm UHML
- (UI) +/- 1%
- Strength +/- 1 g/tex
- Colour Rd +/- 1.0 units
- Colour +b +/- 0.5.
- Trash Area +/- 0.10%
- Trash Count +/- 5

Calibration & calibration check frequency

As highlighted earlier, calibration should ideally only be conducted where required. In contrast, calibration checks must be performed frequently to ensure accuracy of the test results. It is recommended that calibration checks are conducted at the beginning, middle, and end of each shift. Calibration records should be kept for all the instruments and analysed to determine if there are any trends.

Participation in round trials

The main aim of Round Trials is to determine the long-term reproducibility of each instrument, and if an instrument was found to be out of tolerance, the testing facility can take corrective action. There are a number of recognised International Round Trials that classing facilities can participate in. Some of the more well know ones are ICA Bremen, which is free and conducted quarterly, USDA which has a small fee and conducted monthly, and the International Cotton Advisory Committee (ICAC) task force on Commercial Standardization of Instrument Testing of Cotton (CSITC) which is also conducted quarterly.

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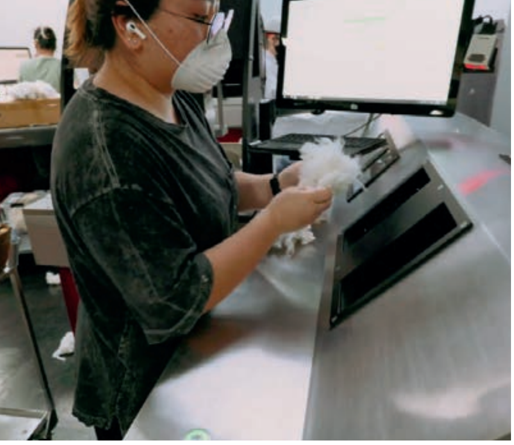
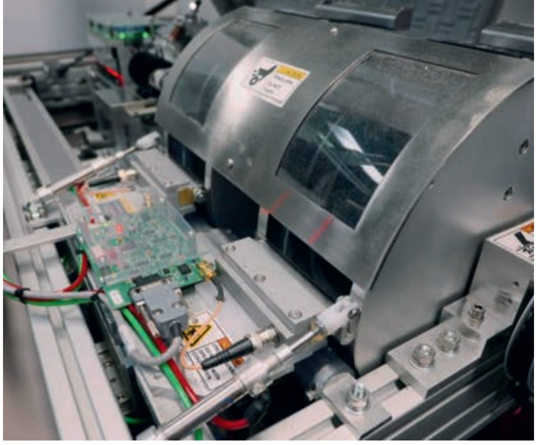

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