If you are participating in the presentations this year, please provide a written report and a copy of your final report presentation by 31 October.
If not, please provide a written report by 30 September.

Part 1 - Summary Details

Please use your TAB key to complete Parts 1 & 2.

CRDC Project Number: **CMSE1001**

Project Title: Investigate new SFC measurement in Australian cotton

Project Commencement Date: 07/09 **Project Completion Date:** 06/10

CRDC Program: Value Chain

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Part 3 – Final Report Guide (due 31 October 2008)

Background
The most common definition of short fibre content (SFC) is the proportion by weight of fibre shorter than one half inch (12.7 mm). The value is of concern to textile manufacturers because it relates directly to the amount of waste extracted in combing and cotton with high values has a detrimental effect on the quality of yarn and fabric. Understanding the level of short fibre content (SFC) found in Australian cotton, particularly in new long staple, fine Australian Upland varieties is important in the current industry push towards high quality 'niche' cotton.

Two new instrument technologies for measuring fibre length distribution including SFC have been assessed in this project. The instruments are the aQura2 manufactured by Premier Evolvic, Coimbatore India and the Optical Fibre Diameter Analyser (OFDA) 4000 manufactured by BSC Electronics, Perth WA. Both automatically prepare multiple arrays of aligned fibres that are then scanned; one using a CCD camera and the other using a photo-electric method. The automatic arrangement and direct measurement of fibre arrays potentially enables more accurate assessment of the length distribution in a sample and therefore of the SFC.

Following is a review of fibre length measurement, which provides the reader with background to the terms and test methods used and described in this project.

Measuring Fibre Length
Cotton fibre length is usually defined as the upper-half mean length (UHML) or 2.5% span length (2.5%SL) from a Fibrogram beard diagram. Both measures coincide in a roundabout way with the historic classer's staple. Historically, fibre length is measured in inches (in $1/32^{nd}$ inch divisions) although conversion into millimetres is now common.

There are various methods of measuring fibre length. Length can be measured simply by aligning the end length of a fibre against a ruler and noting its length. However, this approach is tedious and cotton fibres in any sample vary considerably in their length such that measuring a representative sample in this way is impractical. In the past cotton classers were trained to evaluate 'staple' length by measuring the length of a paralleled bunch of fibres against one of their digits. The Textile Institute's definition of staple length noted that "the staple length corresponds very closely to the modal or most frequent length of the fibres when measured in a straightened condition" [1].

Accurate determination of fibre length can be determined using fibre arrays or staple diagrams produced using comb-sorter apparatus. Figure 1 shows an actual array of fibres pulled from the comb-sorter in incremental length groups and lain out on a black velvet covered board. Figure 2 shows the measurement of SFC from an array. Arrays include all fibre lengths in a sample and so SFC can be defined on a numerical basis (SFC(n)), or on a weight basis (SFC(w)) if the length groups are weighed, as the relative number of fibres shorter than a given length – usually 12.7 mm or ½ inch. A Chinese SFC standard exists where the number is relative to fibres less than 16 mm.

The diagrams can be used to define upper 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 by weight, and other length parameters such as mean length, 'effective' length and SFC [2, 3]. The 'effective' length is derived using a series of rules defined by Clegg [4] for a measurement on the array that nominally equates to the UQL from which the short fibres have been eliminated. 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.

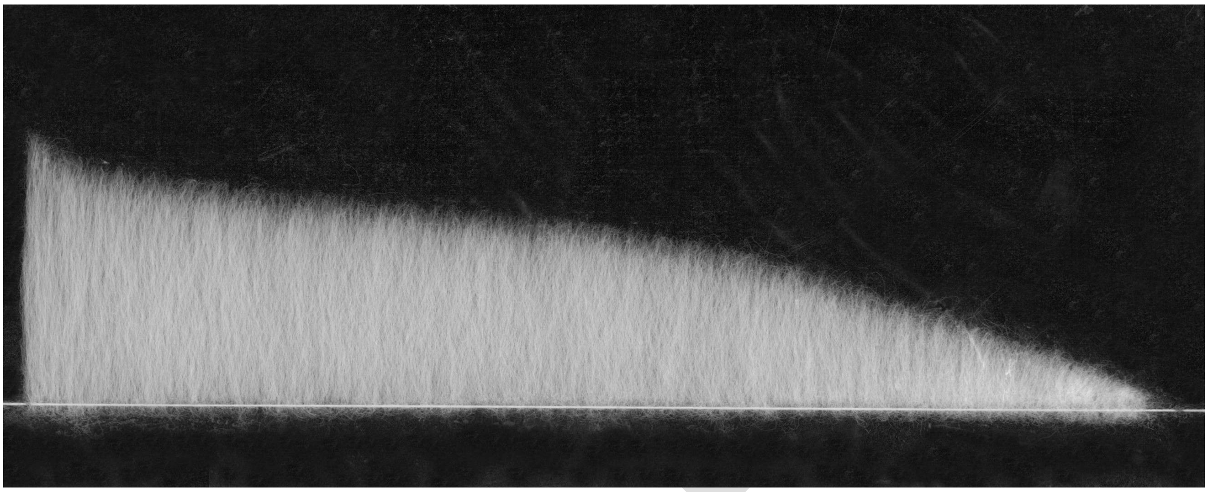


Figure 1 - Comb-sorter staple array of ginned cotton (by CSIRO Materials Science and Engineering)

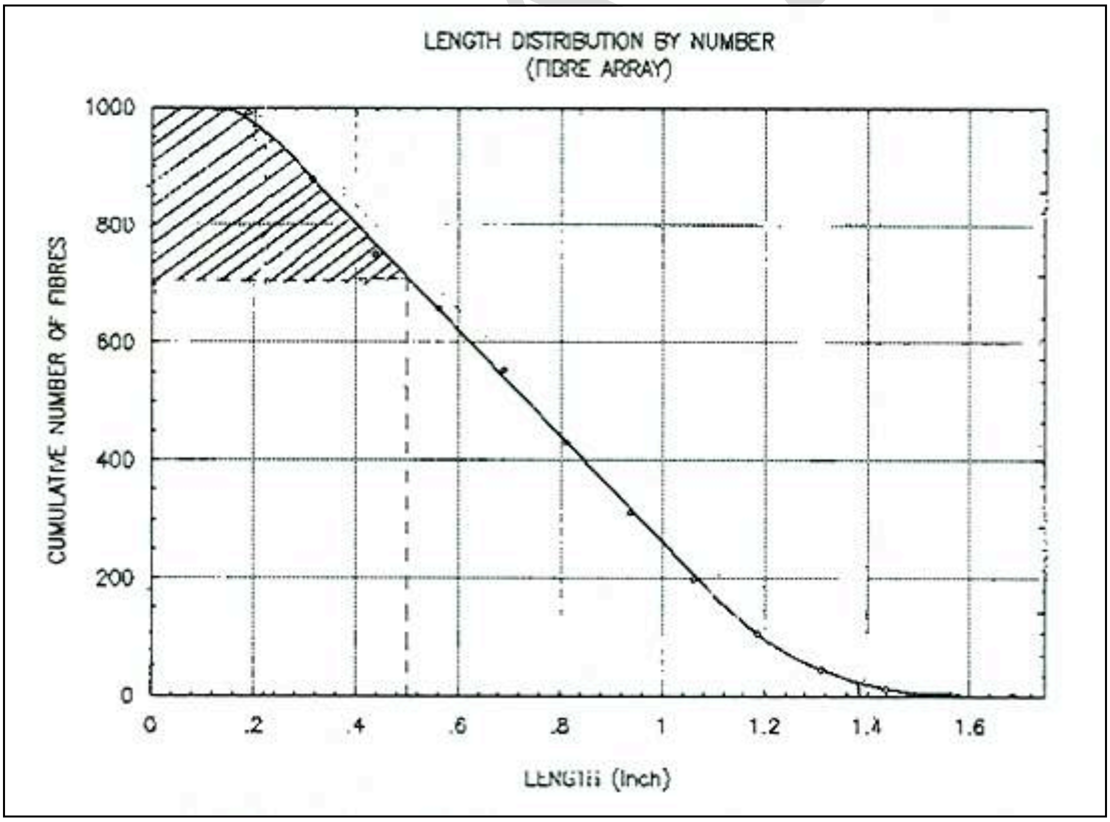


Figure 2 - Comb-sorter staple or cumulative fibre length array showing measurement of SFC by number (from Steadman, R. G., Cotton Testing, *Textile Progress* 1997)

Whilst comb-sorter methods are accurate they are unacceptably expensive in terms of operator cost, too slow and often too imprecise between multiple operators and laboratories for routine testing for commercial trading purposes. To this end the Fibrograph Tester instrument was developed in the early 1940s by Hertel [5]. Initially used as a stand alone instrument it was later incorporated into HVI lines. Test specimens are fibre beards prepared either manually for stand alone and older HVI instruments, or automatically from a bale sample by newer HVI units. The fibre beard is held in a comb that is inserted into the instrument and scanned by a light source. The variation in density (light intensity) of the different lengths of fibre is recorded and reproduced in the form of a length-frequency curve called a Fibrogram (Figure 3). 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), although this accounting is not able to compensate for all variation in SFC in a sample.

