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Contents

Introduction

Whitefly and aphids are harmful to cotton, not only because they affect growth and fruit formation, but they also damage fiber quality. Stickiness is caused by many factors, but most common sources of stickiness are sugars secreted by whitefly and aphids. Both insects suck sap from leaves. The sap is rich in sugars but poor in amino acids, and amino acids are essential for normal insect growth. Thus, whitefly and aphids have to suck a large amount of sap to meet their amino acid requirements. Unfortunately, they can digest only a small quantity of the liquid. The residual solution is ejected in the form of a droplet of honeydew. Honeydew is rich in excess sugars and becomes a source of stickiness in cotton. The honeydew secreted by whitefly is rich in trehalulose (sugar), which is the main source of stickiness during spinning. The first article provides details on many aspects of stickiness, including testing methods, surveys of stickiness undertaken by the International Textiles Manufacturers Federation every two years, and the problem of dealing with sticky cotton at a mill.

The primary desire of cotton growers, researchers and everybody related to cotton production is to increase yields. The long-term trend shows that world yields increase, and then stagnate after few years. Breeders often attribute increases in yields to the accumulation of high-yielding genes in new varieties. But, researchers don't know how many high yielding genes exist, and they don't know how many genes can be added to varieties. Breeders continue to pile up these genes in their favorite varieties without knowing the highest target they can achieve. Some researchers believe that the process of increases in yields has slowed partly due to high emphasis on resistance characteristics in biotech varieties. Others believe that yields continue to increase without any diversion from development of biotech cotton. An understanding of the indeterminate nature of the cotton plant indicates that the cotton plant already has a huge potential for increased yields, and so far only a part of that potential has been utilized. Achievements thus far can be attributed to changes in the plant type grown, better agronomic management, and plant protection measures. The article discusses many more aspects of increases in yields and suggests non-traditional approaches to increase yields.

Micronaire is commonly used to express maturity and fineness of cotton. Lower micronaire usually means finer cotton. However, a lower micronaire value can also be due to immature and weak fibers. On the contrary, high micronaire value could mean coarse cotton, but that could also be due to highly mature and strong cotton. Thus, the micronaire value is not always a true reflection of fiber maturity and fineness. However, the central problem in managing fiber fineness and maturity is the absence of a convenient and accurate test method to assess these properties. CSIRO Textile and Fibre Technology, Australia, in conjunction with the Faserinstitut Bremen, Germany, undertook a survey of the current practices regarding fiber maturity and fineness measurement in 2004. The survey found that more than 80% of spinners and 60% of merchants measured maturity and fineness routinely. However, 95% of 56 laboratories that participated in the survey measured micronaire, either using a stand-alone instrument or integrated within a HVI, to assess fiber maturity and/or fineness. CSIRO, Australia is developing two technologies for measuring fiber maturity (SiroMat) and fineness (Cottonscan) quickly, directly and accurately. The technologies have reached a prototype stage and have the potential to be commercialized.

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The Stickiness Problem in Cotton

Stickiness due to insects was not a problem until the early 1980s', what stickiness did exist was due to plant sugars. However, in the last 25 years, stickiness has become a significant problem affecting all cotton-producing areas. The problem is linked to the widespread occurrence of whitefly and aphids, and while there are many factors to be considered, extensive use of insecticides has played the single most important role in increasing the impact of whitefly.

Stickiness is often detected only at the moment of spinning and, while other contaminants may be eliminated or significantly reduced prior to and during spinning -- albeit at a high cost -- stickiness cannot be eliminated, and honeydew on cotton can contaminate all the machines used in the transformation process from fiber to yarn, i.e. opening, carding, drawing, roving and spinning operations. Increasing the heat of drying towers when ginning honeydew-contaminated cotton can increase the ginning ratio, but the extra heating results in higher fiber breakage. Apart from the frequent stoppages required to clean machinery, honeydew deposits also cause irregularities in the card web, sliver and thread, and lead to the production of poor quality yarn. Consequently, price discounts are applied indiscriminately to all cotton originating from any area thought to be affected by stickiness.

Where Do the Sugars Come from?

Stickiness is caused by honeydew produced either by the cotton plant itself (physiological sugars) or by feeding insects (entomological sugars). Seed coat fragments and the oil released when seed coats are crushed, can also cause stickiness, but this is a rare and negligible source of contamination. Entomological sugars are by far the most common source of stickiness in cotton.

The physiological or natural sugars come from cellulose precursors, as well as from leaf and flower nectary secretions. Cellulose is one of the chief constituents of the cell wall in cotton and other field crops; in fact, cotton fiber is 91% cellulose. Cellulose is made of repeated units of monomer glucose and is therefore considered a polysaccharide. It is hard to avoid the impact of cellulose in plants, but nectary-related sugars can be reduced by planting nectariless varieties. These varieties have been commercialized in many countries, but their negative impact on beneficial insects has limited their use.

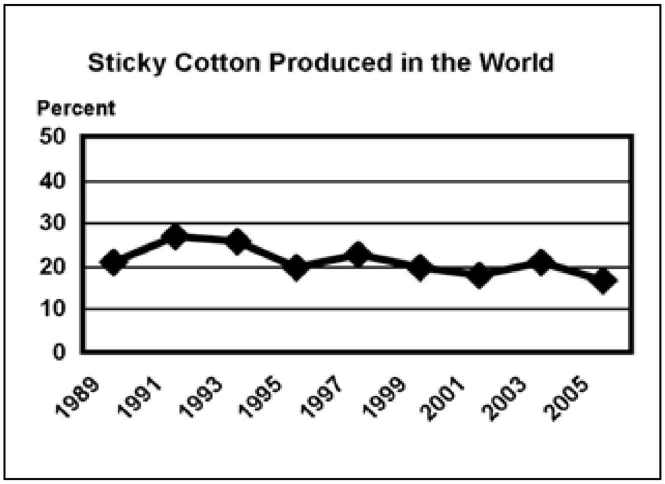
It is estimated that at least 80% of the stickiness problem is due to insect sugars commonly called honeydew. The three main honeydew-producing insects are sweet potato whitefly *Bemisia tabaci*, silver leaf whitefly *Bemisia argentifolii* and aphids *Aphis gossypii*. Aphids and whiteflies are sucking insects that suck sap from leaves. The sap is rich in sugars but poor in amino acids that are essential for insect growth. Thus, whitefly and aphids have to suck a large amount of sap to meet their amino acid requirements. The insects only digest a small portion of the sap and the residual solution is stored in their dilated rectum until it is excreted in the form of a droplet of honeydew. The honeydew released is rich in excess sugars and becomes a source of stickiness in cotton.

Not all sugars create stickiness. Plant sugars dissipate faster than entomological sugars and are not considered responsible for causing stickiness. The main entomological sugar responsible for most of the problems during spinning is trehalulose. This isomer of sucrose has a lower melting point and is able to absorb more moisture during storage. Melezitose, another sucrose isomer, accounts for 38% of honeydew from aphids, while trehalulose accounts for only 1%. However, trehalulose makes up almost 44% of whitefly honeydew (Hequet, *et al*., 2001). This is why stickiness is more related to whitefly than to aphids.

ITMF Survey on Stickiness

Stickiness is a problem in many countries, but none of them publish estimates of their levels of stickiness. Such information comes only from the International Textile Manufacturers Federation (ITMF). In 1982 the Federation decided to undertake surveys of the level of contamination of cotton around the world. The ITMF published the first contamination report in 1983, but it did not include stickiness. Cotton contamination, including large and small trash materials made of cotton, is commonly referred to as visible foreign matter and is usually added to seedcotton or lint during and after picking. Most stickiness is caused by insects secretions before picking, but stickiness is still considered to be a form of contamination. Hence, in 1988, the ITMF decided to include stickiness in its contamination survey and, the first report that included stickiness was published by the ITMF in 1989. Stickiness has been a part of every ITMF contamination survey since. The surveys are undertaken every two years, and a report is published every odd year.

In the ITMF survey respondents were asked if they had experienced stickiness in the cotton they processed in the preceding 12 months, and their answers in 1989 indicated that 21% of the cotton they processed had stickiness. It was not possible to estimate the level of stickiness, as no efficient means of assessing stickiness were available. Thus the survey only indicated the presence or absence of the problem but not the degree of stickiness or the extent of the problem at the mill. The 1991 survey showed that 27% of the cotton spun by respondents had stickiness. The data in the chart below show that stickiness is declining, as only 17% of cotton was found to be sticky in the report published in 2005. The main reason for the decline in the problem is the efficient control of whitefly and aphids.



