Cotton quality assessment and classing in the 21st century

L. Hunter
CSIR, Division of Manufactory and Materials Technology, Port Elizabeth SOUTH AFRICA
Correspondence author lhunter@csir.co.za

ABSTRACT

The characteristics of cotton lint, in particular the cotton fiber properties and the type and amount of non-fibrous matter present, determine its processing conditions and behaviour as well as its application and performance in the end-product. The cotton lint characteristics therefore determine its textile performance and application, and ultimately its textile quality and value and ideally also its commercial value and price. It is therefore hardly surprising that considerable research and development efforts have been directed during the 20th Century to the development of test methods and instruments which can measure and class the relevant lint characteristics objectively, accurately, rapidly and cost effectively. These efforts have led to the successful development, commercialisation and worldwide adoption of advanced methods and instruments for testing and classifying cotton lint. This paper discusses the development and present status of the instrument testing and classification of cotton lint.

Introduction

The physical, chemical and related characteristics of cotton lint determine its textile performance and behaviour, in terms of processing waste and efficiency (including spinning breaks), and yarn (Figures 1 and 2) and fabric quality, and ultimately both conversion costs and product price and quality. For example, about 60, and even up to 70%, of yarn costs are due to the fiber costs (Figure 3). Being a natural product, cotton lint characteristics vary greatly, and often unpredictably according to environmental and genetic factors, as well as with picking and ginning conditions. Even on the same plant, the properties, notably length, cross sectional dimensions and maturity, of fibers on the same seed as well as from different seeds vary greatly. It is therefore not surprising that such great importance is attached to the accurate measurement of those lint characteristics known to affect textile quality and price (Table 1). Initially, the assessment of the lint characteristics was done subjectively, by cotton graders, with instrument measurement of certain properties, such as micronaire, color, length and strength, being added during the first half of the 20th century. It was, however, only with the commercial introduction of the HVI system in the late 1970's that it became possible, for the first time, to measure, on a commercially acceptable and routine basis, the lint characteristics of every bale of cotton produced. In parallel with the developments in the instrument measurement of cotton lint characteristics, considerable research was undertaken during the past century to quantitatively relate measured changes in cotton fiber properties to actual changes in processing performance, notably spinning end breakages, and yarn properties, strength in particular, with the ultimate objective of being able to predict in advance the textile processing behaviour and yarn quality from measured cotton characteristics. If this could be done, then cotton yarns and fabrics could be "engineered" and produced in the most cost effective manner.

This paper briefly reviews developments in cotton fiber testing and also touches on some anticipated future developments.

Developments in cotton fiber testing

The initial cotton fiber instrument measurement (laboratory) systems, developed during the first half of the 20th century (e.g. Pressley tester in the early 1940's and the Stelometer in the early 1950's), tended to be time consuming and to be fairly operator dependent, and it was increasingly realized that what was ultimately required were systems, preferably automatic or even on-line, whereby all fiber characteristics could be measured accurately, rapidly and cost effectively, with little operator involvement. Nevertheless, it took many decades before this goal was reached. A major step in this direction was the development in the 1960's and 1970's of the High Volume Instrument (HVI) system for testing cotton rapidly.

General

Today, fiber measurement is essentially evolving along three routes, namely semi-automatic or automatic High Volume Instrument (HVI) systems, Low Volume Instrument (LVI), also referred to as laboratory test instruments, and On-Line (e.g. at the cotton gin, card, etc.). For HVI systems, measurement is presently carried out on fiber bundles (composite samples) as opposed to single fibers, whereas LVI systems measure either bundle (e.g. Uster Fibrograph 730, Colorimeter 750, Micronaire 775 and Fibroglow 380) or single fiber (e.g. AFIS) samples. The ultimate aim is to independently measure once only, on an accurate, routine, rapid and cost-effective manner, all those cotton characteristics which determine processing route and performance, product quality, utilisation and application, and ultimately the commercial value and then to be able to quantitatively relate these properties to the subsequent textile processing performance, utilisation and quality, on a mill specific basis. The results so generated should accompany the bale until it reaches its final destination.

HVI testing

The development of laboratory fiber testing instruments during the first half of the 20th century laid the foundation for the development of high volume systems. The next tentative step occurred in the early 1960's when the instruments were put together in assembly-line fashion, with the real development of HVI's and a practical system for cost effectively measuring cotton quality on every bale, beginning in 1967. The HVI system, incorporating the measurement of length, length uniformity, strength and micronaire, and computer data storage, was "born" in West Texas in 1979, HVI Classing "going live" then. Video camera based trash measurement was developed in the late 1970's and added to HVI during the first half of the 1980's. Since 1993, the entire US cotton crop, including American Pima, has been HVI classified, Classer's Grade, however, still being done by the Classer. In 1992 Pakistan introduced its own Color Chart for HVI.