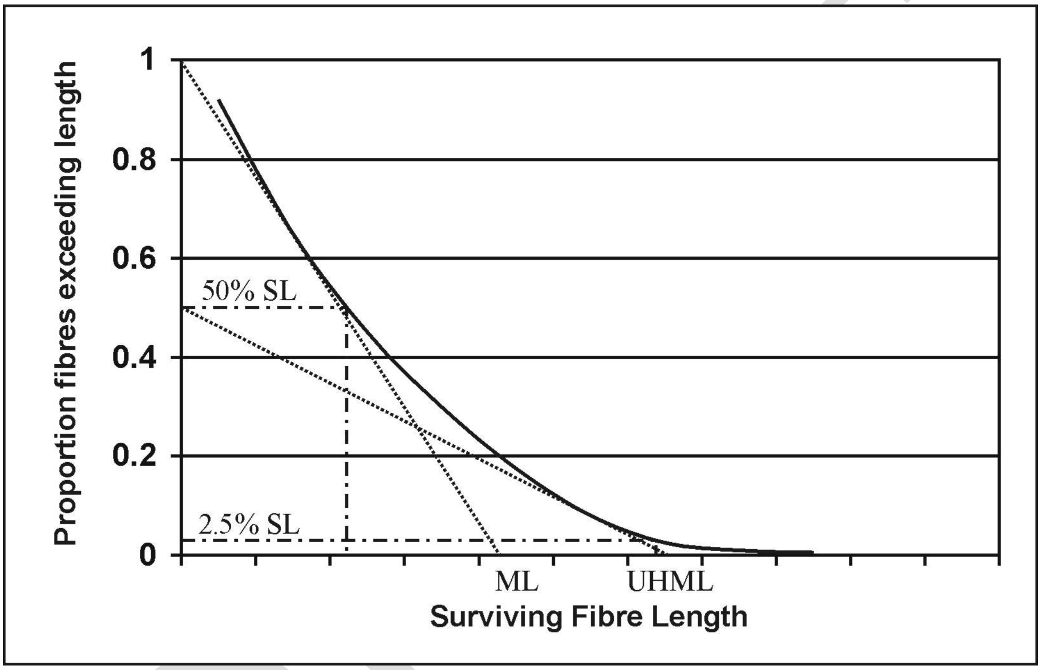


Figure 3 – Fibrogram (or beard diagram) showing position of mean length (ML), upper half mean length (UHML) and 2.5% and 50% span length (SL) measurements.

Two different kinds of fibre length measurement can be generated from a Fibrogram; mean lengths and span lengths. Mean lengths e.g., UHML, which is the mean length of the longer half (50%) of the fibre by weight [6], and the mean length (ML) are more commonly used since they relate to the mean of percentages of fibres represented in the Fibrogram. Span lengths, 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 that extend from the comb.

Proponents of the Fibrograph make the point that the fibre beard scanned to produce the Fibrogram expresses a fibre length distribution comparable to the situation, during the processing of fibre into yarn, at any instant of time, of fibres caught and protruding from draft rollers or aprons (see Figure 4). It is this relationship, some say, which makes the Fibrogram information superior to comb-sorter arrays. However, fibres held in the Fibrograph comb are less parallel in arrangement than fibres found in sliver and yarn assemblies. Further, fibres in the comb are caught randomly along their length and there is a high probability, dependent upon fibre length, that the ends protruding from the comb represent the same fibre curled around one or more teeth of the comb. Much work has been undertaken in the past to relate comb-sorter measurements to Fibrogram measurements in order to provide calibration material for the Fibrograph. However, although significant correlations have been obtained on some data sets [7], the relationships between the two are never perfect since the fibre assemblies are never the same and each measures or senses different parameters.

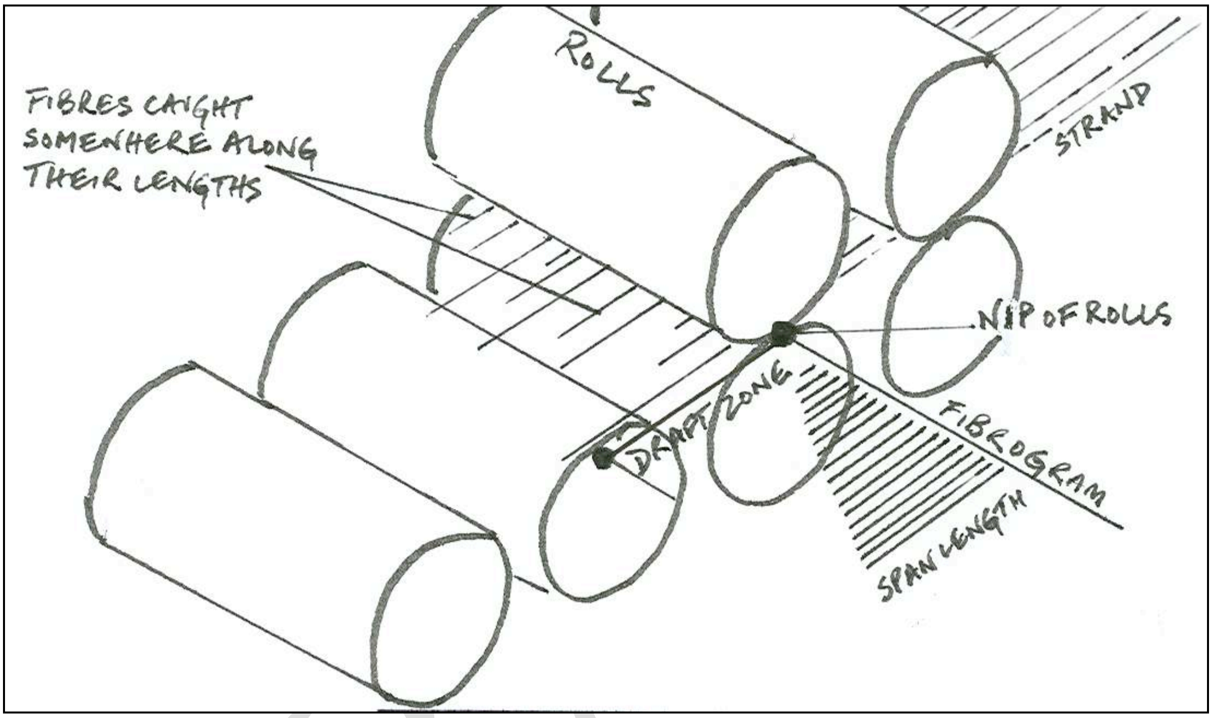


Figure 4 – The beard diagram superimposed in the draft zone of a short staple draw, roving and/or spinning frame showing the position of fibres along their lengths during processing.