The number of countries where whitefly is a problem for cotton increased over the last two decades. Whitefly, as a pest of cotton, has been introduced into new countries, the most prominent among them being Australia and Uzbekistan. However, the behavior of whitefly is now better understood, which helps to control the pest. Researchers have not relied exclusively on insecticide control; many integrated pest management options have been adopted and have helped to contain the pest. Whitefly and aphids have not been eliminated as a pest on cotton in any country.

The ITMF survey is not a statistically reliable procedure for determining the percentage of sticky cotton produced in the world, but it is the only source of such information we have. The survey has consistently shown that Sudan, Cameroon and Chad are among the countries producing the most cotton that is sticky in the world, but many other countries, like Burkina Faso, Mexico, India, Pakistan and USA, have also been found to produce sticky cotton, although not every year.

Dealing With the Stickiness Problem in Sudan

The ITMF reports from 1989 to 2003 showed that Sudan was consistently on the top of the list of sticky cotton producing countries. However, in the 2005 ITMF report, the problem of stickiness in cotton produced by Sudan was greatly reduced. No doubt, Sudan continued to produce sticky cotton, but not all the cotton it produced had the stickiness problem. Moreover, a part of the sticky cotton produced in Sudan could still be spun without significant problems. But Sudan was saddled with the reputation of being a sticky cotton producing country and was punished in the international market: stickiness discounts were applied to all cotton produced in Sudan. The country suffered heavy losses because almost all cotton produced there is exported.

However, Sudan is now better able to measure stickiness and isolate heavily affected bales. This is allowing Sudan to market its cotton more efficiently. With financial assistance from the Common Fund for Commodities, the International Cotton Advisory Committee sponsored a project entitled Improvement of the Marketability of Cotton Produced in Zones Affected by Stickiness. CIRAD-CA of France was a partner in the project. It helped to test cotton for stickiness and conducted spinning trials in which it ran mixes of slightly sticky cotton and non-sticky cotton (ICAC, 2002). The French Textile and Apparel Institute also arranged large scale testing of sticky cotton bales at commercial mills. The project started in January 1997 and concluded at the end of June 2001. The three main objectives of the project were: 1) to create testing and evaluation methods to determine the degree of stickiness in cotton, 2) to identify a threshold for economical processing of sticky cotton, and 3) to evaluate the financial viability of processing sticky cotton.

The project tested thousands of samples year after year and concluded that there was significant variation in stickiness among bales within a single lot, meaning that separation for stickiness must be done on a bale-by-bale rather than lot-by-lot basis. The data showed that the level of stickiness (measured by the H2SD stickiness tester and taken as the average number of sticky points on a sheet of aluminum foil) could be 40 in one year and then drop to only 20 the next year. The project also found that commercial testing of cotton for stickiness could reduce litigation and concluded that a single classification threshold might lead to a maximum of 25% litigation risk for the borderline bales, but the project did not make any concrete recommendations on the number of sticky points that would eliminate the chances of litigation. The fundamental reasons for variations in stickiness are varietal differences. Some varieties are more sensitive to insect infestation, and some areas are more conducive to whitefly and aphid infestation than others.

Studies of the effect of stickiness on the spinning process and yarn quality show that the number of sticky points on the H2SD foil has a high correlation with spinning performance, and although the sticky points on the foil were of various sizes, size did not correlate with spinning performance. The roving frame is the most sensitive piece of spinning equipment to stickiness but fifty sticky points on a sheet of aluminum foil (measured by H2SD) almost stopped the spinning process at the card. Work done outside the Project show that as few as 15 points on the sheet of foil begin to affect spinning efficiency. Breakage incidence and machine efficiency also correlate positively with the presence of trehalulose, melezitose and sucrose.

The CFC/ICAC project (ICAC, 2002) also concluded that relative humidity played an important role in the spinning of sticky cotton. Cotton with 50 sticky points can be processed successfully by lowering the relative humidity in the spinning mill to 40%, instead of 57.5%±2.5%. Carding and drawing frame output were reduced by stickiness, but it had no effect on sliver quality. It was only from the roving frame onward that stickiness affected regularity. Ring spinning was found to produce more defects as a result of stickiness than rotor spinning, and ring spun yarn showed a significant increase in the number of thin places, even at lower levels of stickiness. With lower levels of relative humidity, ring spun yarn proved to have a higher number of thin places, and when the number of sticky points was more than 20, lowering the humidity worsened the problem.

Cotton that was only slightly sticky was still found to produce a higher number of neps in the yarn. A change in humidity from 40% to 45% and 55% did not lower the number of neps. In its analysis of the financial viability of testing every bale for stickiness, the CFC/ICAC project concluded that H2SD testing of two samples per bale would cost US$1.52/bale. The cost included operators, machine depreciation -- based on a five-year life of the machine – and all other costs.

Stickiness Testing Equipment

Some problems caused by stickiness in spinning may be avoided if the level of stickiness is known before starting the spinning operation. Many methods, both physical and chemical, are available to detect stickiness, but the problem remains that these tests still lack a uniform standard by which to determine the degree of stickiness. Hector and Hodkinson (1989) reviewed in detail the methods used to test stickiness. Some of the more popular and/or recent methods are discussed below.

Minicard

The Minicard is the earliest physical method developed to test for stickiness. The Minicard method measures the stickiness of the card web passing between two steel rollers of a miniature carding machine. A 10-gram sample of lint cotton is processed through rollers, and the degree of stickiness is subjectively measured as the amount of cotton that sticks to the rollers. The results correlate very well with the actual stickiness encountered during spinning. This is why the ITMF International Committee on Cotton Testing Methods has recognized the Minicard as the reference method for a long time. However, the method is slow and the rollers have to be cleaned after every test, so manufacturers have been holding out for faster, automated machines. As a result, no Minicard machines have been produced for a long time.

Sticky Cotton Thermodetector

CIRAD-CA developed its own device known as the Sticky Cotton Thermodetector. A sample of cotton is placed on aluminum foil on the bottom plate of a heating press and heated to 82.5ºC for 12 seconds. The honeydew droplets on the fibers melt and stick to the foil. The non-sticking cotton is removed and sticking points are manually counted. Of course, manual counting allows for greater variability in the data, but the Thermodetector is faster than the Minicard, and its results correlated well with the Minicard method. The Thermodetector was simpler, cost less to use and had the additional advantage of leaving a permanent record of the test results. Each test can be run in an average of six minutes. However, the process is still slower than industry standards, and the human factor can result in high data variability. The ITMF International Committee on Cotton Testing Methods has recognized the Sticky Cotton Thermodetector as a reference method for many years, and there are an estimated 150 Sticky Cotton Thermodetectors in operation around the world.

High-Speed Stickiness Detector (H2SD)

The manual Thermodetector was upgraded to the H2SD with the addition of image analysis to count sticky points. A sample of 3-3.5 gm of cotton is pressed for 30 seconds between a heated pressure plate at 54°C and an unheated pressure plate. The sticky points are counted and point size and distribution are determined by image-analysis using dedicated computer software. The plates are automatically cleaned between samples so that the H2SD is able to analyze a new sample every 35 seconds. The ITMF International Committee has not yet recognized the machine as a reference method, but by early 2006, there were six machines working in Egypt, France and the USA.

Shenkar Tester

Cotton testing equipment manufacturers have been striving to develop a testing method that is faster, less expensive and more accurate. The Shenkar Tester was developed in Israel, at a time when Israel had a severe whitefly problem. The machine is based on the principle that stickiness problems occur at the drafting mechanism of the draw frame. The tester consisted of 4-5 draft mechanisms on a draw frame. The raw cotton was recirculated at least 10 times through the tester ensuring that it was thoroughly opened and minimizing the chance of cotton with little stickiness escaping detection. The sample size was 3-5 times larger than that used in the Minicard, and each test took 2-3 minutes to complete. Shenkar tester results correlated poorly with the Minicard test, and it never spread to other countries.

Fiber Contamination Tester

Lintronics developed the Fiber Contamination Tester almost 10 years ago in Israel. Like the Sticky Cotton Thermodetector and the H2SD, the Fiber Contamination Tester also measures physical sticking points (at 65% RH). The instrument creates a thin web, which is passed through two drums/rollers. The sticking points are transferred under pressure to the drum where they are scanned by a laser beam that detects and records the number of sticky points. A set of cleaning brushes then removes the sticky spots from the drums when the counting is done. Because the cleaning, counting and recording are automated, samples may be processed as quickly as one every 45 seconds.