From its development in the late 1960's, commercial introduction in the late 1970's and used for cotton classing in the early 1980's, the HVI testing of cotton has made enormous strides and has become widely accepted globally, there now being some 1500 systems (Figure 4) in place in 70 countries. In fact, the invention and development of the HVI system can probably be regarded as one of the greatest cotton fiber related innovations of the 20th Century. Despite certain shortcomings, HVI remains the only, and best, method for the wide scale and cost-effective testing and classing of the 90 million bales of cotton produced worldwide. More than 95% of the present installations of HVI systems fall under the Zellweger Uster umbrella (viz Motion Control Inc., Spinlab and Zellweger Uster). Nevertheless, new systems for the high volume testing of cotton, such as by Premier Technologies (e.g. ART), Schaffner Technologies Inc. (IsoTester) and Lintronics (FQT FIBRO-LAB), are now appearing on the market. Certain of the newly developed systems can test for all the traditional HVI measured properties, plus neps, seed-coat neps, stickiness and maturity as well as additional color parameters (separately from those of trash and other contaminants), although in some cases, this is accompanied by a loss in testing speed.

In the early 1990's, Near Infra-Red (NIR) modules for measuring maturity and sugar content (the latter being discontinued soon afterwards) were added to a few HVI's. The separation of Classer's Grade into Color Grade and Leaf (Trash) Grade in 1993 also represented an important step forward, and the USDA has been studying the conversion of Rd (brightness) and +b (yellowness) to HVI Color Grades which more closely match the Universal Color Grade Standards, and the feasibility of using HVI color as the official color grade.

The latest automatic HVI systems enable virtually all the main fiber characteristics of a cotton sample to be measured in less than 30s, using only one operator. The success of this system is illustrated by its rapid worldwide adoption, the installed systems having the capacity to measure the entire global cotton crop of some 20 m tons (90 m bales). The latest HVI systems measure (or in some cases derives) a wide range of cotton lint characteristics, including fiber length and its distribution (including short fiber content), micronaire, maturity, trash, trash (leaf) grade, color, color grade, UV, moisture content strength and elongation (neps as an additional model). The accuracy of the HVI measurement of short fiber content, maturity and trash still need to be assessed by international round trials, while HVI measurement systems for stickiness and other contaminants are yet to be developed.

The above moves a long way towards the full complement of cotton lint characteristics of relevance to textile processing behavior, performance, value and utilization (Table 1). In fact it can safely be said that the lint characteristics being measured by HVI today account for the bulk of the variations in the textile processing behavior and yarn quality of cotton. Nevertheless, the accuracy and reproducibility of the HVI test results for some of the abovementioned properties have not as yet achieved the levels required by industry.

Another important development relates to the rapid individualized fiber measurement systems for cotton (e.g. electro-optical systems such as the AFIS), enabling properties such as length (including short fiber content), neps (fibrous as well as seed coat), trash, dust, fineness and maturity (also immature fiber content), and their respective distributions, to be measured, the number of AFIS systems in place worldwide now being some 650 (Figure 5). The advantage of such systems is that they supply more detailed information, even down to the individual fiber level, also covering properties presently not measured by the HVI systems. A module, based upon this principle, can be added to the HVI, allowing neps to be measured on a lesser number of bales compared to the HVI. The main drawback of these systems, in terms of the routine high volume testing of cotton, is their relative slowness, although high-speed systems are now making their appearance.

The application of NIR, and other parts of the electromagnetic spectrum, for the measurement of certain cotton properties (e.g. maturity and moisture content) also represents an important field of research. Such measurement systems, being contactless and nondestructive, lend themselves to on-line applications.

Recognizing the substantial effect of moisture content on cotton fiber properties, notably on strength, where a 1% change in moisture content can change strength by as much as 10%, it is important to note the development of rapid conditioning systems as well as the "in situ" measurement of the moisture content of the sample during HVI measurement.