Other methods for measuring fibre length include the Uster Advanced Fibre Information System (AFIS) length and diameter module, which yields information on single fibre length and is able to build and report length by number and length by weight distributions. The AFIS is also calibrated to measure fineness and maturity, neps and trash and dust. Measurement is based on detecting the amount of light that is scattered and occluded by a fibre or particle as it is transported by air through a beam of near-infrared light. When the fibre or particle impinges on the beam the electro-optical sensor records two signals i.e., scattered and occluded light. A computer program analyzes the signals and presents mean and distribution data on the particular parameter. The AFIS takes a 0.5 gram specimen of fibre hand-drawn into a 25 cm sliver. Five thousand fibres per replicate and five replicates per sample are typically tested. Test time per replicate is around 3 minutes including sample preparation, which limits the test to laboratory analyses rather than commercial testing. Issues with the measurement itself include the influence of operator technique in preparing samples [8], the breaking of fibres as they pass through the individualizer and exclusion of fibres from the test on the basis of their presentation to the sensor [9]. Despite these shortcomings the AFIS is used widely to measure the accuracy of and calibrate faster test methods like HVI. This is because its frequency distributions provide reasonably good measures of differences in the fibre length distribution for both raw fibre and semi-processed products.

Cotton length measurements using the Peyer Almeter AL-101 system are less frequently reported. This instrument, a version of which is widely used to test wool fibre length is less common in cotton testing because of speed and sample preparation issues. The measurement is based on a scanning light measurement like the Fibrograph but is able to return a staple diagram by number on the basis that the fibre ends of the sample are aligned during the test. Using an estimate of the sample weight allows the AL-101 to calculate length characteristics according to three length distribution types; unbiased distributions by number, weight-biased and a length-weight span length distribution [10].

The Premier aQura2 is a new cotton test instrument that works similarly to the Peyer instrument except that it is modified particularly for cotton fibre measurements and provides values of length, effective length and SFC used in the cotton lexicon. Measurements are based on arrays with the fibre ends aligned on the one axis. Sample preparation is also reportedly more automated thereby reducing error associated with preparation issues.

The BSC Electronics OFDA 4000 is a new wool fibre test instrument that measures wool, typically wool top, fibre length and diameter in a similar specimen presentation format to the Peyer and Premier instruments, i.e. by combing and scanning fibre arrays, except that a CCD camera is used to assess fibre properties, rather than a light or capacitor sensor. This allows greater physical detail to be measured, e.g. a profile of a fibre's diameter along its length can be measured. The application of this instrument to cotton testing and test data compared with comb sorter array, AFIS and HVI data is discussed in more detail in this report.

Length Uniformity

Length uniformity is generally defined as either the uniformity index [10] (UNI), which is the ratio between the ML and the UHML expressed as a percentage, or the uniformity ratio (UNR), which is the ratio generally between the 2.5%SL and the 50%SL. Table I lists the descriptive designations given to HVI generated values of uniformity index by the USDA AMS [11]. Inter-laboratory coefficients of variation (CV) for UNI are good; across a range of different cottons tested as part of the Bremen Round Trials between 2003 and 2005, inter-lab CVs ranged between 0.67% and 1.09% [12].

Table I – USDA Descriptive Designation for HVI Uniformity Index Values

Descriptive Designation	HVI Uniformity Index
Very high	Above 85
High	83 to 85
Average	80 to 82
Low	77 to 79
Very low	Below 77

Short Fibre Content

Short fibre content measured by the HVI is referred to as short fibre index (SFI) and is the most widely used value to describe SFC in a sample, even though short fibres are not actually measured directly by the HVI Fibrograph, nor until recently could the instrument be calibrated [13]. Typical SFI values vary from 4 to 12% in ginned lint but are much lower in un-ginned lint. Precision is generally poor by comparison with test methods for other properties. Figures 5 and 6 from a sub-CSITC Round Trial in 2008 examining variability in SFI values from 10 HVI 1000s located in the USA and elsewhere [14] illustrate this point. Figure 5 shows the variability between HVI (office no.) and measurement days for short cotton with high SFC (cotton 1) and Figure 6 shows the same protocol for long cotton with low SFC (cotton 5). Knowlton's conclusions from this trial were:

- Between HVI 1000 instrument SFI levels are relatively close together.
- Refinement of SFI cotton calibration procedure may further improve level agreement.
- SFI calibration levels vary more on cottons with higher short fiber contents.
- SFI measurement variation increases dramatically as short fiber content increases.
- Uncertain why some HVI 1000s perform better than others when setups and calibrations were performed similarly (e.g. compare HVI 9 variability to others).

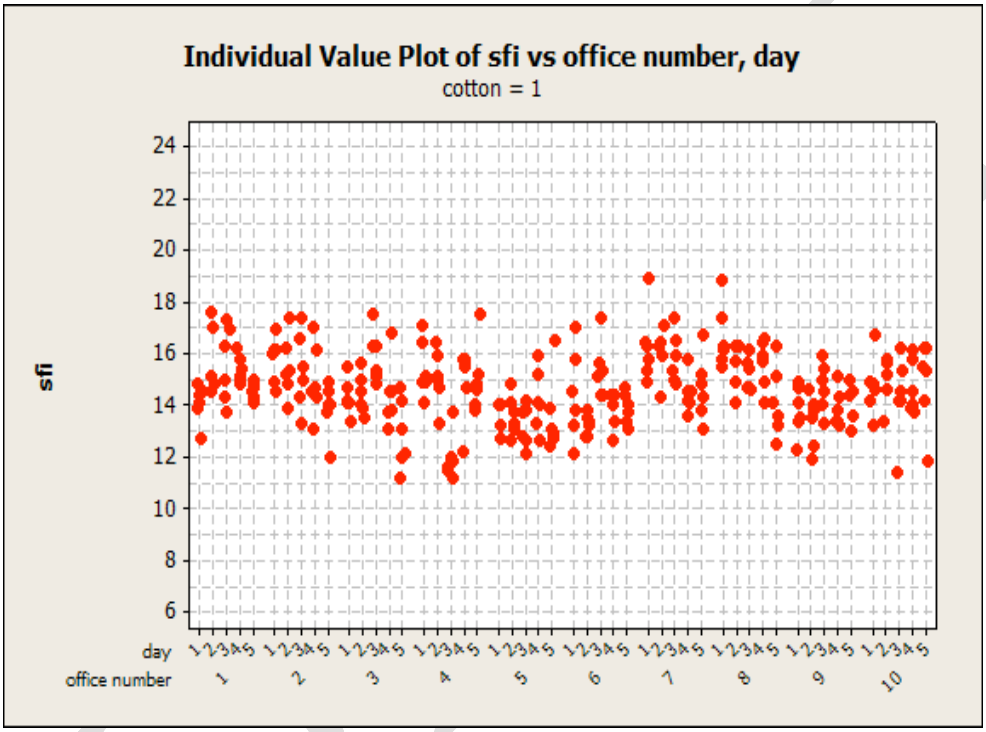


Figure 5 – Variability in SFI between HVI machines (offices) and days for short cotton

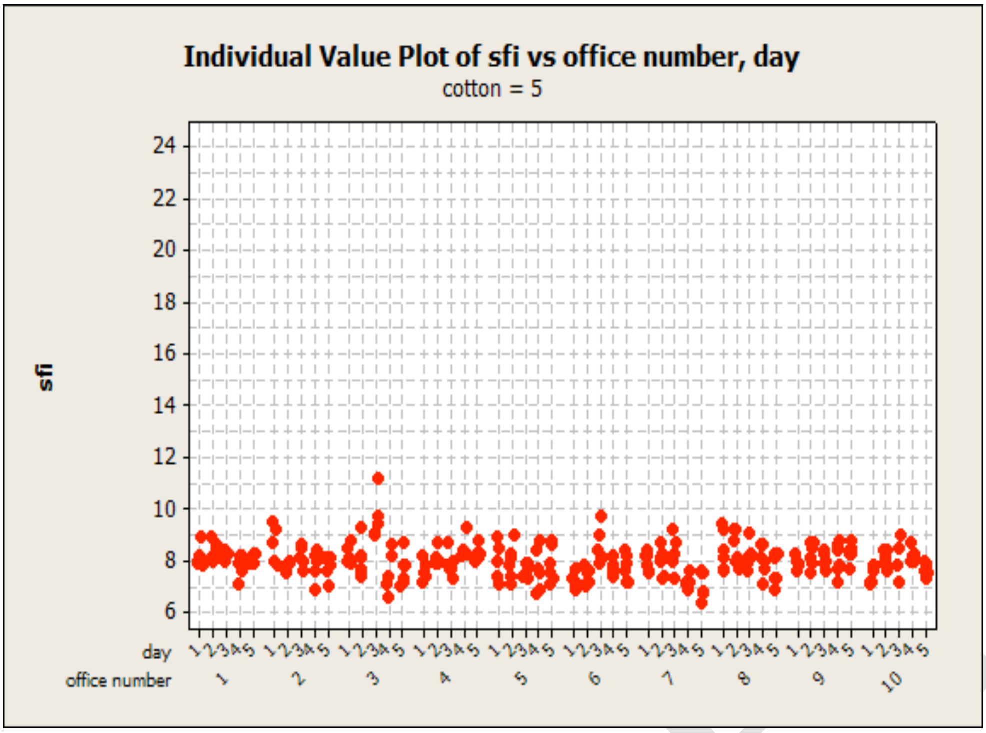


Figure 6 – Variability in SFI between HVI machines (offices) and days for long cotton

