Cotton Quality - Fibre to Fabric

FIBRE PROPERTIES RELATIONSHIPS TO FABRIC QUALITY

by

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ABSTRACT

COTTON QUALITY – FIBRE TO FABRIC

FIBER PROPERTIES RELATIONSHIP

TO FABRIC QUALITY

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The textile industry has a recurrent white speck nep problem in cotton. “White specks” are immature clusters of fibres that are not visible as defects until dyeing, after which they remain white on the surface of a darkly dyed fabric, or appear as non-uniform streaks in the fabric. Both results render the fabric unsuitable for commercial fashion fabrics. The white speck potential of cotton is difficult to predict except in extremely immature cottons. Competitive synthetic fibres are uniform in length and strength and never have a maturity problem resulting in dye defects. They are much more predictable in the mill. As a result, cotton faces the risk of being replaced by synthetic fibres. Industry requires a method to predict fabric quality from cotton bale fibre properties to minimize this risk.

This research addresses the problem of predicting white specks in dyed cotton fabrics. It is part of a large study, which is supported jointly by US and Australian agencies. The main objective is to predict fabric quality from bale fibre properties given controlled gin and mill processing. Gin and mill processing must be controlled so that field and varietal effects can be seen without the interaction of mechanical processing differences. This results in achieving other objectives, including the provision of baseline data for Australian varieties, ginning effects and comparison of ring and open-end spinning.

Initially a reliable method for measuring white specks had to be found. Several systems have been evaluated and are reported here. The systems accuracy was compared using fabrics from the US Extreme Variety Study (EVS), which was grown specifically to have different levels of white specks. The fabrics made from the US (Leading Variety Study 1993 (LVS) and The American Textile Manufacturers Institute (ATMI) Cotton Variety Processing Trials, 2001) and the Australian (1998 & 1999) variety studies were analysed using AutoRate-2-03, the best of the image analysis systems studied. The final release of AutoRate (February 2003) was developed by Dr. Bugao Xu to measure white specks on dark fabrics in conjunction with this research. This final analysis of these studies results in white speck prediction equations from high-speed fibre measurement systems. This information should be immediately useful to as a tool to measure the effects of field and ginning practices on the levels of white specks without having to carry the research out to finished fabrics. Cotton breeders will be able to use the equations in the development of new varieties with low white speck potential, by eliminating varieties with high white speck potential early on. The research will continue on a much larger scale in the US and hopefully a WSP (White Speck Potential) value will be incorporated into the US Cotton Grading System.

Certification of Dissertation

I certify that the ideas, experimental work, results, analyses, software and conclusions reported in thesis dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

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Signature of Candidate	**Date**

ENDORSEMENT

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Thanks to Dr. John Patrick Jordan, my Director at SRRC, for backing me on this project from the start and for all of the support he's provided and to Dr. Alfred French, my Research Leader, for his tireless efforts editing and his support. Deborah Boykin of the Mid South Area, USDA was also instrumental in assisting with the statistical analysis. In addition, I'd like to thank Wilton Goynes and Bruce Ingber of the Southern Regional Research Center who provided many of the photomicrographs. Melanie Smith, Denise Burthlong, Amy Nunenmacher, Mia Schexnayder, Kitty Pusateri, Jason Hamide, and Terri Von Hoven of the Southern Regional Research Center for their the invaluable assistance and tireless efforts.

Appreciation is expressed to cottons and to Queensland Cotton and Namoi Gins for custom ginning the AU98 & AU99 cottons and Robert McLaughlin of IFC for processing the AU99 cottons. Appreciation is also expressed to David McAlister for coordinating the US2001 field to yarn study, along with personnel of the Cotton Quality Research Station, ARS, USDA, and Clemson, SC for processing for the LVS, AU98, and US2001 cottons. The careful efforts of the SRRC Textile personnel who wove and dyed all of the fabrics were key to the research and their efforts are much appreciated, as are the efforts of all SRRC personnel who were involved in fibre, yarn and fabric testing.