A problem today could be the different generations (hardware and software) and makes of HVI systems in place worldwide and the reproducibility and agreement of the results they produce. Although the use of universal calibration procedures and materials (cotton, tiles, etc.) as well as participation in round trials (USDA and Bremen) provide some safeguards in this respect. Results of the various interlaboratory round trials (Table II) are reassuring but do not exclude the possibility that some HVI systems may be testing consistently "out of tolerance". One way to overcome this particular problem would be to introduce a "certification scheme" whereby only laboratories with test results falling within the preset tolerances are allowed to use the certification mark. Such certification schemes are already widely used and highly regarded for wool (Interwoollabs) and mohair (Mohairlabs).

Micronaire

The HVI micronaire values generally agree very well with those provided by the traditional laboratory instruments and also have a better interlaboratory reproducibility than the traditional laboratory instruments (Table 2). Recent developments include calibration by means of high and low mechanical air orifices, in place of calibration cottons, these being used together with a high uniformity high micronaire carded cotton to first of all ensure accurate chamber volume since the orifices are capable of only calibrating the air systems. Benchmark calibration cotton standards, however, still serve as the final reference and were used to establish the values for the master orifices which are then in turn used to establish the values for the calibration orifices. A three to five percent improvement in reproducibility has apparently been achieved. At the Universal Cotton Standards Conference in June 2002, it was resolved to create "Universal HVI Micronaire Calibration Cotton Standards", comprising one low micronaire and one high micronaire cotton. These standards will become effective and available on 1 July 2003.

Length and length uniformity

The HVI measurements of length (UHML) and length uniformity (LU), also termed uniformity index (UI), have a high interlaboratory reproducibility, the interlaboratory CV of both being a highly acceptable 2% or even less (Table 2) and generally lower than that of the traditional "stand alone" laboratory instruments. Furthermore, the agreement between the absolute values recorded by HVI and the traditional laboratory instruments is generally good.

Short fiber content

Two ways of deriving short fiber content (SFC) from HVI measurements are presently available, the one using an algorithm to derive a short fiber index from the fibrogram, the introduction of a cotton calibration routine improving the accuracy. The other is based upon a regression analysis (prediction), involving UHML and length uniformity, a cotton calibration routine having also been introduced. It remains to be proved, however, that either of these provide sufficiently accurate and reproducible measures of SFC for the diverse range of cottons available worldwide, particularly also considering the variability of short fiber levels within a bale of cotton. The system is being assessed using bales with high SFC relative to their length. Another issue revolves around the definition of SFC, most popular is the percentage fibers shorter than ½" (12.7 mm). Some favour a definition which is relative to the actual fiber length, since in practice SFC is closely related to the fiber length, shorter cottons obviously containing a greater percentage of fibers shorter than 12.7 mm. The question has also been posed as to whether fibers shorter than 4mm should not be classified as fiber fragments and excluded from the short fiber values. A new image based system (IsoTester) can reportedly provide a true measure of short fiber content and the fiber length distribution.

Strength

Strength was one of the properties measured by the first HVI system but virtually from the outset, there were differences between the HVI strength values and those of the traditional laboratory instruments, such as Stelometer and Pressley. This has been complicated by the fact that two different sets of calibration cotton, namely HVI-CCS and ICCS, respectively, have been used to calibrate the HVI for strength, the former leading to values approximating those of the Pressley instrument and the latter (i.e. ICCS) approximating those of the Stelometer. This has led to considerable confusion as it is often not stated which calibration cottons, and therefore strength levels, are applicable. Furthermore, because of a number of differences between the HVI test and the Pressley/Stelometer test, such as tapered vs parallel beard, speed of test, sampling and preparation of specimen, determination of specimen mass etc., it is highly unlikely that there will be an "equivalence" between the HVI values and those of the lab instruments. It was strongly advocated by the ITMF that the HVI-CCS be used exclusively so as to lead to one level for strength.

Elongation

The accurate and reproducible measurement of elongation remains a problem. Nevertheless, the redesign of the strength measuring device minimizes mechanical deflections, thereby reducing related errors in elongation measurement. This together with the use of calibration cottons for elongation, could lead to the more accurate and reproducible measurement of elongation in future.

Color

Virtually since its inception, HVI has provided instrument (Colorimeter color filter method) measures of color, in the form of +b and Rd, and few fundamental changes in the original technology have occurred since then. It is widely recognized, however, that additional color related measures are required (e.g. redness - greenness and color variability) to properly and accurately describe the color characteristics of cotton lint. In this context there would be benefit in moving towards CIELAB color co-ordinates (L*, a* and b*), using a full visible range spectrophotometer and digital image analysis. Furthermore, the color values obtained should be those of the cotton fiber, independent of the color of trash or any other contaminants.