As a proponent of the HVI system of classing Knowlton's conclusions tend to gloss over the fact that HVI SFI values range widely for various reasons; the Fibrogram's inability to directly measure short fibres, no widespread use of a calibration procedure for SFI, variable specimen preparation and the generally high variability in SFI values that arise from genetic, production and post-harvest factors. Inter-laboratory CVs for SFI for various cottons tested as part of the Bremen Round Trials between 2003 and 2005 ranged between 15.8% and 24% [12].

Accuracy of the measure of HVI SFI is also debatable. Calibration and selection of appropriate predictors are the main issues. In the past, SFI has been calculated from Fibrogram data using first-order algorithms that used measures such as 2.5%SL and 50%SL and the 2.5%SL and the uniformity index [15] as independent variables. More recently SFI in HVI lines has been predicted using second-order algorithms containing HVI length and uniformity index [16] (see Equation 1). It is noted that because these length measures are functions of the fibre-length distribution they will only work well for cotton exposed to similar picking and gin practices. Currently, a SFI value determined by an algorithm, which calculates the fibre array curve from the Fibrogram, is being tested. From this a weight-based length distribution is derived from which the percentage of short fibres at one half inch is calculated. The mathematical basis for the conversion algorithms is described in reviews by Woo [17] and Zeidman and Batra [18]. The relationship between SFI measured this way and SFC measured by the AFIS is reasonable with a correlation of 0.96 quoted for a series of standard cottons with different staple length [19].

$$Z = a + bX + cX + dX^2 + eY^2 + fXY \qquad (1)$$

Where
Z = predicted short fibre index,
X = HVI length,

Y = Uniformity Index,
a = 384.3966, b = -120.3791, c = -6.7003, d = 12.4901, e = 0.02957 and f = 1.0306

As well as the issue of repeatability in the SFC measurement recent debate has also centred on the definition of SFC; the view held is that the one half inch definition is inadequate given that spinning machinery is largely adjusted to accommodate the proportion of longer fibres, synonymous with the standard measures of staple length. The argument for changing the one half inch benchmark is that for a given amount of fibre damage short-staple cotton will show a higher percentage of short fibres than longer staple cotton. One inch staple fibre is not necessarily unfortunate if processing equipment i.e., draft zones have been set up for this length fibre. Short fibre content is therefore a relative number that should be minimized as a proportion of the measured long or effective length so that problems associated with uncontrolled fibres can be avoided. Heap [20] proposed a measure of relative SFC, defined as the percentage of fibres by weight shorter than one half of the staple length (or UHML). Kearny-Robert *et al* [21] proposed and illustrated the concept of the broken fibre content (BFC), which they propose would be a more accurate measure of SFC, since the term allows for separation of inherent SFC from 'phenotypic' SFC. El-Moghazy and Krifa [22] define the Length Utilization Efficiency (LUE) expressed as the ratio between the percentage of fibres longer than an upper threshold, of nominally 1 inch, and those shorter than a lower threshold, nominally ½ of one inch, although its value at these thresholds had yet to be determined.

Objectives
The aim of this project was to conduct a technical audit of two new instruments; the Premier Evolvic's aQura2 and the BSC Electronics Optical Fibre Diameter Analyser (OFDA) 4000 instruments with respect to the measurement of Australian cotton fibre length, in particular SFC. Results and operation of the new instruments are compared with the operation and results from current test methods including HVI, AFIS and manual arrays.

The project objectives and their achievement status are listed in Table II below.

Table II – Project Objectives

Objective	No.	Milestone	Performance Indicator	Status
Define and collect set of cottons for length analysis	1.1	Range of cotton samples including competing export cultivars and samples of same cultivar ginned or mechanically treated to give variation in SFC are collected.	Samples represent range of cultivars and treatments	**Completed**
Arrange access and use of length measuring instruments	2.1	A range of test methods for measuring lengh and SFC are organised to analyse sample set	Test methods arranged include the proposed new test instruments by BSC Electronics and Premier Evolvics, plus HVI, AFIS and Suter Web Array test methods	**Completed**
Analyse sample set by test methods for measuring length and SFC	3.1	Sample set is measured using standard procedures published for each test method	Test results reflect the range and the various errors and biases of each test method	**Completed**
Analyse and cross-correlate test results including transformation of results to express relative SFC	4.1	Data set is accumulated for analysis	Test results reflect the length and length distribution characteristics of each sample	**Completed**
Benchmark Australian cotton vs. competing export cultivars	4.2	Report data analysis results	Data analysis contributes to ITMF Cotton Test Method Committee Meetings on SFC analysis	**Pending completion of Cottonspec database**
	4.3	Compile final report	Final report is forwarded to CRDC, ACSA and ACGA	**Completed**

Methods and Materials

A set of Australian and overseas raw and partly processed fibre samples incorporating standard cultivars (and one Pima cotton) have been assessed by a range of fibre length test instruments and methods according to their standard operating procedures (SOP) as defined by manufacturers and/or by internationally recognised standards. The test methods examined and parameters measured are listed in Table III. The list of the fibre and semi-processed samples measured by each test method appears in Appendix 1. Semi-processed samples were examined to determine the sensitivity of each method to changes in the length distribution with the increase or removal of short (broken) fibres from the distribution. Samples of seven cottons (from the RLL series of field to fabric studies) taken at six stages of processing from bale opener through to second draw-frame sliver were used for this part of the study.

A table of short fibre index (SFI) values from HVI assessment is being compiled through the Cottonspec project. When finished, the table will list average and extreme values of SFI and UNI on cottons used in a large (>250K spindles) fine count mill in China over two years. The mill uses cotton from Australia, China, Brazil and USA.

Table III – Test Methods, Parameters Examined and Glossary of Names

Method/Instrument	Standard used	Parameters measured and glossary of names
Comb Sorter	ASTM D1440-90	• Maximum length **(maxL)** • Effective length **(effL)** • SFC by number **(SFC(n))** • SFC percent < 1 cm **(%<1cm)**
AFIS PRO	Manufacturer SOP	• Mean length by weight **(AFIS ML(w))** • Coefficient of variation of length **(AFIS CVL(w))** • Mean length by number **(AFIS ML(n))** • Coefficient of variation of length **(AFIS CVL(n))** • SFC by number **(AFIS SFC(n))** • SFC by weight **(AFIS SFC(w))** • Upper quartile length by weight **(AFIS UQL(w))** • 5% span length by number **(AFIS 5%SL(n))**
HVI	ASTM D4604-91	• Upper half mean length **(HVI UHML(w))** • Mean length by weight **(HVI ML(w))** • Uniformity index **(HVI UNI)** • Short fibre index by weight **(HVI SFI(w))**
aQura2	Manufacturer SOP	• Length by weight **(aQura L(w))** • 5% span length by number **(aQura 5%SL(n))** • Effective length **(aQura effL)** • SFC by number **(aQura SFC(n))** • SFC by weight **(aQura SFC(w))**
OFDA 4000	Manufacturer SOP + adaptations	• Mean length by number **(OFDA ML)** • Coefficient of variation of length **(OFDA CVL(n))** • Hauteur by number **(OFDA H)** • Coefficient of variation of length **(OFDA CVH(n))** • 5% span length by number **(OFDA 5%SL(n))** • 75% span length by number **(OFDA SFC1(n))** • 90% span length by number **(OFDA SFC2(n))**

Two comb sorter arrays were prepared according to ASTM D1440 for 14 of the reference set raw cotton samples by two experienced technicians at CSIRO Materials Science and Engineering (CMSE). Figure 7 shows the correlation between technician effL average values. It is noted the significance of the relationship between these values is dependent upon the experience and care of both technicians. The significant correlations ($R^2 > 70\%$) between technician averages for maxL and effL with minmal offset ‘warranted’ averaging these values against which other test methods were compared. SFC(n) and %<1cm values were also averaged, although it was noted that between operator variation in these measurements was large.