Thanks to Dr. Barry Bavister for his long hours of editing, his invaluable assistance, moral support, and especially for making me take time out to relax when I was too stressed.

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1. INTRODUCTION

Improving the quality and marketability of cotton fabrics through improved fibre quality measurement technology could enhance the economic viability of cotton. In this dissertation, I set out a starting point for such improved technology. It is based on a program of field experiments conducted with the cooperation and assistance of leading fibre research groups in the U.S. and Australia. No other countries are producing the controlled conditions for growing and processing samples that are necessary for this project. The global and country specific context to the studies is explained in this introduction.

Globally [1](Cotton Australia, 2003)

The main cotton producing countries in the world are China, USA, India, Uzbekistan and Pakistan. Together they account for nearly 80% of world production.

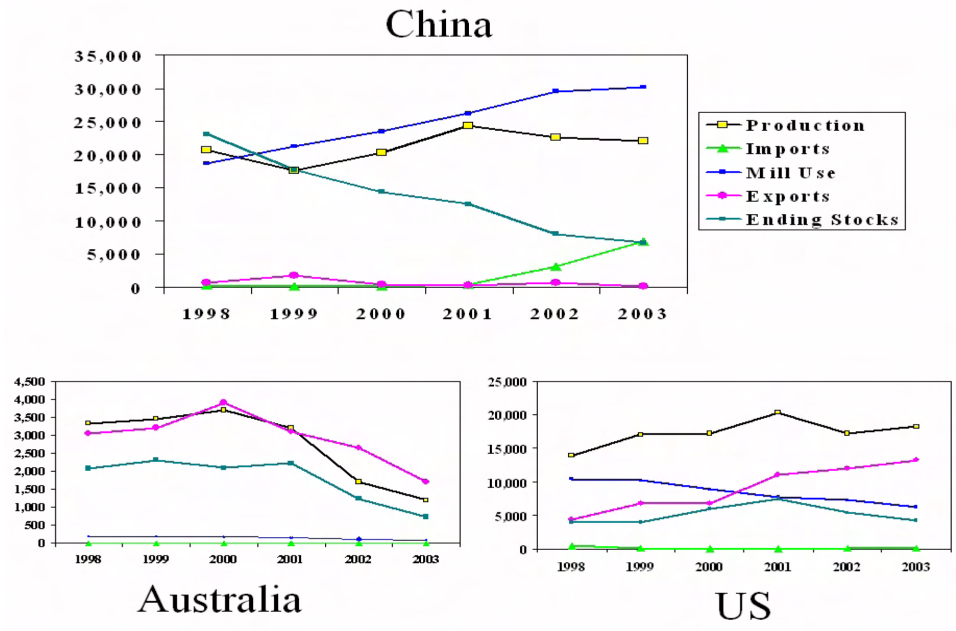


Figure 1.1: Cotton production, imports, exports, mill use and ending stock in China, the U.S. and Australia for 1989 to 2003 [2](National Cotton Council, 2003).

World consumption of cotton is estimated at more than 91 million bales per year, each bale weighing about 227kg (500 lbs). This cotton is produced on a total global growing area of 31.6 million hectares. It is grown in over 90 countries, 75 of which are developing nations.

Of the major producers, China's mill use has increased in recent years while that in the U.S. has decreased, and in conjunction with this, China's imports have increased and the U.S. exports have increased (Figure 1.1).

Australia [3](Cotton Australia, 2003)

Australia grows just over 3 million bales each year compared to China's 17 million and the USA's 16 million bales. Australia is a relatively small producer, but is the third largest exporter in the world cotton marketplace. Australia exports over 95% of its cotton. The value of these exports in 2000/01 was in excess of $1.5 billion. Australian dollars.

Over the five-year period to 2002, Australian cotton production has been relatively stable, with an average of 3.2 million bales produced from 470,000 hectares (1,815 sq. miles). Of this, 65% were in NSW with the remainder in Queensland [4](see Figure 1.2). The 2002/03 crop produced 1.62 million bales, is a 50% reduction on 2001/02 crop, due to the impacts of drought [5](CottonWorld, 2003).