The issue of HVI Color Grades is a different one as this attempts to convert the objectively measured HVI values of Rd and +b into the traditional Color Grades. In 1998 the USDA HVI Color Conversion Chart was adjusted to more closely match the Classer Color Grades. The 2000/2001 cotton classing season in the USA was the first to officially utilise HVI Color Grades for Upland color classification, and reportedly performs very well. At this stage the Upland cotton Classer's role was reduced to classifying leaf and extraneous matter only (i.e. Trash and Leaf Grades), the Classer's Color Grade being eliminated. From 1 July 2001 separate classification of Color and Leaf Grade for American Pima came into effect.

Because the USDA Color Grades and Charts are not always suitable for cottons produced in other countries, there have been attempts to develop country specific HVI Color Grades and Charts, particularly color grading charts, software for this purpose having being supplied to collect color information and to generate color charts. Pakistan has progressed the furthest in this respect, introducing their own HVI Color Grade Charts in 1992. Nevertheless, if done properly, such can exercise could require a prohibitively large study and data base as well as considerable effort to maintain.

Trash

Although trash measurement, in the form of the number and percentage area of trash, has been available on HVI's for many years, it is one of the areas where further improvement is required, particularly in terms of the nature or type of trash and the ability to classify the trash accordingly (e.g. bark, grass, etc.). Ghorashi reported at the 2002 HVI Working Group meeting on the development of an algorithm for the HVI Trashmeter so that trash particles can be analyzed individually, particularly their size distribution, with a view to determining the impact of pepper trash (i.e. trash which falls between the categories of cotton leaf particles and dust) on spinning performance. Work continues on the development of systems (machine vision) which can differentiate between, and measure, different types of trash (e.g. leaf, bark and seed coat fragments) as well as on the utilization of CCD camera/imaging (spectral and color imaging analyses) and different color space co-ordinates (e.g. CIE) as well as Expert Systems and Neural Networks, for providing a more accurate and practically meaningful measure of cotton color and color distribution.

The development of HVI Leaf Grades for Classification is underway, an HVI Leaf Grade algorithm (using both percentage area and count) showing promise. Its performance will be assessed during 2003. The use of photographic HVI trash standards in place of the present cotton samples (standards) mounted under glass is also under investigation. Instrument determination of grass and bark by Uster and Schaffner Technologies is being evaluated by the USDA.

Maturity

Although various efforts have been made over the years, and continues to be made, to introduce an HVI measurement of maturity (e.g. NIR and derived) it appears that, for the diverse range of cottons produced worldwide, the best method at present still is the double compression air-flow test (e.g. SDL Micromat). Nevertheless, the latest HVI systems do provide a "derived measure or estimate" of maturity.

Stickiness

As in the case of maturity, considerable effort has been directed over a number of years towards the HVI measurement of stickiness, an NIR based measurement having been incorporated in HVI systems at one stage but then withdrawn thereafter (in 1995). On certain of the new generation high volume testing systems (e.g. Lintronic FQT Fibro-Lab), sticky spots on card rollers are measured directly. Nevertheless, an NIR based technique which can directly measure chemical compounds specific to honeydew could still hold potential. The most widely used methods today are still the "stand alone" laboratory testers, such as the CIRAD developed stickiness testers.

Calibration

Sampling, calibration and other test procedures need to, as far as possible, eliminate or at least minimise errors due to the following (Ghorashi: Bremen 2000):

- Cotton variability
- Instrument (hardware and software) variability
- Calibration cottons
- Operator
- Atmospheric and cotton conditioning

The USA represents a good benchmark as to what is possible, where the reproducibility of their some 12 laboratories, involving about 235 HVI systems can be summarised as follows:

Micronaire	:	± 0.1 unit
Strength	:	1,5 g/tex
Length	:	0.5 mm

A report was presented at the 2002 HVI Working

Group meeting on a reference strength measurement developed by the Bremen Fiber Institute which provides an independently controlled system for calibrating HVI systems for strength thereby preventing any possibilities of drift in HVI strength levels with time. Work by the USDA and other laboratories on a Universal Reference Strength Tester appears to have come to a halt.