Stickiness Tester

The Stickiness Tester was developed by the USDA and patented in 1997 (Anthony, 2001), and the method is available for lab testing and on-line measurement during ginning. The lab version consists of a cabinet, an infrared-based moisture sensor, and a resistance based moisture sensor operated in conjunction with a compression platen. The infrared moisture sensor responds to the level of natural sugars, insect sugars and moisture in the sample, while the resistance sensor is only slightly affected by sugars. One moisture sensor measures the resistance of a sample and this result is used as a reference moisture level. The resistance sensor may include more electrodes for measuring resistance, pressure and temperature. The pressure sensor ensures that the sample is adequately compressed for accurate testing. A computer program is then used to determine stickiness by analyzing the variation between the reference and the sugar based moisture contents. According to Anthony (2001), the Stickiness Tester can predict stickiness correctly about 75% of the time and requires less than five seconds per sample.

Chemical Methods

Many more physical methods, including Elsner's heating method and the Rotor Ring test have been tried without much success. Chemical methods were tried because stickiness was originally caused by physiological sugars. In the beginning, the chemical methods were based on the assumption that stickiness was directly related to reducing sugars i.e. glucose and fructose. A value of greater than 0.3% sugars by weight was often accepted as a level that would create stickiness problems, although in Texas stickiness problems were expected at a sugar content of 0.6% (Hector and Hodkinson, 1989).

Sugars were extracted from cotton by washing and many methods were developed using the color reaction. Sugar solutions were also made to react with a standardized potassium ferricynanide solution and titrated with ceric sulphate using ferroin as an indicator (Perkins Method, Perkins, 1971). Other similar methods included the silver nitrate method, the Fehling-Massat test, Benedict's test, the Folin test and the Formazan method. The Bremen Honeydew Test focused on both reducing and non-reducing sugars. One test employed widely in the US textile industry measured the pH of the cotton surface. Acidic cotton turned yellowish, indicating that it had stickiness. The test was simple and quick but it did not meet the accuracy requirements of the industry. Ultimately, it was generally agreed that sugars, reducing or non-reducing, individually or as a whole, were not always related to the stickiness problem.

High Performance Liquid Chromatography

High Performance Liquid Chromatography (HPLC) identifies and measures both reducing and non-reducing sugars. The main sugars of insect honeydew (trehalulose from whiteflies and melezitose from aphids) and of plant origin (glucose, fructose & sucrose) are all readily identified by HPLC. The benefit of High Performance Liquid Chromatography analysis is the identification of sources of contamination (whitefly, aphid or plant), which may help determine specific mitigation measures. However, the test does not provide information on the distribution of sugar particles and the stickiness problem in the cotton tested.

Conclusions

There are only two recognized reference methods to test stickiness and both have limitations. Most of the other methods test for entomological sugars but none is capable of testing for stickiness related to crushed seed. In the present situation, different types of stickiness have to be identified by different methods. Stickiness may vary from year to year and equal levels of stickiness may not give rise to the same problems in spinning. The challenge thus is twofold: to develop an efficient, effective and automatic testing method, and to correlate the level of stickiness to the problems encountered during spinning.

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Understanding Increases in Yields in Cotton

Botanically, the cotton plant was a perennial tree that early growers and researchers domesticated and transformed into an annual crop. Transformation of a perennial into an annual may take place through a process of natural selection or through the actions of man, but the domestication of the cotton plant was most probably intentional, the result of conventional breeding and directed toward specific priorities. In many respects the transformation and domestication process is now complete, at least as far as the known cultivars are concerned, but we have no way of knowing how long it took to mold the original perennial tree to grow as an annual plant. We known from excavations in Mohenjodaro, now part of Pakistan and in Peru that cotton was used as far back as 3000 B.C. and 2500 B.C. respectively, but the findings do not indicate whether the cotton produced in those days came from annual plants or was harvested from perennials.

Many of the wild uncultivated species maintained by cotton research programs around the world are still perennial and almost no efforts are being made to convert them into annual plants, because their yields are uneconomical, they have poor fiber quality and probably also, because of their anticipated behavior after domestication. Furthermore, it may not be possible to annualize all the 39 species currently known to exist in the world. Many wild species carry useful genes that can be used in conventional breeding programs, and although there are some species-specific genetic barriers to such uses, annualization in itself cannot solve the problem.

The domestication process gave birth to formal conventional breeding of cotton that still goes on and will continue to go on as long as there is a demand for cotton. The history of conventional breeding may be divided into pre-Mendelian and post-Mendelian periods. The post-Mendelian period is characterized by a more scientific approach that has led to tremendous success in attaining target objectives. Conventional breeding based on the work of Gregor Mendel has produced a steady stream of improved varieties with increased yield and quality, inbuilt resistance to pests, short plant size, higher harvest index and many special characteristics for specific production conditions. However, the primary focus of all conventional breeding programs around the world has always been improvement in yield. These breeding programs have obviously succeeded in achieving higher yields, but the basis for claimed increases may be challenged.

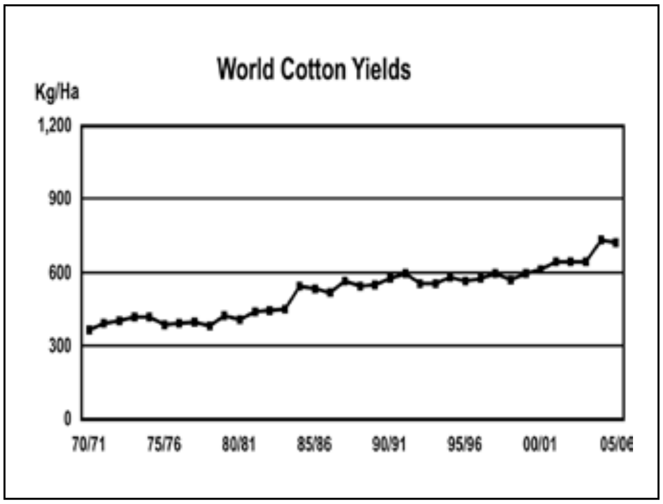
Yield increases are usually attributed to the accumulation of high yield genes in new varieties, but it is not known if there is a limit to the number of such genes that may be accumulated in one variety and it is not known if more high-yield genes are available to be added to the existing high-yield varieties. Until the answers to these questions are known, breeders will continue claiming piling up genes in their favorite varieties. It is like trying to identify colors in dark because they do not know how far they have already gone or how much is still to be done.

Meredith W.R. (1995) conducted trials on obsolete versus modern varieties in 1993 and 1994 and found that breeders in the USA were currently achieving less progress in yields than they had achieved in previous decades. He suspected that slower progress in yield improvement might be due to an increased emphasis on fiber quality or to a decrease in useful genetic variability and decreases in programs promoting genetic variability. Some of these conclusions are specific to US conditions but he also proposed that “useful genetic variability for some characteristics is limited” and suggested looking for other breeding approaches. Chaudhry, M.R., (1997) put the same thing in different words when he referred to the stagnation in yield increases in the world during the 1990s (1997). He claimed that the available genetic potential has been utilized under certain specific growing conditions. He added that the potential for higher yields is always present in the plant varieties grown in various countries but that the capacity of those varieties to expresses their full potential is limited by specific factors. These constraints currently limiting the plant’s capacity to express or surpass the prevailing yield levels must be identified and eliminated if further progress is to be achieved in yield improvement. Increases in yields will be proportional to our capacity to eliminate the current constraints and/or supply the enabling conditions plants need to reach optimum vegetative and reproductive growth.

Increases in World Cotton Yields

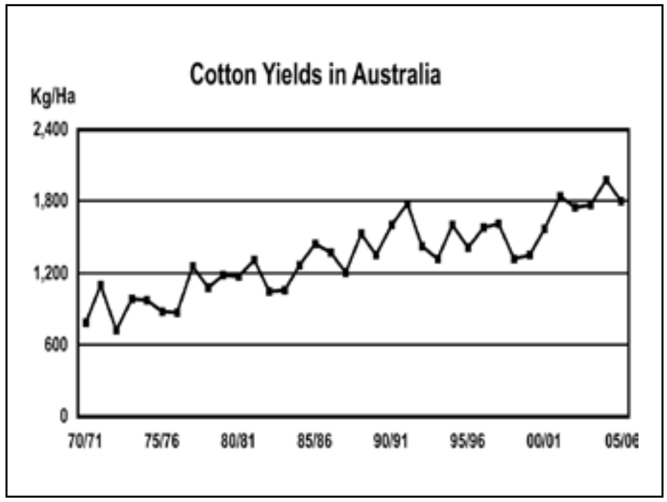
Cotton yields in the world almost doubled from 369 kg/ha in 1970/71 to 724 kg/ha in 2005/06. Data for 2005/06 is not final yet but the average increase in the last 35 years from 1970/71 to 2005/06 comes to almost 10 kg/ha per year or 2% per annum. There have been periods of slow growth or even no growth in world yields. The average world yield increased very little during the early 1970s and did not grow at all for eight consecutive years following the 1991/92 crop year. The record world yield was 748 kg/ha in 2004/05. The world yield has increased continuously since 1999/00, but the reasons for that increase are not known. There were no new technological breakthroughs that could account for the 25% increase in yield in six years (1999/00 to 2004/05). Good weather is always credited when there are no other reasons to explain higher yields.