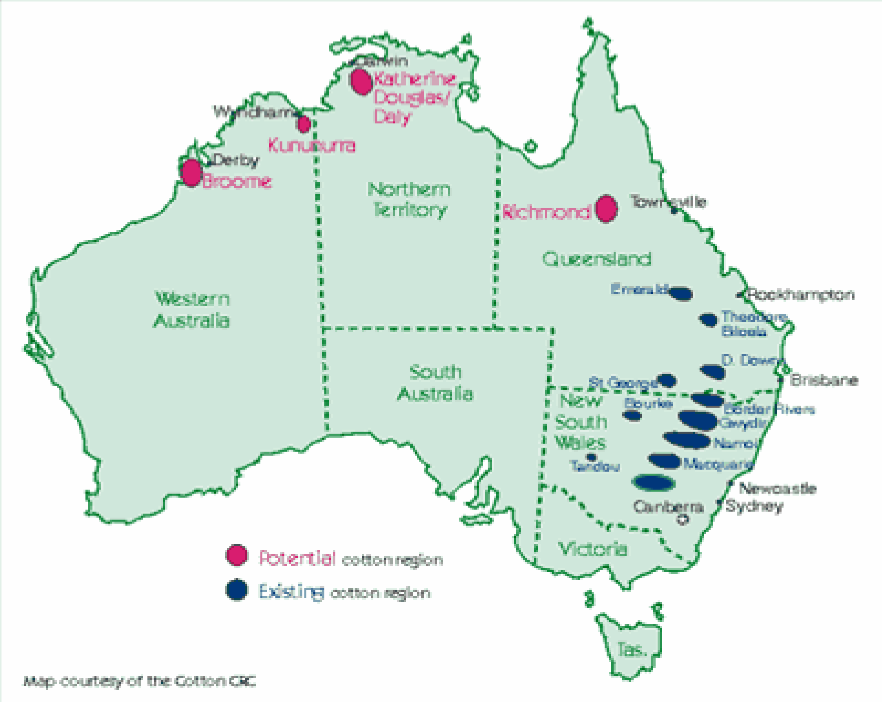


Figure 1.2: Australian cotton is grown mainly in central and northwestern NSW and central and southern Queensland. Potential cotton growing areas are shown in the north [6](Cotton Australia, 2003).

U.S. [7](National Cotton Council, 2003)

U.S. cotton farmers annually produce between 16 and 18 million bales, each weighing approximately 227 kgs (500 lbs), representing a total net value of eight to nine billion Australian dollars [8](Cotton Australia, 2003).

Business revenue stimulated by the crop in the U.S. economy is estimated at some $120 billion. Cotton is grown in 17 states covering more than 12 million acres or about 19,000 square miles (4,921,000 hectare) (see Figure 1.3) [9](National Cotton Council, 2003).