It is essential that calibration procedures and material (cotton, tiles, etc.) are consistent in their values and produce one universal level for each of the properties tested. In terms of the consistency of values, the ideal would be to move away from cotton as a calibration material, whether it be in lint, carded or any other form, since the natural variability inherent in cotton will always introduce problems in terms of calibration specimen variability and the associated errors in calibration level. Considerable progress has already been made in this respect for example in the use of calibration tiles for color and trash and now recently mechanical orifices for micronaire. Unfortunately, however, it is as yet not possible to do away with the cotton calibration samples entirely since there are certain HVI functions and environmental parameters which still require the use of cotton to correct for any of their variations. It is imperative, however, that clever ways be found to circumvent such obstacles and to have a complete HVI calibration and checking system independent of cotton calibration samples. With respect to the question of one universal calibration level for each of the important cotton fiber properties, this is particularly relevant for strength where the use of HVI-CCS and ICCS, respectively, leads to two strength levels (the former approximating Pressley 1/8" gauge and the latter Stelometer 1/8" gauge) with the associated confusion. Decisions taken at the 1998 ICCS Committee meeting in Memphis, particularly around the continued supply in future of only one ICCS calibration cotton ("C" standard) with a length value (in addition to Stelometer strength and elongation and micronaire values), represent an important step towards one HVI calibration level for strength and the elimination of the dual, and confusing, strength levels. In contrast to this, moves by organisations in other countries, to again produce ICCS-type calibration cottons could represent a retrogressive step, unless the normal or calibration values are pitched at the HVI-CCS levels, rather than at the original ICCS levels, or else both values must be given but the latter would still lead to ambiguity and confusion. Nevertheless, there are encouraging signs that the world is moving towards the adoption of one set of calibration samples (HVI-CCS).

Moisture content

The addition on modern HVI systems of moisture content measurement of the cotton sample, for example a resistance based measurement at the same time as the color is measured, represents a useful development which enables "out of condition" test results to be flagged and, if necessary either discarded or corrected to a standard moisture content (e.g. 8%), a 1.5% change in cotton moisture content causing an approximate 2 gf/tex change in strength. With respect to the latter, correction can only be approximate as cottons can differ in their actual equilibrium moisture content under the standard atmospheric conditions of 65% RH and 21°C as well as in the magnitude of the changes in their properties, notably strength, with changes in moisture content. Nevertheless, the above should lead to an improvement in HVI results, notably strength, provided any results obtained on cotton samples with moisture content outside the acceptable tolerances, for example 6.75 to 8.25%, are discarded. The introduction of Rapid Conditioning, which reduces the time to condition from some 48 hours to some 15 minutes, also represents an important step forward.

Automatic HVI based classing

HVI classing of cotton was started in Lamesa (Texas) by the USDA in 1980 and since the early 1990's the entire US cotton crop, both Upland and Pima, has been classified by HVI, the Classer initially only providing the Color and Trash related Grades, where-as the Classer today only provides information on Leaf and Trash and extraneous matter.

Zellweger Uster (now Uster Technologies) and USDA are working together in the development of an HVI based automatic classing system (ACS). When the samples arrive at the classing station they are first examined by the manual classers to determine Leaf Grade and extraneous matter. Once the Classer has examined the sample he or she places it into the compartments of a loading machine after which the cotton is not touched again by human hands. The samples are loaded into cassettes and conveyed automatically to the testing stations where specimens are prepared and tested automatically. This system, which is capable of distinguishing between leaf and extraneous matter, has been under evaluation since November 2000. Some actual classification samples were run during 2002 and improvements introduced for assessment during 2003. Dr Shofner (Bremen 2000) has predicted that by 2020 there will no longer be any manual classing methods and that it would take place at the gins.

Future developments

The next millennium will witness further development and a steady growth in HVI systems, with the next generation of HVI systems providing accurate measures of all the important fiber length and tensile properties, color (possibly using a CCD camera/imaging colorimeter and different color space co-ordinates), trash level and type (including seed-coat fragments), stickiness, micronaire, maturity and fineness, dyeability and "shiny neps", and will utilize different wavelengths of the electromagnetic spectrum to measure certain properties, notably those relating to color (even "light spots"), dyeability, stickiness, fineness/maturity and "shiny neps". In the not too distant future, the accurate HVI Classification of cotton lint, without any human intervention, will be a fact. Much of this could take place at the gin and incorporate gin monitoring and control (e.g. IntelliGin and GinWizard).