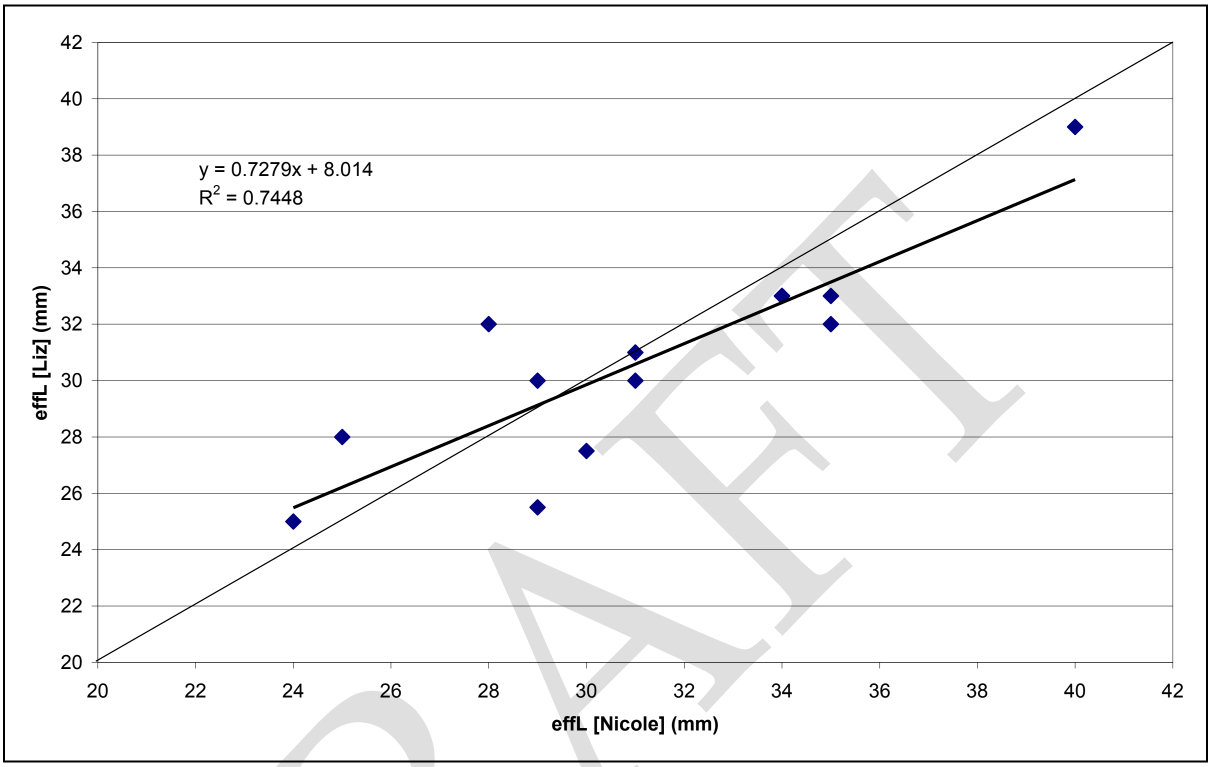


Figure 7 – Comparison of average technician values for effective length by the comb sorter array method

AFIS PRO length tests on the full set of cotton samples (57) were also conducted by experienced operators at CMSE according to the Uster SOP. AFIS results represent the average of five replicates per sample with 5000 fibres measured in each replicate.

HVI tests were conducted on 14 of the raw fibre samples in the set at Auscott Classing Offices Artarmon NSW using a HVI1000 calibrated and operated according to the Uster SOP. Two replicates were tested per sample.

aQura2 tests were performed on 17 samples in the set, including paired raw fibre and 1st drawn sliver samples (from the RLL series), by Premier Evolvics technical staff at their headquarters in Coimbatore India. aQura2 results represent an average of three replicates per sample. The test results of interest included L(w), 5% SL(n), effL and SFC by (w) and (n), as well fibre array distributions that are also available. The L(w) result on the aQura appears to represent the mean of the longest 2.5% of fibres rather than the mean length, which is also symbolized by capital L by the other test methods, e.g. AFIS, OFDA and HVI. The aQura2 also returns a normalized SFC number by (w) and (n) similar to that proposed by Heap [20], although these were not analysed in this study.

OFDA 4000 tests were performed on the full set of cottons by CMSE technical staff at Deakin University, Waurn Ponds VIC according to an adapted SOP developed through discussions with BSC Electronics and Deakin University staff. Test samples were tested after an extended trial period, which was required for operators to develop experience in positioning the shorter cotton fibre samples in the instrument combs, so the sampling jaws would pull and present fibre bundles of acceptable density for measurement. Four replicates per sample were tested once the procedure was established. Coefficients of variation of less than 5% between replicate length values were deemed acceptable.

As the OFDA 4000 is designed to measure wool fibre length, largely from top (akin to sliver) but also from wool staples, it interprets length values common to wool classification and quality assurance [23, 24]. Values include the Hauteur and Barbe fibre lengths and the CVs around these measures. Hauteur is a term used for the length of fibre on a weight basis in a worsted wool top, which has been combed and prepared such that the fibres are largely parallel and have a reasonably uniform distribution. Barbe is a similar term but applied to the length of fibre in assemblies that have been processed on the semi-worsted and woollen machines, rather than worsted machines (for Hauteur). We investigate both the ML and Hauteur measurements in this study; the Hauteur value as an alternate to the ML measure.

Measurements of SFC on the OFDA 4000 were taken from the fibre arrays (by number) that are accumulated during measurement. Of particular note were the values of the shortest 10% and 25% of fibres, which are described by the 90% and 75% percentile length groups. Reviewing the actual lengths of (raw cotton) fibres measured in these groups, it was noted the shortest 10% of fibres commonly measure less than 1 cm (between 7 and 12 mm), and the shortest 25% of fibres measure between 12 and up to 24 mm for a Pima-type cotton. These numbers nominally correspond well with SFC (12.7 mm) by number values given by AFIS and the Array methods.

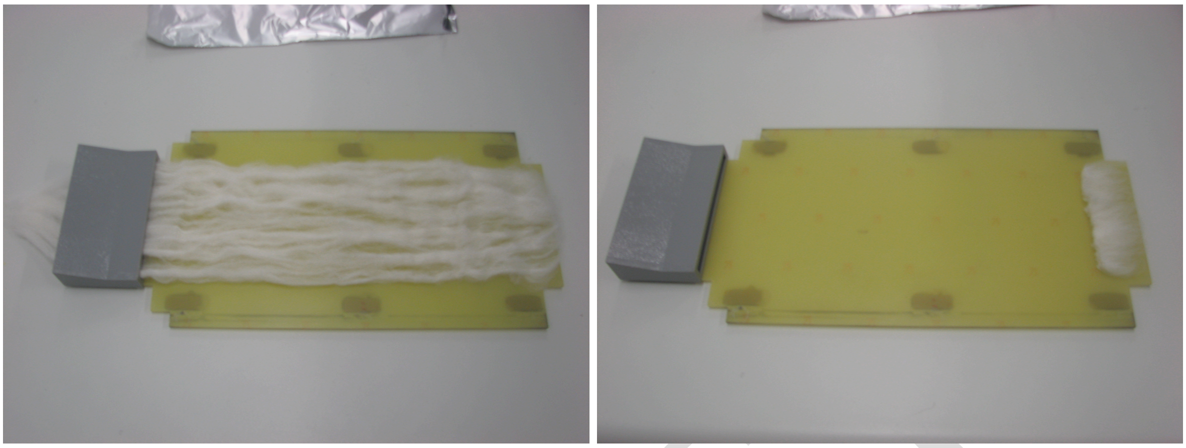
Figures 8a and 8b show sliver and raw fibre samples prepared for embedding in the OFDA 4000 combs. Note the gauge length between the combs is 5 mm compared with 3.17 mm (1/8 inch) for the comb sorter combs, with a pin density of 2 mm compared with 1.4 mm the comb sorter pins. This meant selection and control of shorter cotton fibre lengths (lengths of 25-30 mm cf. with > 50 mm for wool and animal hair) was compromised. Figure 9 shows fibre lengths from cotton sliver withdrawn across the camera field of view (fov) for analysis. That the fibres are not fully extended in the plane they are drawn in does not affect the measurement as the image analysis program is able to follow the 'true' fibre length presented. However, some malfocus error might be expected as the cotton beards were not well supported in the focal depth plane. Lengths recorded beyond the maximum fibre length were a consequence of fibres not being untangled by the combs and a twisted extended length of fibres being recorded as a single fibre.