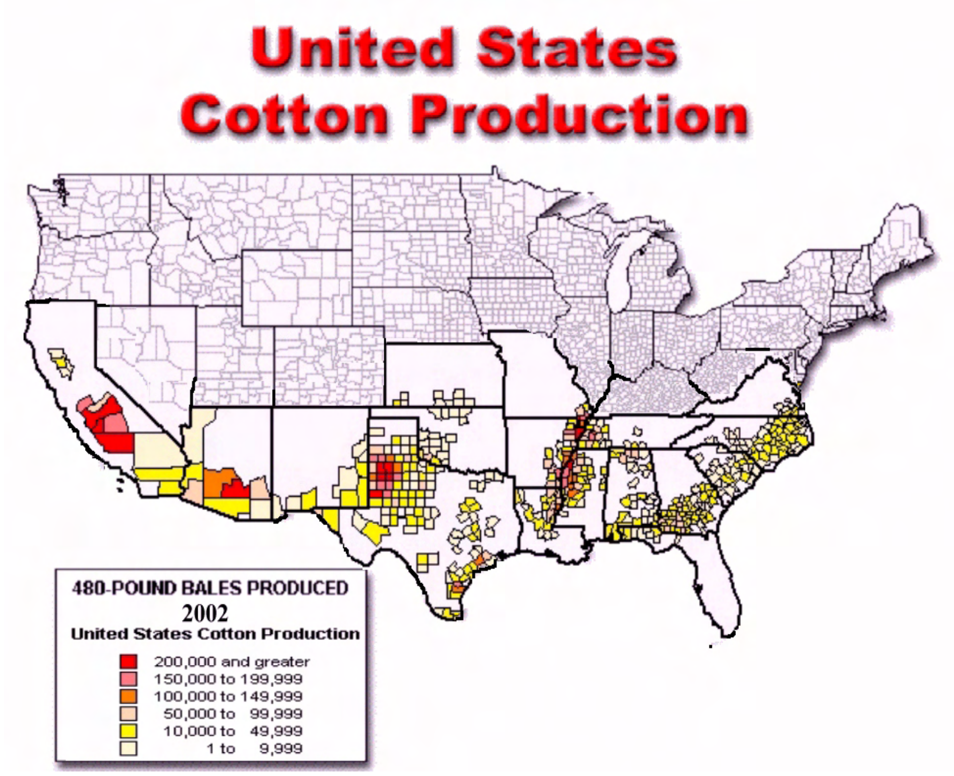


Figure 1.3: In the US, cotton is grown in 17 states, across the cotton belt (southern part of the US from the east coast to the west coast. [10] (National Cotton Council, 2003)

Not all of this cotton represents a quality product. The United States textile industry alone loses as much as two hundred million dollars annually (a conservative estimate) due to dyed fabric defects [11](Goynes, 1996) associated with white specks. The white speck phenomenon has been a recurrent problem since 1874 and is often associated with poor weather conditions, and/or with certain cotton varieties.

1.1 Project Overview

White specks are a specific type of fibre defect that result in high financial losses to the cotton industry. Fibre entanglements are called neps. Neps that involve immature fibres do not dye properly and appear as white specks on the dyed fabric. This dissertation presents an experimentally derived link between the properties of baled cotton and the quality of resulting fabrics (indicated by the level of white specks in the fabric). The results are presented as predictive equations for different fibre measurement systems, with the intention of providing a White Speck Potential (WSP) that can be incorporated into cotton grading systems used for marketing.

The equations are derived from a database of measured cotton parameters that was accumulated during a six-year research program (sixteen years when including initial research) on two continents (North America and Australia). A number of measurement techniques were developed during the course of the project to acquire the data, and these are explained.

The international cotton industry uses non-standard, U.S. units of measurement, and so these units have been adopted in this dissertation. SI units are also provided where appropriate throughout the dissertation

1.2 Project Aims

The aims of this project are:

i) To develop reliable systems for measuring white speck in fabric samples;
ii) To produce a database of measured fibre properties and white speck values; and
iii) To produce regression equations that will allow white speck potential in fabrics to be estimated from fibre properties.

Previously, several varieties of cotton with known histories had been evaluated and rated for white speck content [12](Goynes et al., 1996). Microscopical examination of white speck neps from these samples identified them as clumps of cotton fibres that are severely immature, containing only the outer cell wall of the fibre. Their flat, unsupported structures cause them to clump into bundles that are very difficult to separate into individual fibres. Identification of the nature of the white specks led to this research project to identify causes of underdevelopment and ways to predict their presence in undyed fibres.