Concluding remarks

The past has witnessed the move from an entirely manual or subjective assessment of natural fibers to the objective assessment of the most important natural fiber properties. The challenge of this century will be to extend this process to cover all those fiber characteristics of importance to textile processing performance, value and utilization, with central computer capturing, analysis and summary of all results. An even greater challenge for this century is establishing accurate and robust predictive relationships, which are universally applicable, between the measured fiber characteristics on the one hand and their textile and end-use behavior and performance on the other hand. Various knowledge based "expert" (artificial intelligence) computer systems will undoubtedly feature strongly in this regard.

A further challenge for the new millennium is the non-destructive and on-line measurement of textile properties, with closed loop control of processing, the concept already operating with the IntelliGin system. Undoubtedly, these challenges will be met within the first quarter of this century.

Engineered fiber properties (breeding and growing), processing and yarn, fabric and end product manufacturing and properties will become a fact of life and so too the automatic "in-process" (initially off-line, but ultimately "on-line") monitoring and closed loop control of fiber characteristics and processing conditions, from the farm through to end-product manufacturing, thereby optimizing every link in the value chain.

The world is rapidly moving towards a boundaryless "global village" and every effort should be made, also in the field of cotton testing and trading, to "speak one language and with one voice" and to eliminate any unnecessary ambiguity and confusion. This requires clearly defined and universally agreed upon test methods, test procedures, calibration procedures, calibration materials, calibration levels and units and atmospheric conditions. Preferably, the calibration materials and methods used should have little, if any inherent variability, be consistent over time and free of human error. The ITMF HVI User Guide (2001) and the USDA "Guidelines for HVI Testing" (www.ams.usda.gov/cotton) go a long way towards achieving some of these objectives.

What is further required, are tests and values which are based upon sound scientific principles and which accurately describe and quantify all the relevant cotton characteristics, taking into consideration the diversity of cottons from various parts of the world. What is essential is that a specific test measurement and value should be scientifically correct, accurate, reproducible, consistent, etc. after which it is up to any user of the information to utilize, interpret and transform such values so as to suit their particular requirements.

Table 1. Cotton lint quality characteristics which ideally should be measured and those presently measured by HVI and AFIS systems.

Lint characteristics			HVI	AFIS
Very important				
1.	Length and length uniformity		*	*
1.	Short fiber content		+	*
2.	Strength		*	0
3.	Non-lint content, subdivided as follows:			
	(I)	Average trash (level and size)	*	*
	(II)	Trash particle size distribution	0	*
	(III)	Trash type and colour	0	0
	(IV)	Dust: level and size	0	*
	(V)	Seed coat fragments	0	*
	(VI)	Foreign matter and contaminants (eg plastics)	0	0
	(VII)	Wax	0	0
	(VIII)	Cleanability	0	0
5.	Micronaire / fineness		*	*
6.	Average maturity		+	*
7.	Single fiber maturity, fineness and distribution (including "dead" fibers)		0	*
Important				
8.	Color (+b, rd, cie color co-ordinates)		*	0
9.	Fiber only color & uniformity (spottedness, etc.)		0	0
10.	Dyeability (e.g. Uv reflectance)		0	0
11.	Neps (size and distribution)		+	*
12.	Elongation		*	0
13.	Stickiness (mainly honeydew)		0	0
14.	Entanglement (preparation)		0	0
Less important				
15.	Friction (probably largely related to surface wax)		0	0
16.	Elasticity, modulus and work-to-break (related to some of the abovementioned fiber properties)		+	0
17.	Bulk or crimp (related to convolutions and other properties)		0	0

* Can be measured

+ Can be measured but improvement and development still required

0 Cannot be measured

Table 2. Average interlaboratory variation for laboratory "stand alone" instruments and HVI systems (Bremen and USA Round trials).

TABLE II
AVERAGE INTERLABORATORY VARIATION FOR LABORATORY "STAND ALONE" INSTRUMENTS AND HVI SYSTEMS (BREMEN AND USDA ROUND TRIALS)