Test values from the new instruments were assessed on a range of criteria including their:

- Relationship to values from the comb sorter array method and AFIS.
- Relationship to HVI length values and calculated ML and SFI values.
- Ability to reproduce fibre length distributions in terms of range and shape. This was tested by measuring samples from raw fibre processed through to final draw-frame passage sliver.
- Precision in terms of replicate variation.

- The ease and practicality of preparing and measuring fibre specimens using these instruments.

Statistical analyses were performed using Minitab 16 (2010) and MS Excel.



Figures 8(a) – Sliver specimen prepared for the OFDA 4000 comb bed. 8(b) – Raw fibre sample is prepared by manually stapling the fibre sample prior to insertion into the comb bed. The yellow fibreglass sheet pictured is clipped to the underside of the comb bed.

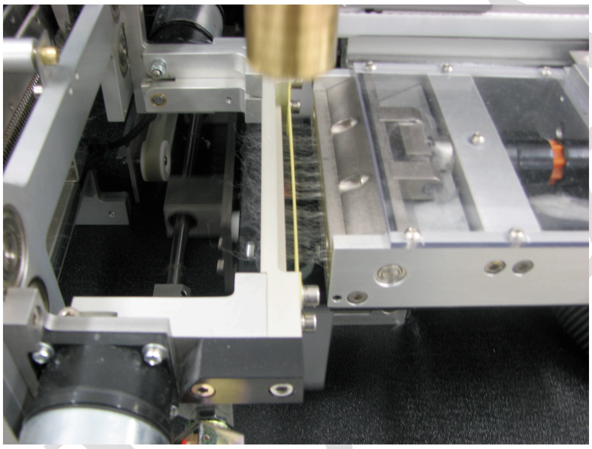


Figure 9 – OFDA 4000 jaws pull a fibre fringe from the comb bed across the camera fov, which analyses the fibre profile in length and diameter.

Results

Relationship with comb sorter and AFIS values

Tables IV to VII list (Pearson) correlation coefficients and probabilities for the relationships between OFDA 4000 and aQura2 values (see Table III), with Array and AFIS values. While Array values are affected by higher experimental error than AFIS or the other methods reviewed here the correlation values are surprisingly good and reveal the causal significance of the relationships. In reviewing the correlations we look for high levels of significance between like values, e.g. Array effL and aQura effL, and levels of significance for parameters that could be used to predict the less accessible SFC part of the length distribution, much in the same way as the USDA are researching the relationship between UHML and UNI with SFI.

The most significant correlations are highlighted in bold. The importance of these relationships is attached to both their statistical and contextual significance. For example, the relationship between OFDA 75%SL(n) and %<1cm values has a smaller, albeit still significant, R value than other relationships. However there is a good causal relationship between these parameters, i.e. both techniques capture the proportion of the distribution less than 1 cm.

Correlations highlighted in bold italics are those where statistical significance was expected, but the measured level was less than expected. For example, all SFC(n) values were generally poorly correlated with each other.

Highly correlated relationships between SFC parameters and readily measurable values, e.g. longer span lengths and mean lengths, were not evident by these methods, despite the wide range of length values in the cotton samples measured, e.g. UHML values varied in the set from 26 mm through to 37 mm. Indeed, this wide range of samples but with very different length distribution shapes illuminates the folly of using mean or upper mean values or ratios to predict SFC values of samples with unknown production and processing history.

Table IV – OFDA 4000 vs. Array Length Values (R, *p-value*) N = 14

		Array			
		maxL	**effL**	**SFC(n)**	**%< 1cm**
OFDA 4000	**ML**	**R= 0.836**	**0.875**	-0.245	-0.627
		***p*= 0.000**	**0.000**	0.399	0.016
	CVL(n)	0.168	0.104	-0.093	-0.081
		0.565	0.724	0.751	0.783
	H	0.850	0.885	-0.238	-0.631
		0.000	0.000	0.413	0.105
	CVH(n)	-0.542	-0.560	0.015	0.324
		0.045	0.037	0.959	0.259
	90%SL(n)	0.042	0.283	***-0.334***	***-0.321***
	SFC2(n)	0.886	0.327	***0.244***	***0.263***
	75%SL(n)	**0.785**	**0.875**	***-0.336***	**-0.673**
	SFC1(n)	**0.001**	**0.000**	***0.240***	**0.008**
	5%SL(n)	**0.862**	**0.903**	-0.257	-0.656
		0.000	**0.000**	0.374	0.011

Table V – aQura2 vs. Array Length Values (R, *p-value*) N = 14

		Array			
		maxL	**effL**	**SFC(n)**	**%< 1cm**
aQura2	**L(w)**	**R= 0.955**	**0.943**	-0.555	-0.655
		***p*= 0.000**	**0.000**	0.096	0.040
	5%SL(n)	**0.954**	**0.950**	-0.555	-0.663
		0.000	**0.000**	0.096	0.037
	effL	**0.962**	**0.951**	-0.561	**-0.675**
		0.000	**0.000**	0.091	**0.032**
	SFC(w)	-0.650	-0.646	***0.585***	***0.591***
		0.042	0.044	***0.072***	***0.072***
	SFC(n)	-0.437	-0.457	***0.509***	***0.473***
		0.206	0.184	***0.133***	***0.168***

Table VI – OFDA 4000 vs. AFIS PRO Length Values (R, *p-value*) N = 57

		AFIS PRO							
		ML(w)	**CVL(w)**	**ML(n)**	**CVL(n)**	**SFC(w)**	**SFC(n)**	**UQL(w)**	**5%SL(n)**
OFDA 4000	**ML**	**R= 0.733**	-0.263	**0.678**	-0.209	-0.542	-0.510	**0.758**	**0.764**
		***p*= 0.000**	0.046	**0.000**	0.115	0.000	0.000	**0.000**	**0.000**
	CVL	0.122	***0.472***	-0.014	***0.452***	0.191	0.216	0.268	0.314
		0.360	***0.000***	0.915	***0.000***	0.150	0.104	0.042	0.016
	H	**0.754**	-0.195	**0.676**	-0.134	-0.511	-0.472	**0.802**	**0.816**
		0.000	0.142	**0.000**	0.314	0.000	0.000	**0.000**	**0.000**
	CVH	-0.140	**0.559**	-0.245	**0.493**	0.363	0.369	-0.009	0.033
		0.295	**0.000**	0.063	**0.000**	0.005	0.004	0.947	0.808
	90%SL	0.051	-0.257	0.118	-0.284	***-0.192***	***-0.209***	-0.020	-0.044
		0.706	0.052	0.376	0.031	***0.149***	***0.116***	0.883	0.740
	75%SL	0.609	-0.531	0.634	-0.450	**-0.595**	**-0.581**	0.545	0.527
		0.000	0.000	0.000	0.000	**0.000**	**0.000**	0.000	0.000
	5%SL	0.704	-0.029	0.596	0.007	-0.407	-0.367	**0.790**	**0.814**
		0.000	0.827	0.000	0.957	0.002	0.005	**0.000**	**0.000**