1.3 Previous Work

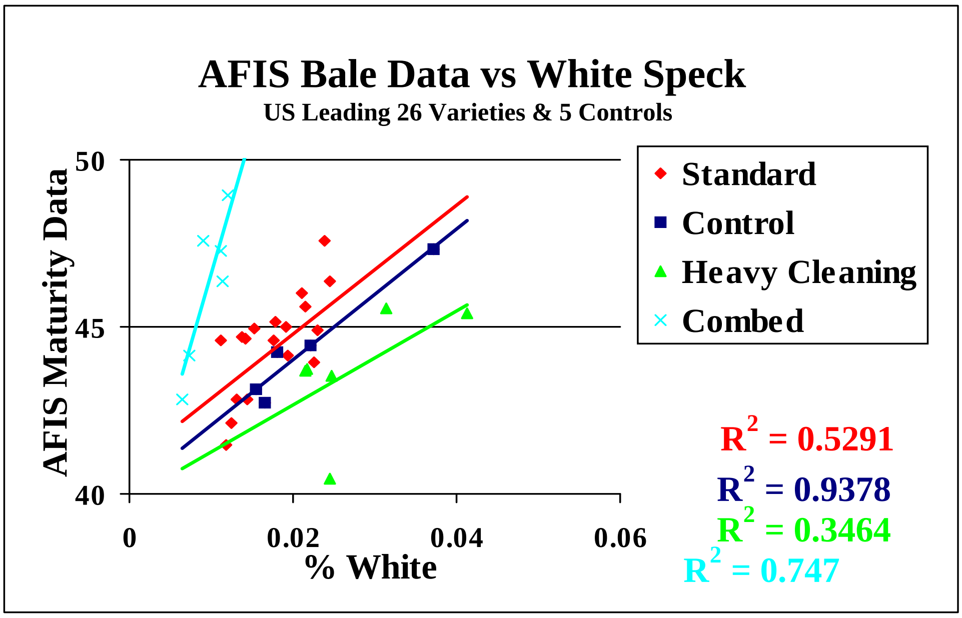


Figure 1.4: US Leading Variety Study indicates that processing differences are discernable and future studies should have controlled ginning.

This project is an extension of the candidate’s work in conjunction with Agriculture Marketing Services (AMS, USDA) on the 26 leading varieties in the USA. That study included varieties producing a wide range in the levels of white specks in the finished fabrics and resulted in a scale (% white) for the quality of fabric with respect to white speck. True varietal differences were not readily discernable in the study results because of the processing interaction shown in Figure 1.4. The varieties were collected from different gins and therefore had been processed differently. Such interactions must be quantified before the extent of white speck formation can be established.

1.4 Justification

Constant demands to improve competitiveness through increased productivity are driving the cotton textile industry to continually upgrade equipment and increase the intensity and speed of processing. However as speeds increase in cotton processing, so does the number of neps, especially white speck neps. It has become increasingly important to know the white speck potential of a bale of cotton before processing it. HVI data provide a basis for controlling the properties that are important to a particular operation. However, definitive guidelines are needed so that testing methods and sampling techniques give statistically sound white speck and fibre maturity data. In previous studies, the candidate defined minimum sample sizes and developed techniques for this purpose using both AFIS **[13]**(Bel-Berger, 1999) and image analysis techniques **[14]**(Bel-Berger, 1998), which together provide the tools to undertake this research.

Cotton breeders would like to improve fibre quality to improve future varieties, and the mills need to know what measurable fibre properties are considered the most vital for quality during processing. Producers and ginners also need to be aware of these fibre properties, but often receive contradictory responses from the textile mills. Breeding programs have been geared towards producing longer, stronger, and finer cottons, but with a primary emphasis on yield. Other elements, such as the percent immature fibres or strength of seed coat attachment, often change along with the targeted fibre property. Seed coat attachment is strongly related to variety. From 14 to 24 % of white specks are from seed coat fragments that have short immature fibres attached. A series of field studies conducted from 1997 to 2001 (sixteen years when including initial my research from 1987 to 1997) is presented in this dissertation to identify measurable fibre properties that can be used to predict white speck neps using high-speed fibre measurement systems.

1.5 What is a Nep?

A technical description of neps is presented in Section 2.7. However, they are the cause of the problem addressed in this thesis and a general understanding is required in this introduction.