There is no doubt that weather conditions have a significant impact on yields but the question remains, was there no good weather for eight consecutive years between 1991/92 and 2000/01 followed by invariably good weather every year since 2001/02. Biotech varieties may improve yields, though not always, but the total world area planted to biotech varieties had already increased to 16% by 2000/01. After that, yields increased in almost all cotton producing countries, but biotech cotton was grown on significant areas in only a few countries in 1999/2000. The use of biotech cotton is still not approved in Pakistan, and India had not yet adopted biotech cotton in 1999/00. Was there a flood of new high-yield varieties released in the late 1990s that boosted yields? No, there wasn't! And, conventional breeding programs are still the same as they were in the 1980s or even earlier. So, while many continue to make ambiguous claims that relate yield increases to good weather conditions, the simple truth is that the real reasons for the increases in world yields are not clear.



Cotton yields are the highest in Israel. But that country's total cotton area has declined to around only ten thousand hectares in 2005/06 and one might easily suppose that only the highest yielding areas have been retained in cotton production. The world's second highest yielding country is Australia, which has sometimes even surpassed Israel. On average, 400,000 to 500,000 hectares are planted to cotton every year in Australia, and most cotton is produced under assured irrigation. Rainwater is collected to irrigate cotton, thus the amount of rain received in winter has a significant impact on yields in Australia. This is also the main reason for Australia's year-to-year yield fluctuations. Cotton yields in Australia increased at a higher rate than the world average. Constable (2000) concluded that breeding high yielding varieties accounted for 45% of the Australian's yield increase. He also observed that improvements in soil-nutrition-irrigation management contributed 25%, better insect management 20% while better disease management practices contributed 10% to the increase in yields. However, no such an assessment is available for world yields, and as noted by Meredith (2006), it is difficult to attribute specific effects to specific technologies when they are all changing at the same time.

During the 1960s and 1970s, Australia did not have a strong breeding program and growers planted Deltapine varieties from the USA almost exclusively throughout the country. In the mid 1970s, however, the Australians drastically improved their variety development program by centralizing their breeding efforts at the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Narrabri, Queensland. By the early 1980s varieties developed by CSIRO researchers started to become available and by 1994 over 90% of the area was planted to CSIRO varieties. Deltapine and CSIRO used two different kinds of germplasm in their breeding programs, and the shift to CSIRO varieties did not affect yields in Australia.



Two Widely Diverging Views on Yield Increases

Dr. William R. Meredith, Jr. of the USDA, Mississippi, USA, is perhaps the best known cotton breeder worldwide. He presented a paper entitled Obsolete Conventional vs. Modern Transgenic Cultivars Performance Evaluations at the 2006 Beltwide Cotton Conferences and observed that modern varieties released since the adoption of biotech cotton in the USA do not have particularly higher yields than the obsolete varieties released in the twenty-two years prior to the adoption of biotech varieties (1974 to 1995).

Meredith (2006) selected 17 conventional varieties and 12 of the most recent biotech varieties and planted them at three locations in Mississippi in 2004 and two locations in 2005. The 12 biotech varieties included the five most popular varieties that accounted 76% of the area planted to cotton in the state. Irrigation was applied when needed and insecticides were vigorously used to protect the crop against insect pests and provide for a fair comparison between insect resistant transgenic and conventional varieties. The yield and fiber quality data average for three groups showed that the varieties developed from 1974 to 1995 were superior in yield over the group of varieties developed from 1936 to 1965. However, the yield performance of the most popular biotech varieties released from 1996 to 2003 was not better than the varieties released from 1974 to 1995. Boll weight decreased slightly after 1936, and fiber quality characteristics did not show any improvement.

Yield and Fiber Quality of Obsolete and Conventional Varieties

Year of Release	No. of Varieties	Average Yield (Kg/ha)	Boll Weight (g)	Seed Weight (mg)	Staple Length (mm)	Uniformity Index	Strength (g/tex)
1936 to 1965	8	1,224	5.2	10.1	29.1	83.9	29.8
1974 to 1995	9	1,481	5.1	10.1	29.4	84.2	29.8
1996 to 2003	12	1,483	4.9	10.0	29.1	84.1	29.9

It is known that biotech varieties have been developed using the backcross method. First a high yielding variety is developed and then the required Bt gene/genes are inducted through backcrossing. The backcross method is well known as an efficient breeding method for adding a single gene to an established variety. However, no yield increases are expected in the recurrent parent receiving the desired gene. If the gene being transferred to an existing variety has some deleterious effects, or even some favorable effects, as is the case with the Bt genes currently in use, adverse effects could be expected in the resultant genotype. Meredith (2006) observed that if back crossing into older varieties continues for the sake of expressing specific genes, one cannot expect an increase in yield and fiber quality above the performance of old varieties. Conventional breeders take eight to ten years to develop a new variety, and then it takes 4-5 years to convert that variety into a biotech variety. Meredith (2006) also concluded that if the regulatory life of a specific transgene is 13-15 years, there is very little time available for conventional breeders to produce a marketable commercial variety, and this will discourage breeders from using conventional breeding.

Backcrossing has become an integral part of breeding programs to develop biotech varieties. Backcrossing can only be avoided if both parents have the Bt gene, but that has not been the case so far, and besides, it would narrow the gene base of the breeding material used in hybridization. Moreover, all potential parents to be used in hybridization should be kept ready with the transgenes in them. The genetic base is already narrow enough in most breeding programs around the world, and backcrossing or using both parents with transgenes is a further strain on the deteriorating germplasm situation in the world.

Delta and Pine Land Company based in Scott, Mississippi is the largest cotton seed company in the USA. Data from the USDA show that 43% of the cotton area of the USA in 2005/06 was planted to varieties developed by the Delta and Pine Land Company. Deltapine varieties are grown in many other countries including Argentina, Australia, China (Mainland), Colombia, South Africa and Turkey. D&PL released 45 new varieties between 1981 and 2005. Kerby (2006) reviewed the yield performance of these varieties on the basis of the data from large plot on-farm tests, growers' fields, small scale testing by the Company and data from university variety trials. He divided varieties into four groups i.e. varieties developed from 1981-1988 (Group 1), 1989-1995 (Group 2), 1996-2000 (Group 3) and 2001-2005 (Group 4). He compared the data in two different ways and concluded that Group 2 (1989-1995) showed yield improvement averaging about 3.5 kg/ha/year over Group 1 (1981-1988). Group 3 (1996-2000) had high yields that averaged 3.7 kg/ha/year over Group 2. Group 4 (2001-2005) had yields that averaged 16.8 kg/ha/year increase over Group 3. With regard to fiber quality, Group 2 vs. Group 1 showed modest improvements in length, strength, and uniformity, but had a small increase in micronaire. Group 3 vs. Group 2 was the opposite showing modest declines in length and strength, no change in uniformity, but a small decline in micronaire. The most recent five years (Group 4 vs. Group 3) demonstrated an average increase of 0.1% (0.07 mm) staple length/yr, strength increased by 0.06 g/tex/yr, micronaire decreased by 0.01/yr, and uniformity improved by 0.015/yr.

Contrary to what Meredith (2006) found, Kerby (2006) concluded that over the last 25 years (from 1981-2005) significant progress has been made in both yield and fiber quality. Kerby also found that most of that progress has been made in the last five years. There are only two minor exceptions to the data presented by Meredith, 1) he was not able to include in his trials seven new varieties that were released in 2004 and 2005 and, 2) not all the 12 transgenic varieties included in the trials were Deltapine varieties. Neither one amounts to a major exception. The conclusions of both trials are widely divergent.

Where to Go from Here?