Table VII – aQura2 vs. AFIS PRO Length Values (R, *p-value*) N = 17

		AFIS PRO							
		ML(w)	**CVL(w)**	**ML(n)**	**CVL(n)**	**SFC(w)**	**SFC(n)**	**UQL(w)**	**5%SL(n)**
aQura2	**L(w)**	**R= 0.786**	-0.001	***0.662***	0.054	-0.411	-0.366	**0.881**	**0.906**
		***p*= 0.000**	0.996	***0.004***	0.838	0.101	0.149	**0.000**	**0.000**
	5%SL	**0.784**	0.005	***0.659***	0.054	-0.410	-0.366	**0.878**	**0.905**
		0.000	0.984	***0.004***	0.836	0.102	0.149	**0.000**	**0.000**
	effL	**0.802**	-0.024	***0.682***	0.022	-0.445	-0.400	**0.890**	**0.912**
		0.000	0.927	***0.003***	0.935	0.074	0.111	**0.000**	**0.000**
	SFC(w)	-0.607	0.164	-0.587	0.260	***0.466***	**0.492**	-0.615	**-0.647**
		0.010	0.529	0.013	0.314	***0.060***	**0.045**	0.009	**0.005**
	SFC(n)	-0.408	0.012	-0.389	0.156	***0.284***	***0.326***	-0.427	-0.471
		0.104	0.964	0.123	0.549	***0.270***	***0.202***	0.087	0.057

Relationship with HVI and calculated ML and SFI values

Tables VIII and IX show correlations between the OFDA 4000 and aQura2, with standard HVI length values. The HVI mean length (ML) is calculated from UHML and UNI values by the simple conversion ML = (UNI x UHML)/100.

High correlations between SFI and all OFDA 4000 and aQura2 mean length and longer span length values reflect the derivation of the SFI from UHML and ML HVI values. In part the high correlations also reflect the fact that only raw fibre samples were measured by HVI. Therefore the confounding effect of distribution shape is mitigated in this sample set. The prevalence of high correlations between nearly all HVI and aQura2 parameters is interesting and may reflect the use of HVI length measures in the calibration of the aQura2.

Table VIII – OFDA 4000 vs. HVI Length Values (R, *p-value*) N = 14

		HVI			
		UHML	**ML**	**UNI**	**SFI**
OFDA 4000	**ML**	**R= 0.843** ***p*= 0.000**	**0.824** **0.001**	**0.649** **0.016**	**-0.717** **0.006**
	CVL(n)	0.241 0.427	0.241 0.428	0.211 0.490	-0.096 0.754
	H	**0.869** **0.000**	**0.847** **0.000**	**0.654** **0.015**	**-0.714** **0.006**
	CVH(n)	-0.415 0.159	-0.399 0.177	-0.299 0.321	0.429 0.144
	90%SL(n) SFC2(n)	0.245 0.420	0.222 0.465	0.079 0.797	-0.136 0.657
	75%SL(n) SFC1(n)	**0.836** **0.000**	**0.810** **0.001**	0.598 0.031	**-0.644** **0.018**
	5%SL(n)	**0.913** **0.000**	**0.891** **0.000**	**0.693** **0.009**	**-0.730** **0.005**

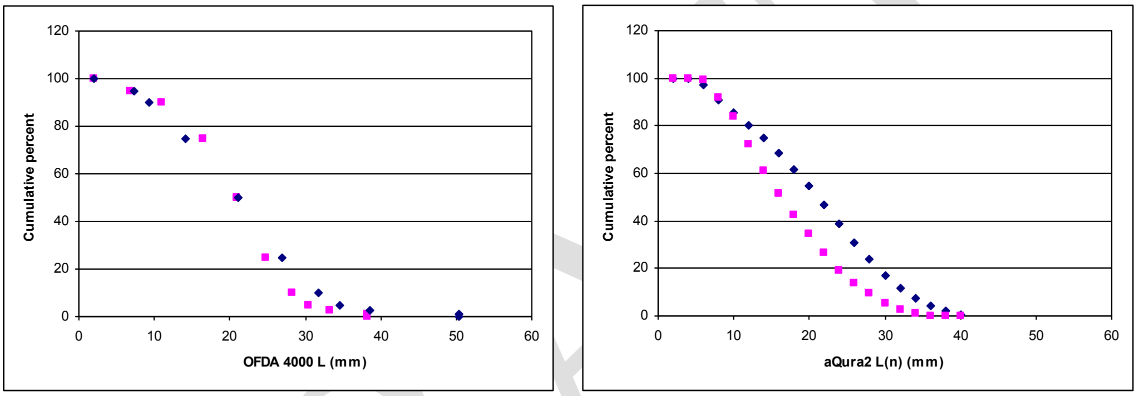
Table IX –aQura2 vs. HVI Length Values (R, *p-value*) N = 14

		HVI			
		UHML	**ML**	**UNI**	**SFI**
aQura2	**L(w)**	**R= 0.983** ***p*= 0.000**	**0.985** **0.000**	**0.871** **0.001**	**-0.865** **0.001**
	5%SL(n)	**0.986** **0.000**	**0.990** **0.000**	**0.880** **0.001**	**-0.872** **0.001**
	effL	**0.984** **0.000**	**0.991** **0.000**	**0.897** **0.000**	**-0.890** **0.000**
	SFC(w)	**-0.707** **0.022**	**-0.761** **0.011**	**-0.873** **0.001**	**0.883** **0.000**
	SFC(n)	-0.517 0.126	-0.578 0.080	**-0.731** **0.016**	**0.742** **0.014**

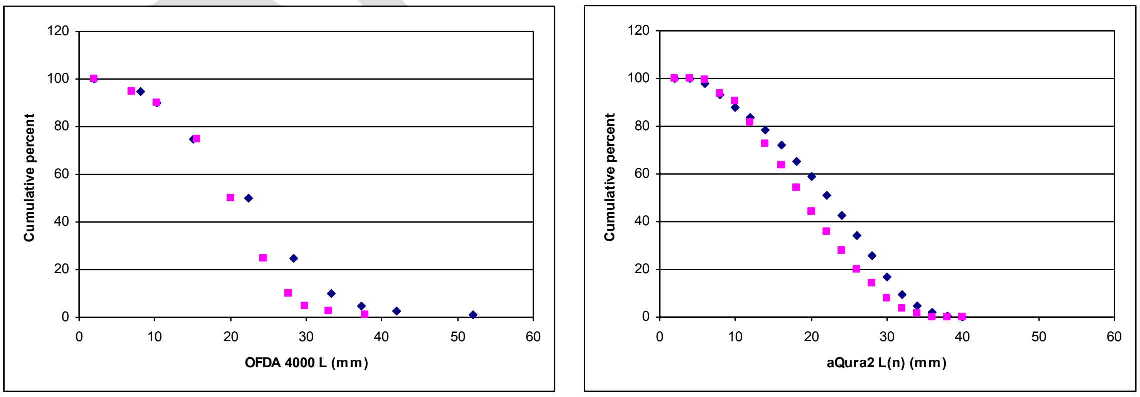
Fibre length distributions

The sensitivity of each instrument method to the fibre length distribution was reviewed by assessing the uniformity and shape of their length distributions, and by reviewing changes in their average values through processing (from raw fibre to 2nd passage draw-frame sliver).

Both the OFDA 4000 and aQura2 provide accumulated length distributions in electronic form, allowing their distributions to be graphed and compared. The HVI and AFIS[1] do not provide any electronic frequency distribution data, so direct assessment of their length distributions could not be made. Figures 10(a) & (b) and 11(a) & (b) show OFDA 4000 and aQura2 distributions of the same samples as raw cotton and then as first passage drawn sliver. Nominally equivalent measures of effL (aQura) and the 25%SL (OFDA) show similar average differences between raw fibre and 1st drawn sliver, however the OFDA distribution appears to show less sensitivity (more inconsistency) at short and at long staple lengths, the latter effect a consequence of entangled fibres not being separated properly by the combs when a fringe is taken for analysis by the OFDA jaws.