Neps are small tangled knots of lint hairs that appear after ginning in manufactured cotton products. In cloth, they appear as specks. In dyed cloth, the specks are usually lighter than the background [15](Brown & Ware 1958) and are classically considered to be of two different types: mechanical or biological neps. Recent studies have defined coalesced neps as a third and very important type. Mechanical neps only contain fibres and have their origin in the manipulation of those fibres during processing [16](van der Sluijs, 1999), whereas biological neps include foreign material such as seed coat fragments, leaf or stem material [17](Hebert, 1988). In coalesced neps, the immature fibres appear to have grown together in the boll. Mechanical and biological neps involving immature fibres create undyed spots in the finished fabric [18](Hebert, 1988). The coalesced neps, composed solely of immature fibres, always appear as white spots on dyed fabric when they survive processing to the fabric stage.

More than 90% of neps in finished fabric incorporate immature fibre [19](Hebert, 1988). These undyeable spots are known as white speck neps, or more commonly, white specks. Not all neps are white specks, but all white specks are neps, and they contain immature fibres. Some are tangles of immature and mature fibres while many are tight masses of immature fibres. White specks were reported as long ago as 1855. Crum[20] (Crum, 1855) examined a sample of calico, which contained white spots after dyeing. He wrote: “On placing it under the microscope, I found the cotton which had thus resisted the dye to consist of very thin and remarkably transparent blades, some of which were marked or spotted while others were so clear as to be almost invisible, except at the edges. They seem to be particularly numerous during years with weather problems such as occurred with the 1987 U.S. crop. Long, fine, immature fibres have a propensity to nep during processing, so any field condition, harvesting method, gin, or mill processing that increases the level of immature fibres will increase neps in yarns and fabrics.

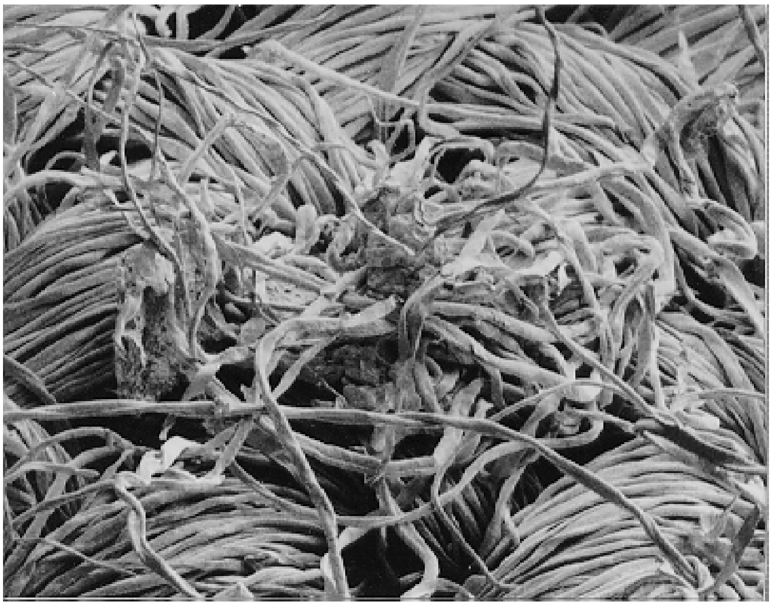


Figure 1.5: Mechanical Nep (Photomicrograph by Bruce Ingber).

White specks show up as dyeability defects. Figures 1.5, 1.6, and 1.7 are close-ups of typical white specks. Figure 1.5 shows an entanglement of mature and immature fibres that appeared as a white speck on the dyed fabric. Figure 1.6 is a coalesced white speck composed of extremely immature fibres adhered together.