Independently of whether one agrees with one or the other, the fact remains that cotton yields have increased in the world. There were periods of slow or even no growth, but yields ultimately always picked up. The reasons might be different but some times they can be better explained by comparison with others. For instance, increases due to the use of organic fertilizers and synthetic insecticides are better understood and are more easily linked to their share in the yield increase. Yields have been increasing since 1999/00 and will soon reach another peak. It would be difficult to predict how long the coming slow growth period may last, but it might last longer than the most recent slump that lasted eight years. In the long run, yields will start to increase again because we have not realized the full genetic potential of cotton. No one knows what the upper limit of that genetic potential might be, but researchers have tried to determine the theoretical maximum yield or genetic potential, which is much higher than the recoverable potential. The recoverable potential can also be regarded as the yield achieved under certain growing conditions.

The theoretical maximum yield has been assessed by Baker and Hesketh (1969) for production conditions in the U.S. They developed two systems of equations based on photosynthesis and respiration data and applied them assuming that any photosynthate not photorespired is translocated to the fruit. One model suggested a maximum yield potential of 4,225 kg/ha. The second model based on the dry weight changes and accumulation of respiratory losses in a single boll predicted a maximum theoretical yield potential of 4,309 kg/ha lint, provided that all flowers mature as productive bolls. Others found that the second model is a more accurate estimate of theoretical yield because it accounts for the decrease in the respiration rate that comes about with advancing fruit maturity. The model is adaptable to other crops so it might also be applicable to other countries with different production conditions.

The theoretical estimate for 1969 was almost nine times higher than the yield achieved in 1969/70 in the USA. The actual average yield has almost doubled in the USA and more than tripled in China (Mainland) and India since, but that still leaves a large gap to be filled by various means. Some more recent work (Constable, 2006) also suggested a theoretical potential as high as 4,313 kg/ha lint in Australia. Constable (2006) used three approaches to estimate the theoretical yield 1) current knowledge of boll growth rate and duration of boll growth period, 2) measurement of radiation use efficiency (the amount of dry matter produced by the plant per unit of light intercepted) and, 3) a crop simulation model where effects of various stresses that limit crop growth were removed.

Boll weight, number of bolls formed and retained by the plant, number of bolls shed and number of buds and flowers shed are interdependent, e.g., if more bolls are shed there is a greater likelihood of forming more flower buds and flowers. Nevertheless, bolls per unit area and number of buds and flowers shed in the same area provide a more practical view of the theoretical yield potential. Some particular approaches other than conventional breeding, crop management and host plant resistance are discussed below.

Big Change in Plant Partitioning

The domestication process mentioned above has brought about tremendous changes other than improved yields. In fact, it is safe to say that that the greater yields have come as a consequence of major changes in plant structure. The most significant change in plant structure that has occurred is the proportion between the reproductive and vegetative forms. One of the most telling changes in the structure of the cotton plant was brought about by the formation of fruiting branches on the main stem early in the vegetative phase and initiation of bolls on the first positions on the branches. On varieties dating back about one hundred years, bolls made up only 17% of the dry biomass of the above-ground parts of the plant, whereas in present varieties the ratio has increased to 45% of the dry weight. Leaves accounted for 21% of the dry weight; that ratio is now down to 13%. The main stem and branches accounted for 62% of the above-ground weight a century ago; in the current varieties stem and branches average only 41% of the dry weight (Fernandez, 2005).

Approximately 40% of the dry biomass of the plant is carbon, which is obtained through the photosynthetic process that takes place in the leaves. The leaves receive solar radiation and the chloroplasts transform the solar energy into chemical energy that the plant uses to fix the carbon that enters the leaf in the form of carbon dioxide through stomata. When the stomata open, they loose water, thus raising the demand for water from the ground. The carbon fixed by photosynthesis is the primary substance supporting growth by way of two main dimensions: one is the formation of biomass; the other the provision of chemical energy for the metabolic processes.

Temperature is another key factor. The amount of energy required to maintain the metabolic machinery in operation is highly affected by temperature; conversely, biomass formation is less affected by temperature. To achieve a higher harvest index, the proper balance must be maintained between the foliage area and the fruit load. Less foliage, or a slower photosynthesis results in lower yields. On the other hand, the loss of fruit in the presence of a normal photosynthesis rate will lead to excessive vegetative growth. Early boll formation contributes to the efficient management of the cotton plant.

Non-Traditional Approaches for Yield Improvement

Conventional breeding seems to have run out of ideas to improve yields. Contributions from other yield improvement factors are always time-limited; yields increase but then stabilize at a given level. Thus, it becomes imperative to find and implement non-traditional approaches to yield improvement. Hake *et al.* (2004) have explored a number of non-traditional approaches, including: improved photosynthetic efficiency, carbohydrate metabolism, hormone manipulation, stress and disease tolerance, nitrogen metabolism, cell cycle regulation, signal transduction and morphological manipulation. The potential is there, but so far none of these approaches have become commercially available. Research is under way on some, and biotechnology may provide opportunities to explore these avenues. A few approaches are discussed here in slightly greater detail.

Convert Cotton from C3 to C4

Photosynthesis is the process by which green plants synthesize carbohydrates from Carbon dioxide. The plant absorbs Carbon dioxide (CO_2) from the air and in the presence of light and water forms the carbohydrates it needs to grow. Some plant species have the ability to utilize almost all the carbohydrates they form during photosynthesis and are called C4 plants. Fast growing plants belong to this category. Cotton is not able to utilize all the carbohydrates formed during photosynthesis and tends either to burn or release a part of its carbohydrates into the atmosphere in different forms. The process of burning and releasing carbohydrates into the atmosphere is called photorespiration. Plants in the C4 category either do not photorespire or release only a small proportion of photosynthetic carbon into the atmosphere. On the average, cotton photorespires about 30% of the photosynthetic rate, which makes the cotton plant grow more slowly. Photorespiration in real terms is a loss of Oxygen, Carbon dioxide and light for the plant during photosynthesis. An increase in sun light intensity, air temperature and Oxygen availability in the atmosphere affects the photorespiration rate. A short supply of Carbon dioxide in the atmosphere and a higher light intensity stimulate the photorespiration process.

C4 plants are able to utilize a large amount of their excess photosynthetic energy to trap and concentrate Carbon dioxide in the bundle sheath cells where carboxylation takes place under much higher Carbon dioxide levels. The cotton plant is sensitive to photo inhibition-photo destruction of the photosynthetic apparatus when photochemical energy cannot be released in an orderly manner. This inhibition appears to be mediated by the photorespiration process as it eliminates excess photosynthetic assimilates. Photorespiration in cotton is known to be catalyzed by the same enzyme that catalyzes the fixation of carbohydrates in the first position. Thus, avoiding photorespiration completely does not seem possible, but it can be decreased to increase productivity. Efforts have been made to reduce photorespiration and some of the approaches include carbon dioxide enrichment and use of methanol (ICAC, 1994).

Enhance Sink Strength

A plant may be very healthy, but it could still be utilizing most assimilates to produce more leaves. Sink strength is the ability of an organ, i.e. boll, to import assimilates for its use. The cotton plant can produce a higher yield if it is able to efficiently convert assimilates into lint and seed. Of course, plant health and fruit protection against insect pests is fundamental to sink strength. The literature shows that 15-35 day old bolls attract most assimilates from the closest leaves. It has also been observed that at 20-27 days of age, the bolls start to draw assimilates from distant leaves. This may be due to the fact that the leaves closer to the boll become older. Loss of fruiting organs is also related to the competition among bolls for assimilates. This also explains why the early-formed bolls have a higher chance to survive and contribute toward productivity. The harvest index has improved significantly in the short stature and short duration varieties but wasteful fruiting forms (buds, flowers and small bolls) continue to be formed throughout the plant's life and, more particularly, towards the end of the crop maturity or cut out stage. Researchers have yet to develop a variety with a harvest index closer to 100%. When this happens, either by increasing the sink strength of the bolls, by stopping the proliferation of wasteful fruiting forms or by any other means, we may witness a dramatic increase in yields.

Increase Photosynthetic Efficiency

Bolls compete for assimilates and consequently if they cannot import sufficient quantities of assimilates the plant sheds them. Young bolls that are in the vicinity of young leaves, close to the terminal or at the distal end of branches, are more liable to suffer from this competition and be shed. The developing cotton seed continues to draw assimilates from the plant until it enters its late maturity stage (over 40 days after anthesis & pollination). The Leaves get old and cannot continue to produce food for the plant and carry out their photosynthesis functions. While a conventional breeding approach cannot deal with this problem, biotechnology can.