PROPERTIES		AVERAGE CV's (%)					
		1987 to 2002		1990 to 2002		1995 to 2002	
		BREMEN	USDA	BREMEN	USDA	BREMEN	USDA
MICRONAIRE	LAB.	3.3	3.7	3.3	3.7	3.6	4.0
	HVI	2.8	2.3	2.8	2.3	2.9	2.4
2.5% SPAN LENGTH / UPPER	LAB.	2.4	2.9	2.4	2.9	2.3	2.9
HALF MEAN LENGTH	HVI	2.1	1.5	2.1	1.5	2.1	1.6
UNIFORMITY RATIO	LAB.	3.7		3.7		3.7	
	HVI	4.0	4.0	4.1	4.1	3.9	5.1
UNIFORMITY INDEX	HVI	2.2	1.1	2.1	1.1	2.2	1.1
STRENGTH	LAB.	5.5	7.4	5.6	7.7	5.5	8.9
	HVI	5.9	5.0	6.2	5.0	6.4	5.3
ELONGATION	LAB.	9.1	13.4	9.2	13.3	8.6	12.9
	HVI	13.8	21.4	13.6	21.6	13.6	22.4
COLOUR Rd	HVI	1.6	2.0	1.6	2.1	1.7	2.2
COLOUR +b	HVI	4.1	5.0	3.9	5.1	4.1	5.1
PERCENTAGE MATURITY	LAB.	8.1		8.4		8.7	
MATURITY RATIO	LAB.	8.6		8.9		9.3	
FINENESS	LAB.	8.0		8.2		8.4	

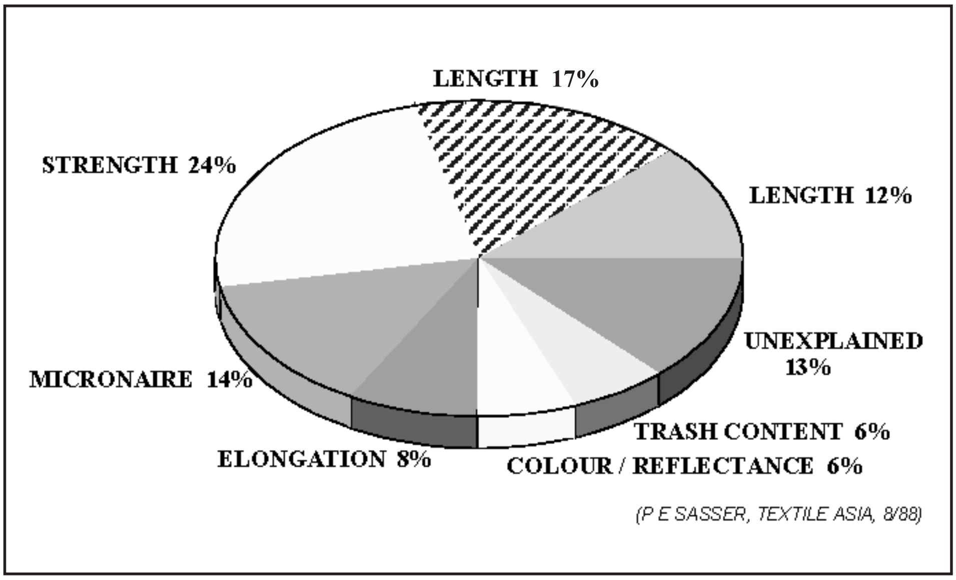

Figure 1. The effect of cotton fiber properties on rotor-spun yarn strength.

Figure 2. The effect of cotton fiber properties on ring-spun yarn strength.

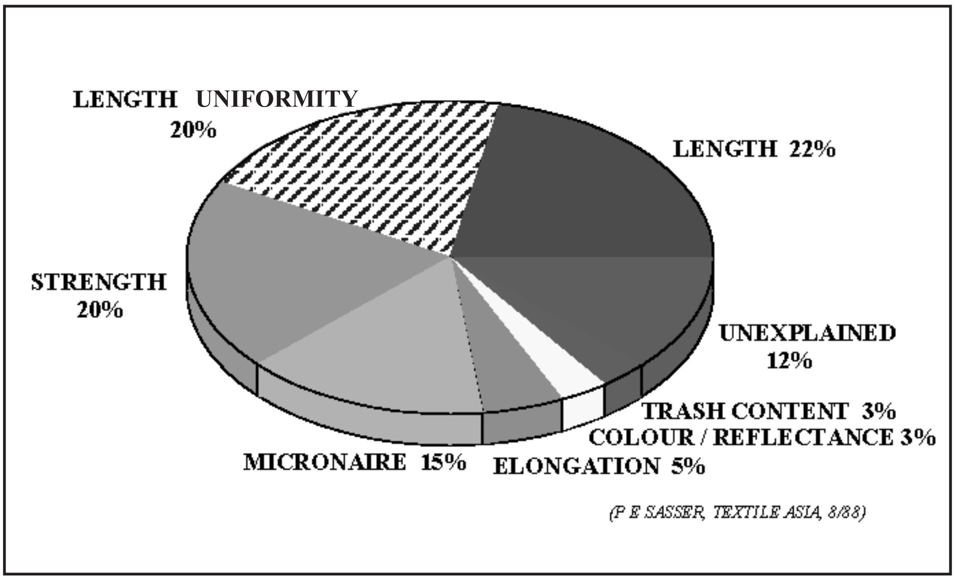

Figure 3. Example of cotton yarn cost components.