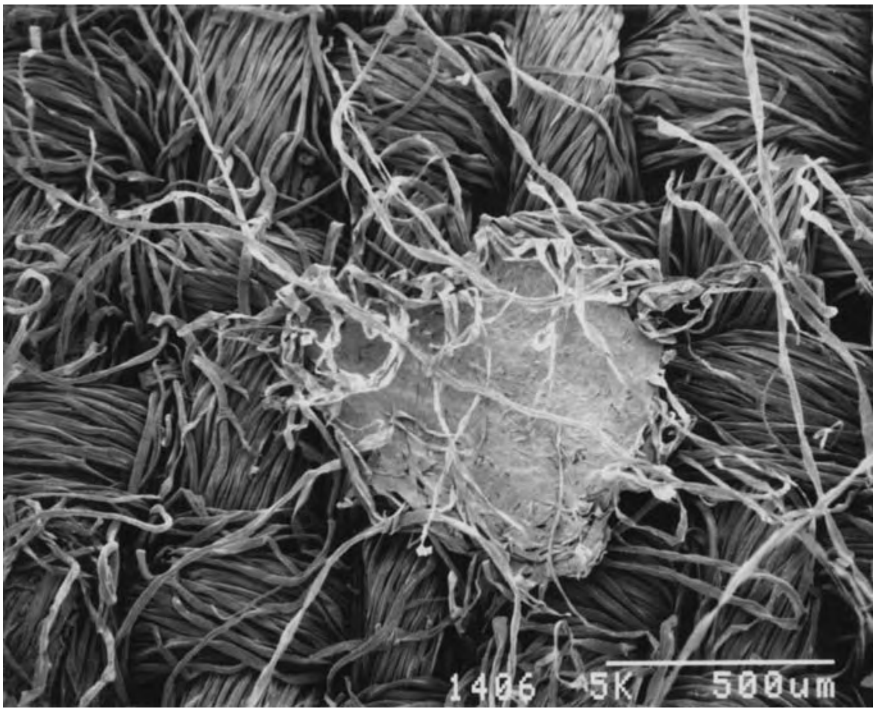


Figure 1.6: Coalesced white speck nep on fabric surface (low magnification) (Photomicrograph by Bruce Ingber).

In Figure 1.7, the white speck neps are very flat and very reflective. These white speck neps are immature fibres that have passed through gin and mill processing, and were incorporated into fabric. Currently, white specks are not detectable until the fabrics are dyed. The dyed fabric is passed over steam cans during drying, essentially polishing the already flat immature fibres to a high shine, making them even more reflective and the problem even more obvious.

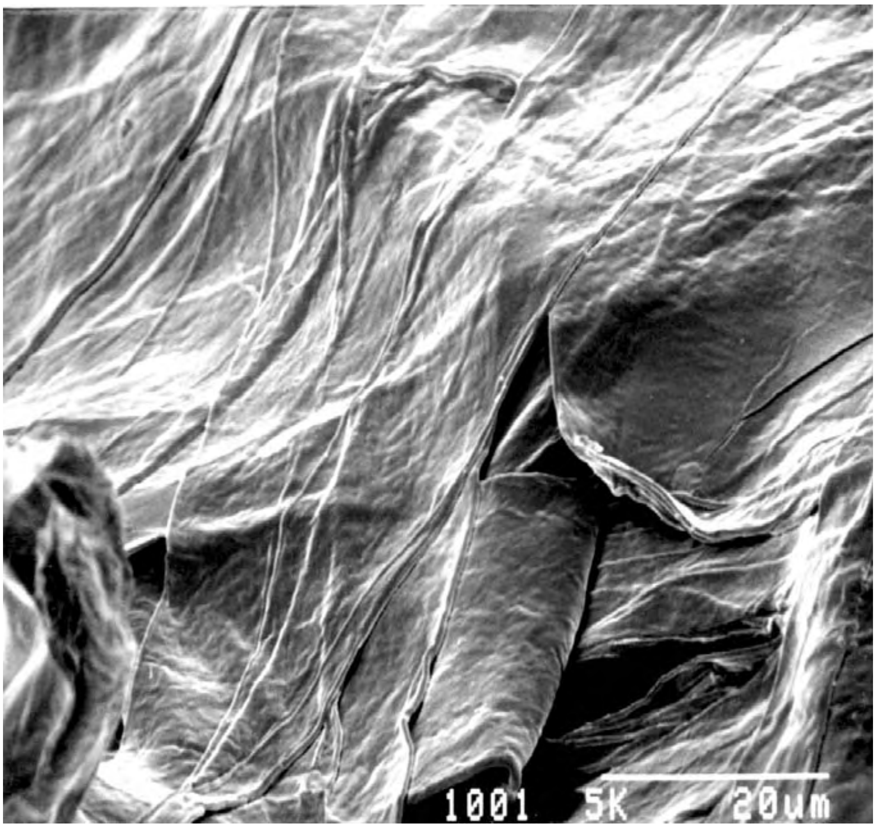


Figure 1.7: High magnification of a white speck nep (note the extremely immature fibres create a reflective surface) (Photomicrograph by Bruce Ingber).