Biotechnology has the potential to enhance the lifetime of leaves and keep them green and healthy longer than normal (enhance photosynthetic efficiency). It can increase yields by reducing sink strength competition among maturing bolls. So far, there is nothing like this on the market nor is it expected to become available any time in the near future, but researchers continue to search for the necessary methods. Photosynthetic energy has three uses: to maintain growth; to achieve more fruit survival to maturity, and; to produce excess growth. Thus, any genetically engineered high-photosynthetic-efficient varieties must be made to apply their additional photosynthetic energy to boll maturation and not for the plant to grow taller and bushier.

Oil Suppression to Enhance Yield

The US Patent and Trademark Office has granted a patent on a technique for enhancing fiber yield by changing the composition of oils in the cotton seed. A paper on the patent was presented at the 2006 Beltwide Cotton Conferences held in San Antonio, Texas, USA in January 2006, but the paper did not expected appear in the proceedings of the conferences.

The technique is based on the inhibition of oil synthesis in cotton seeds in order to reduce the energy-intensive incorporation of sucrose-derived carbon into stored oil so as to increase the supply of sucrose available for sustained fiber and vegetative plant growth.

To achieve this, researchers must produce a transgenic plant by regenerating a whole plant from a plant cell that has been transfected with DNA sequences comprising a gene capable of suppressing the biosynthesis of oil in the developing seed. Plants made according to these specifications exhibit increased production of fiber.

There is an application available on line (see reference below) that explains a method for obtaining a non-genetically modified cotton plant with reduced seed-oil content by selecting native alleles, or alleles produced through mutagenesis, reduce oil content with the resulting increase in fiber yield. The modified genotype can be used to develop commercially acceptable cultivars that contain the cottonseed-oil suppression trait.

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New Research and Development Work from Australia in Cotton Fineness and Maturity Assessment

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CSIRO Textile and Fibre Technology, Australia

The Australian Cotton Industry

The Australian cotton industry is one of the most modern and technically advanced agricultural industries in the world. Nearly all of Australia's cotton is exported to mills in Asia, with Indonesia, Thailand, South Korea, China, and Japan being the main destinations (http://www.austcottonshippers.com.au/). Whilst Australia produces only around 6% of the world's traded cotton, most of it is used by spinning mills for high quality fine count combed yarns and from this perspective Australia is a significant producer of world high-medium and fine cotton.

The cotton that Australia has grown over the last decade has earned a very good reputation amongst spinners for producing high quality yarns. The Commonwealth Scientific and Industrial Research Organization (CSIRO), the Australian Government research and development organization, recently conducted a survey of mills that use Australian cotton to obtain more accurate information on its quality. Results from the survey confirmed that further improvements in nep levels, short fiber content, and a move to micronaire values within the 'premium' range of 3.8 to 4.2 would be beneficial.

The Importance of Fiber Maturity and Fineness and Current Test Methods

The three fiber quality characteristics identified above relate directly or indirectly to a cotton variety's fiber maturity and fineness. From the spinners' perspective, both fiber maturity and fineness are key parameters with sometimes opposing effects on mill productivity and yarn quality. For example, yarn is specified in terms of its weight per unit length, and fiber fineness determines the number of fibers in a given yarn cross

Table I – Micronaire Values for Upland Cotton

Micronaire (µg/inch)	Comments	Discounts Applied, Points* per Pound (Adam 2005 and Australian Cotton Industry 2004-2005)
< 3.2	Significantly immature	400 to 1400 pts off
3.3 – 3.7	Immature	200 to 500 pts off
3.8 – 4.5	Fine and mature fiber for fine to medium count yarn	50 pts on for 3.8 to 4.2 range
4.6 – 4.9	Coarse fiber for coarse count yarn	
> 5.0	Significantly coarse	250 to 700 pts off

* 100 points = 1US cent

section. The use of finer fibers increases the number of fibers in the cross section of a given yarn, which improves spinning efficiency and yarn evenness. Equally, cotton fiber maturity is an important property to spinners and fabric manufacturers because it determines how well fibers will process, both from a chemical and a physical perspective. Immature fiber, that is fibers with little or no fiber wall thickening, is associated with the formation of small entanglements called neps, irregularities in processed fiber assemblies including finished yarns, non-uniform dyeing of fabrics, and decreased processing efficiency. A central problem in managing fiber fineness and maturity is the absence of convenient and accurate test methods to assess these properties.

A limitation of the test methods currently available is slow test times making large numbers of measurements impractical. Another problem is that the test methods measure fiber parameters not solely related to each property e.g., micronaire measures specific surface area by the air pressure differential across a weighed plug of randomly distributed fibers. The micronaire scale is marked in micrograms per inch, and was based on an observed linear relationship between air permeability and linear density for a range of cotton samples of similar maturity. Subsequent testing of immature cotton produced results that varied significantly from actual weight per unit inch determinations. These results were determined on the basis as previously-established theoretical relationships between the measured airflow resistance and the surface area per unit volume of solid fibers with regular cross sectional shapes. However, because cotton fibers are hollow and have irregular cross sectional shapes, this relationship is compromised. A study by Lord (1956) showed that the relationship between micronaire and fiber weight was curvilinear and that changes in fiber maturity produced concomitant variations in micronaire readings. The equation below shows the relationship, determined by Lord, between micronaire (X) and the linear density (H) and maturity (M), of a fiber expressed as a maturity ratio:

$$MH = 3.86X2 + 18.16X + 13$$

Lord's (1956) equation indicates that the micronaire value is actually related to the product of fiber fineness and maturity and its interpretation is ambiguous i.e., a coarse, immature sample and a finer more mature sample can both have the same micronaire value. Despite these shortcomings, the micronaire test is still the most widely accepted test for fiber fineness, and by assumption fiber maturity, on the basis of its simplicity and speed. Moreover, the usefulness of other test methods, e.g., double compression airflow methods, is also currently hindered by inter-relationships that exist between fiber properties and/or reproducibility. Table I lists the typical range of, micronaire values found in Upland cotton, together with comments on the type of cotton they represent from a market viewpoint and the range of premiums and discounts applied to particular values. The need to separate micronaire into its fineness and maturity components is of particular importance to producers of fine, mature cotton, which can be wrongfully discounted because low micronaire values are taken as indicating immaturity. For example, there is cotton grown in the 3.3 to 3.7 range in Table I that is actually fine and mature and therefore should receive a premium rather than a discount.

A further limitation of the micronaire test is that it only gives an indication of the average fiber quality and it does not give any information on the range of fiber fineness or maturity within a sample. For example, two cottons could have the same micronaire value and average fiber maturity but one sample could have a greater proportion of immature fibers than the other. The cotton with the greater proportion of immature fibers will have different processing properties, and the yarn and fabric produced from the two cottons will be of different quality. For example, shiny or dye resist neps are associated with very immature fibers within a sample that are not highlighted by the micronaire or other measurement methods that only provide average values.

Survey of Current Fiber Maturity and Fineness Measurement Techniques

CSIRO conducted a survey in 2004, in conjunction with the Fiber Institute in Bremen (Faserinstitut Bremen), to identify current practices regarding fiber maturity and fineness measurement. In July 2004 this survey was sent to 152 laboratories as part of the well-known Bremen Cotton Round tests. Figure 1 provides a breakdown of the 56 businesses that responded to the survey. The largest segment (31) were laboratories in spinning mills, 9 respondents were test center for merchants, 15 tested for research purposes, probably laboratories in universities and private and public research institutes, and one laboratory in a non-woven mill.