Figures 10(a) and (b) – SGG8000 raw fibre (pink) and as first passage draw frame sliver (blue) (a) by OFDA 4000 (UQL_{raw} = 24.8 mm, UQL_{slvr} = 27.4 mm) and (b) by the aQura2 ($effL_{raw}$ = 25.3 mm, $effL_{slvr}$ = 30 mm)



Figures 11(a) and (b) – RLL7300 raw fibre (pink) and as first passage draw frame sliver (blue) (a) by OFDA 4000 (UQL_{raw} = 24.3 mm, UQL_{slvr} = 28.4 mm) and (b) by the aQura2 ($effL_{raw}$ = 26.6 mm, $effL_{slvr}$ = 29.5 mm)

[1] The AFIS provides a print version of the frequency and accumulated length distributions; and only allows this to be printed for the average result of replicates at the time of testing. After the AFIS data has been saved the print version of the distribution is no longer available.

Figure 12(a) shows a graph of AFIS mean lengths of the seven cottons at each stage of processing through to 2nd draw-frame sliver. The graph shows the expected behaviour of fibre through mill processes (for carded yarn), i.e. a gradual decrease in average fibre length to carded sliver with a levelling or increase in length through to second draw-frame stage as fibres are stretched and aligned. The percent change in fibre length is dependent on fibre properties (the fibre's propensity to break) and the machine settings used to process the fibre; which remove and break fibres. The average pattern across all samples in Fig. 12(a) demonstrates the AFIS measurement is largely sensitive to the expected changes in fibre length during processing.

Figure 12(b) shows the change in OFDA 4000 L values on the same samples as a comparison. Evident here is the greater variability in the fibre length measured by the OFDA 4000. The lines in Fig 12(b) reflect the inability of the OFDA 4000 combs to hold and align fibre consistently (associated with pin density of combs and gauge length of jaws grabbing the fibre fringe), particularly when the sample is entangled (stages from raw fibre through to the DFK). Length values decrease rapidly at card (in accordance with theory - this is where fibre breakage is highest) but then length proceeds to increase through drawing; assumed at this point to be due to the long drawing action of the OFDA 4000 jaws, which excludes fibres extended from the comb but not gripped by the jaws at each draw.

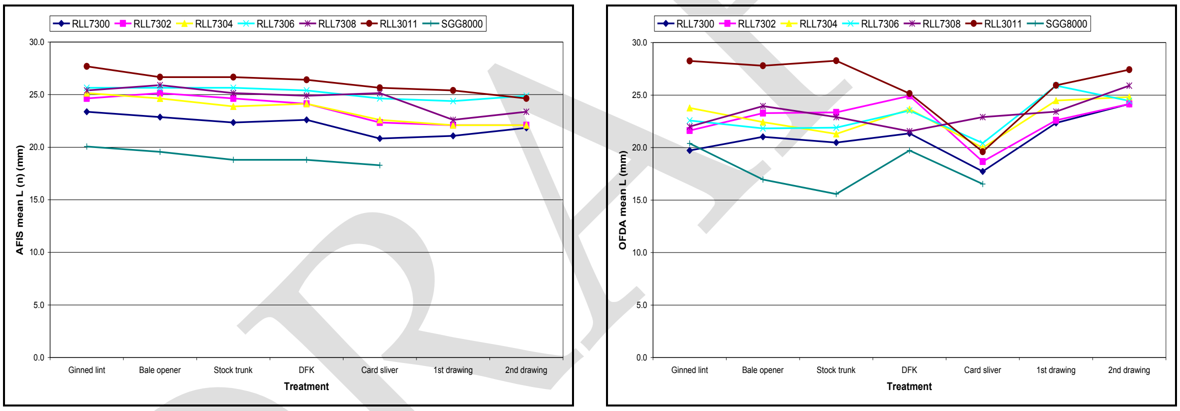


Figure 12(a) – AFIS L(n) values for samples of the seven cottons taken at each stage through to second passage sliver and (b) OFDA L values for samples of the seven cottons taken at each stage through to second passage sliver.

Precision
Precision was not properly assessed in this project due to limited access to some of the test instruments and limited amounts of the samples analysed in this project. The nominal reference tests in this study; the Array and AFIS were subject to a standard number of replicates as per their SOPs. Premier Evolvic was requested to test three replicates of the samples sent to them. This was done for the first set (tested in November 2009) but not the second set (tested in Feb 2010). Similarly, two replicates were requested for HVI analysis but only average results were delivered. For the AFIS, HVI and lately the aQura reasonable inter-lab variation is measured in the Bremen Round Tests, which are conducted three times per year. For HVI the more rigorous CSITC Round Tests and local Classing BMP Tests [25] provide a good picture of variation in HVI. It is noted the Auscott Classing Office HVI units are regularly ranked high in terms of trueness to the CSITC grand average.

Table X summarises the average variation (as the coefficient of variation (CV)) between replicates for SFC(n) or like values measured in this project. Except for the Array results all CV values represent the average variation between replicates for all the samples tested. The values in brackets represent the minimum and maximum CV values between replicates for samples tested in this project. Replicate tests were measured by the same operator on the same day. Array values include the error of two operators. HVI CV values come from the Knowlton cottons analysed in [14]. The actual specimen size measured by the HVI is much less than the 100 g sample presented to the instrument. The beard selected at testing (automatically or manually by the operator) weighs no more than 150 milligrams.

Similar to Knowlton in the assessment of SFI measurement in [14], the SFC results of samples with higher SFC/shorter mean lengths tended to be more variable between replicate measurements.

Table X – Coefficient of variation (CV) for replicate SFC values measured on same day by same operator

Test method	Replicate No.	Replicate size (g)	Replicate measured?	SFC CV_{rep} (raw fibre)
Array	4	0.06	Yes	37.6% (3.3% - 76.7%)
AFIS (PRO)	5	0.5	No[2]	12% (4% - 20%)
HVI	2	100	No	9% (7.5% - 12%)
aQura2	3	?	No	5.5% (2.6% - 9.3%)
OFDA 4000	4	0.5 – 1.0	No	14.4% (3.3% - 26%)

Ease of Use
All of the test methods except HVI are regarded as low volume tests, although the throughput of samples through each varies considerably. Table XI summarizes the requirements including time for each test. In terms of specimen preparation all of the alternate SFC test methods require operators to have reasonable experience; in the case of the Array method, operators must have proven experience and patience. The OFDA 4000 requires further modifications to make it useable for cotton. However, the practice of inserting fibre specimen into the combs is similar to that of the aQura2 and the time required to do this is similar to that of preparing specimens for the AFIS. The AFIS, aQura and OFDA test times

[2] All of the 0.5 g specimen is fed into the AFIS PRO fibre individualizer. However, not all fibres are measured by the light sensor through which the fibres travel.

are similar once the specimen is inserted. Array and OFDA 4000 specimens do not require pre-conditioning; the Array because it is not weight based and the OFDA because it normalises fibre number by direct measurement of fibre diameter while fibre length is measured.

Table XI – Time and pre-requisite conditions for use

Test method	Calibration	Pre-condition 24 hrs std. cond.	Preparation time/specimen	Test time/specimen	Operator experience
Array	ASTM Std.	No	5 mins	30-40 mins	High
AFIS (PRO)	Check cotton	Yes	2 mins	2 mins	Med
HVI	nil	Yes	automatic	30 secs	Med
aQura2	nil	Yes	?	?	Med
OFDA 4000	nil	No	3-5 mins	3-4 mins	High

Conclusion

The two new test methods reviewed in this project offer advantages over current SFC methods in terms of information about the fibre distribution and therefore the accuracy of their SFC measurements, and relative speed compared with current comb sorter array methods. The OFDA 4000 requires adpatations to the comb pin density, distance between combs jaw gauge length and drawing distance to make it suitable for shorter (cotton) fibres. There would be a question from the manufacturer of the OFDA 4000 on the benfit of making these changes without stronger calls for the SFC measurement from the merchant and spinning industry. The assessment of the aQura2 instrument was not as in-depth as that for the OFDA 4000 however the consistency of the results and their correlation with current standards (comb sorter, AFIS and HVI) mean that further investigation of this instrument is warranted.

It is recommended the Australian cotton industry obtain further information on SFC levels in Australian cotton using the AFIS, HVI and one of the new instruments reviewed in this study, nominally at this point the aQura2. Generating a database and historic baseline for the SFC of Australian fibre, and properly defining the inter-relationships between the SFC measurements from each test system, will provide information that will enable growers, ginners and merchants to better manage this property, which is often raised as an issue with Australian cotton by spinners [26, 27, 28].

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Appendix 1