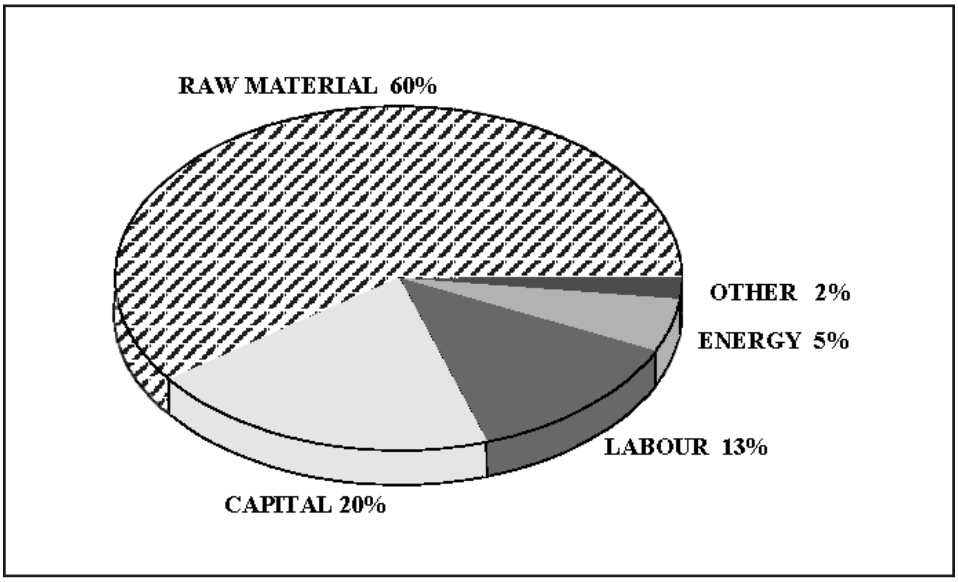

Figure 4. HVI systems in place world-wide.

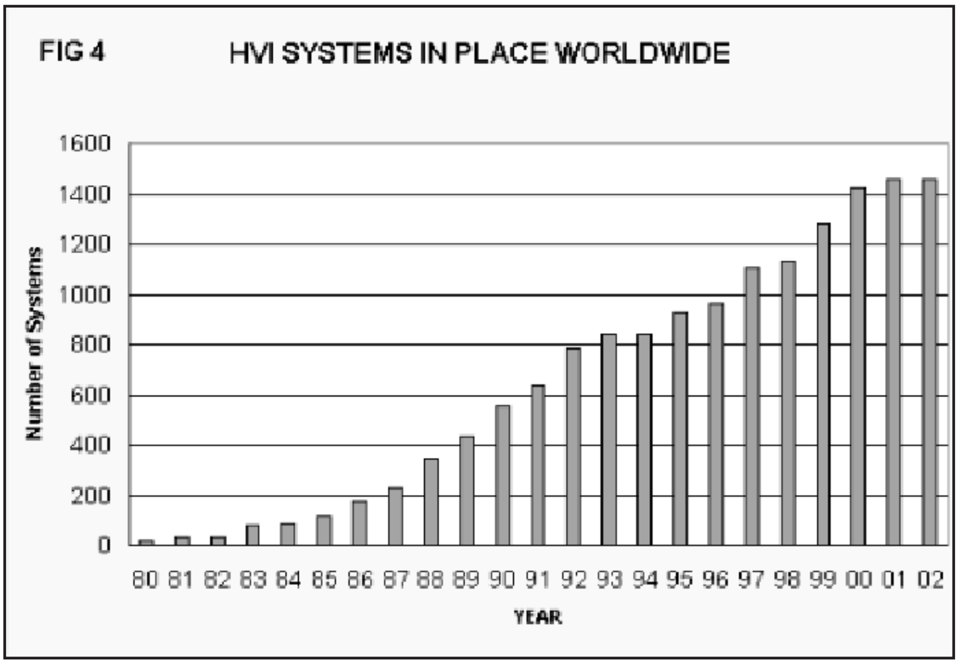

Figure 5.
APHIS systems in place world-wide.