Figure 3
Techniques Currently Used to Measure Fiber Maturity by Industry Segment

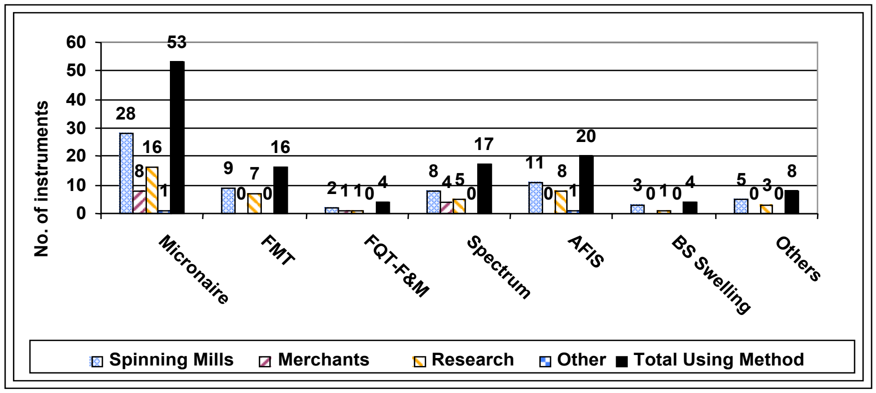


Figure 1
Respondents in the 2004 CSIRO Survey

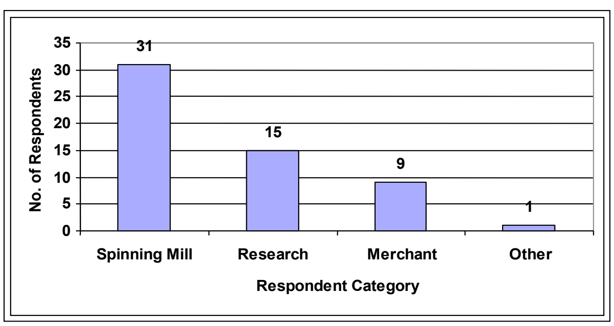
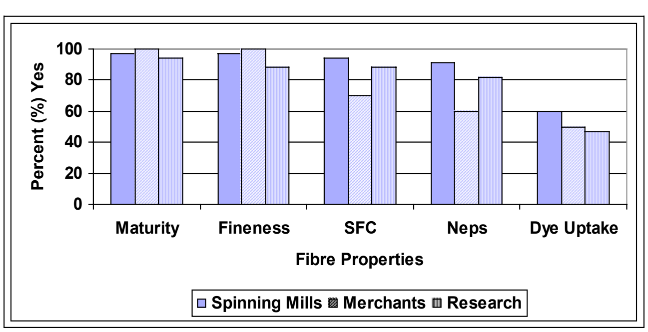


Figure 2
Survey Response to the Question "Is this an Important Fiber Property of Cotton?"



As shown in Figure 2, the spinning mill and merchant categories rated fiber maturity and fineness as being of equal and high importance, while short fiber content, neps, and dye uptake were of lesser importance. However, spinning mills, rated the latter properties as being more important than the Merchant category did. An inference drawn from these ratings could be that problems associated with the later properties are predicted, and thus mitigated, by measuring fiber maturity and/or fineness.

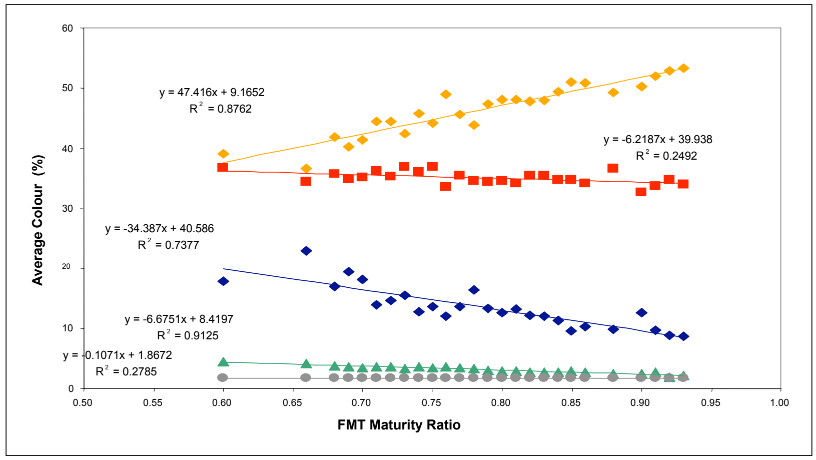
More than 80% of the spinners-test centers and 60% of the merchants-test centers claimed to measure maturity and fineness routinely. Figure 3 shows the range of techniques employed. Fifty-three of the 56 laboratories used micronaire, either using a stand alone instrument or integrated within an HVI, to assess fiber maturity and/or fineness. Most laboratories, particularly those from the Spinning Mill and Research categories, also used other instruments to provide additional information on fiber maturity and fineness. The most popular were the Uster AFIS (20 instruments), the Uster Spectrum (17) and the 'Shirley' FMT (16).

The survey also highlighted what appears to be an information gap with respect to the best way of measuring (and using) these properties. There was a significant difference in the response by the spinning mill and merchant categories, and the Research category, which tended to be less satisfied with current technology.

Most laboratories used micronaire as the main indicator of fiber fineness and maturity. However, most Spinning Mills and Merchants also desired further information on these properties. Hence, laboratories also used other test instruments to gain information.

Test speed is an issue for laboratories in the Merchant category and the survey results suggest that the reason fiber fineness and maturity may not be measured by laboratories in this category is because test methods for these properties are not fast enough. Test speed was less of an issue for the Spinning Mill and Research categories.

Figure 5
SiroMat 'Percent' Maturity Results (2 x 2 mg replicates) Versus Maturity Ratio as Measured by the "Shirley' FMT



New Instrumentation for Measuring Cotton Fiber Maturity and Fineness

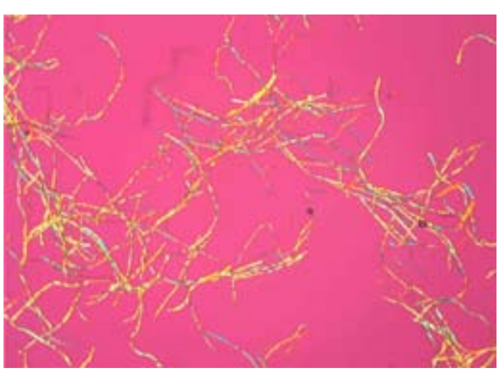
As part of a broader R&D initiative around the post-harvest quality of Australian cotton, CSIRO, in conjunction with the Australian Cotton Industry, is developing two patent pending technologies for measuring fiber maturity (SiroMat) and fineness (Cottonscan) quickly, directly and accurately. Each technology is based on an existing standard technique. In the case of SiroMat the standard method for determining maturity by polarized light microscopy (ASTM D1442) is automated, and in the case of Cottonscan the standard method for determining fineness or linear density by the cut and weigh method (ASTM D1769) is automated too.

SiroMat

The SiroMat method determines fiber maturity based on the colors that fibers assume when viewed under a polarized light microscope. The relationship between the interference colors assumed by fibers under crossed polars and fiber maturity is based upon the orientation of cellulose chains in the fiber wall, which affect the path length of light through the wall. The method has previously been overlooked because classing the fibers on the basis of color was subjective and the manual counting of fibers was too slow. The Standard Method (ASTM D1442) in fact warns against using the method for acceptance testing because "laboratory precision can be poor." However, the advent of color digital cameras and the increased power of today's personal computers have made this approach viable.

In addition, it has been thought that the method was biased by fiber fineness (Lord and Heap, 1988) or, by implication, the path length of light through the fiber. A recent survey of the interference colors assumed by different cottons by Gordon and Phair (2005) showed that there was no difference in color on the basis of genetic origin or intrinsic fineness. Three different cotton species were included in the survey, and thus a wide range of cross-sectional parameters (cross-sectional wall area and perimeter) were represented. The survey demonstrated that the interference colors transmitted by a fiber related directly to a prescribed range of values for fiber maturity, and were not co-dependent upon fiber perimeter or cross-sectional area as previously thought.

Figure 4
Field of View Analyzed by the SiroMat Instrument



Color digital cameras, color image analysis software, and higher powered computers have made automation of the polarized microscopy test viable and allow test times of less than two minutes per sample to be achieved. Moreover, the sample does not require conditioning before testing. Thus, the SiroMat method determines fiber maturity based on the colors fibers assume when viewed under a polarized light microscope set up according to the ASTM standard. Cotton fibers are automatically scanned and analyzed so that selection of fibers or fiber sections and interpretation of their color is no longer subject to operator interpretation. As well as measuring average fiber maturity, the method is able to measure the distribution of mature and immature fibers in a sample. Figure 4 shows an image of cotton fiber segments analyzed by the SiroMat test and Figure 5 shows the relationship between SiroMat results and maturity ratio as measured by the 'Shirley' FMT.

Cottonscan

The Cottonscan instrument is illustrated in Figure 6 (Naylor, 2001 and Naylor and Purmalis, 2005). The approach of this technology is to prepare a known mass of snippets from a sample of test cotton and then measure the total length of the fibers in the sample so that the fiber fineness (mass per unit length) can be directly calculated. The total length is determined by forming a uniform suspension of the snippets in a liquid, which is passed though an optical cell where the snippets are photographed and examined using image analysis techniques. Figure 7 shows a typical image captured by the instrument. Combining this measurement with an independently measured micronaire value (from a HVI) the average fiber maturity can be calculated using Lord's well established empirical relationship between Micronaire, maturity ratio and fineness (Lord, 1956). Further details of the first prototype Cottonscan instrument are described by Gordon and Naylor (2004) and include some preliminary results. As an example, Figure 8, reproduced from Gordon and Naylor, shows the good correlation between fiber fineness and maturity values obtained on the Cottonscan instrument and FMT measurements from six well blended cotton samples.

The primary differences between the two new instruments are that SiroMat measures maturity of individual fibers directly and so can give information about the population and distribution of maturity values in a sample, whereas Cottonscan measures average fiber fineness and then infers an average maturity value from an existing empirical relationship. In terms of operational capabilities, the SiroMat approach is slower than Cottonscan and is focused on being a tool in quality assurance and research laboratories. On the other hand, the Cottonscan measurement time is within HVI analysis times.

Figure 7
Typical Unprocessed Image Captured by the Cottonscan Instrument

Figure 8
Cottonscan Average Fibre Fineness Values Versus Results Obtained With the 'Shirley' FMT (n=5)

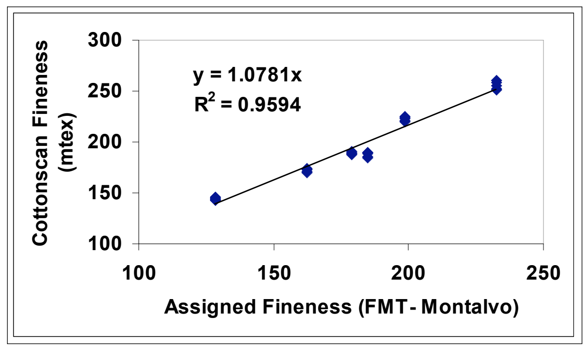
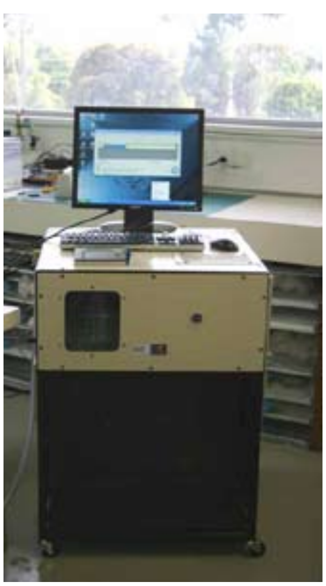


Figure 6. The Cottonscan instrument



More detailed technical progress with the development of these two technologies was presented to the recent ITMF International Committee on Cotton Testing Methods meeting held in Bremen in March 2006.

Conclusion

The Australian cotton industry currently produces high quality, contaminant free cotton very efficiently. The industry is seeking to improve its fiber quality further and is currently undertaking a targeted research and development program. One aspect that has been identified is the need for new technology to accurately measure fiber maturity and fineness independently and thereby improve on the current micronaire value. To this end, two new instrument technologies that automate and provide more precise direct measurements of fiber maturity (SiroMat) and fineness (Cottonscan) are being developed. The primary differences between the instruments are that SiroMat measures maturity of individual fibers directly and so gives information about the population and distribution of maturity values in a sample, whereas Cottonscan measures average fiber fineness more quickly (at speeds compatible with HVI testing) and then infers an average maturity value from an existing empirical relationship.

These two technologies are still in the prototype stage and further R&D is being undertaken in Australia to demonstrate the robustness of the technologies for commercial use. It is an objective of this R&D program that the technologies, once fully developed, will become widely accepted as routine tools for determining cotton fiber maturity and fineness. This will provide efficient and accurate tools to enhance the viability of the world's cotton industry.

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Short Notes

• Thermal Defoliation and its Effects on Fiber Quality

Defoliation is a prerequisite for machine picking of cotton, and it is estimated that almost 30% of world cotton is machine picked. All cotton is machine picked only in Australia, Israel and the USA. Most cotton is machine picked in Argentina, Brazil, Greece, Spain, and many Central Asian countries. It is usually recommended that leaves could be forced to try when almost 2/3 of bolls on the plant have already opened. Defoliation also helps to reduce trash in cotton and minimize gumming of spindles during picking. The advantages of machine picking include lower cost, earlier picking to avoid unfavorable weather conditions and eliminate the need for a second picking. Chemical defoliation is the most popular way to get rid of green leaves for avoiding chlorophyll-staining of cotton fibers. Showler *et al*. (2006) studied thermal defoliation and compared it with chemical defoliation with respect to defoliation efficiency and effects on fiber quality. They used hot air from the propane burner, where the air was heated to 193ºC and directed at cotton plants. The number of leaves on treated and un-treated plots were counted before the plants were hit with hot air. The number of leaves that survived the treatment was counted to estimate the defoliation efficiency (survival was estimated by counting leaves that retained 5% green area or more).

Results showed that thermal defoliation caused the death of 80-98% of leaves after one day of the treatment in all the three experiments. Mortality did not improve much in the following days. The chemically treated plots did not show 30-40% leaf mortality until five days after the treatment. The number of dead leaves increased to 84-87% on the 7th day after chemical treatment. Mortality continued to increase and reached 91-98% 13 days after treatment. Thermal defoliation is quick and dried more leave compared to chemical defoliation, which has a gradual effect. No statistical differences were detected after seven days when mortality rates exceeded 80%. The experiments showed that although thermal desiccation was quick in action, the dried leaved tend to stay attached to the plant. It seems that sudden exposure of green leaves to hot air disrupted the physiological or chemical processes for the formation of a abscission layer at the point of its attachment to stem and leaves.

The below fiber quality data are the average of three locations. One of the locations had lower trash contents compared to other two. The data by location showed no significant differences for any fiber quality characteristic measured in the studies. However, the thermal defoliation

Effect of Thermal and Chemical Defoliation on Fiber Quality

Treatment	Uniformity (%)	Length (mm)	Strength (cN/tex)	Micronaire	Trash (%)
Chemical defoliation	82.4	27.6	30.2	4.9	1.5
Thermal defoliation	82.4	27.5	29.6	5.0	1.6
No defoliation	82.8	27.9	30.0	4.9	1.8

produced slightly shorter fibers, which could be due to the shrinkage of fibers because of sudden, and extremely hot air. The costs of thermal defoliation using hot air are competitive with chemical defoliation, but thermal defoliation is environmentally safer compared to chemical treatments. Certified organic cotton production regulations prohibit the use of chemicals and thermal defoliation is an alternate method that could be certified as an organic practice.

(For more details refer to Effect of Thermal Defoliation on Cotton Leaf Desiccation, Senescence, Post-harvest Regrowth, and Lint Quality published by Allan Showler, Paul Funk and Carlos Armijo in *The Journal of Cotton Science*, 10: 39-45, 2006.)

• India Commercialized Bollgard II Cotton

Biotech cotton was commercialized in India in 2002/03, and in four seasons biotech area has increased to 14% of total cotton area, or 1.2 million hectares. India is the only country where the insect-resistant Bt genes have been commercialized through commercial cotton hybrids. The Genetic Engineering Approval Committee, responsible for the approval of biotech varieties of all crops, recently approved twenty new cotton hybrids/varieties for commercial production during 2006/07, doubling the number of approved hybrids/varieties. Biotech cotton has also been approved for commercial use in north of India. The Genetic Engineering Approval Committee of the Ministry of Environment and Forests, Government of India is a regulatory body that awards final approval for import and release of genetically-engineered organisms in India. The Committee approved Bollgard II biotech cotton hybrids for the Central region in the meeting held in May 2006. Australia and USA are the other countries where Bollgard II has been approved for commercial production. The approval of more hybrids/varieties and Bollgard II are going to boost biotech cotton area in India to 20-25% in 2006/07.

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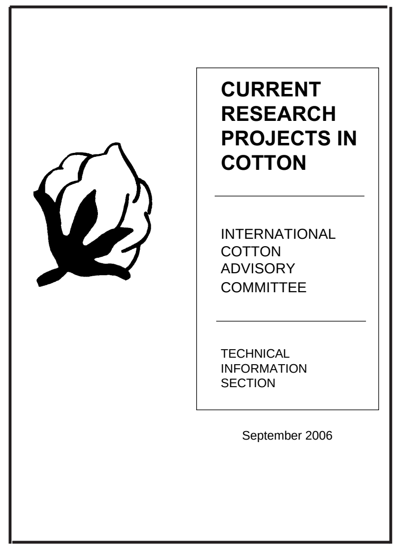

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