The key problem is that the mill does not discover this defect until after the fabric is dyed. The textile industry needs high-speed measurement systems to predict white specks so the problem can be avoided by putting the cottons with high white speck potential into the right product mix where they are not problematic (specifically, whites).

The work described in this dissertation enables this level of management by first quantifying the white specks on fabrics from a range of cottons and then using field-to-fabric studies (known field conditions and varieties with specific gin and mill processing through fabric) to develop predictive equations.

Before it is decided which values from high-speed fibre measurement systems are most predictive of white specks, the level of white specks in dyed fabric and/or the amount of immature fibres needs to be quantified by a consistent method. Several different systems are evaluated. The AutoRate program developed by Dr. Xu (University of Texas at Austin) is found to provide the most accurate results currently available. His program was developed specifically to measure white specks and the candidate was involved in its development by evaluating many versions. The method uses a scanner to obtain an image that is converted into pixels, measured, and analysed by a computer program.

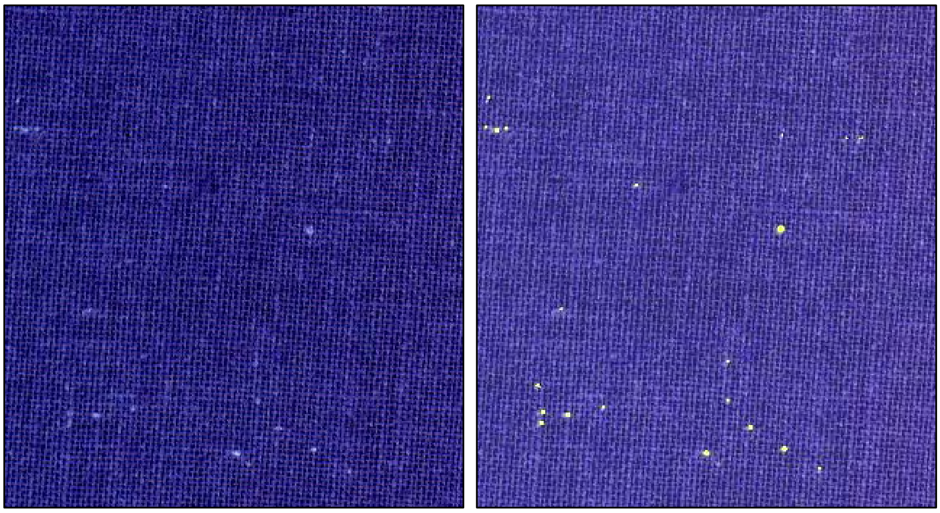


Figure 1.8: (Left) Original scan and (Right) scan brightened to 120 and image analysed on Autorate.

Four 5” x 5” samples are scanned for each fabric sample. The images are adjusted on AutoRate to the same level of brightness (120) and a minimum size (3 pixels per speck) is set to differentiate between real white specks and anomalies. The contrast is set for each fabric. If the fabrics are all dyed and scanned in a batch, the contrast usually remains the same (each dye batch is slightly different and I have noticed that the scanner contrast has a slight drift over time). Figure 1.8 shows the fabric's original scan and the altered image after it is brightened and analysed. This analysis results in a white speck count, the size of the white specks, and the percent white on the fabric.

2. FIBRE PROPERTIES

Cotton fibre is a truly remarkable biological entity, being formed from a single epidermal cell on the surface of a fertilized cottonseed. As the seed develops the seed hair-cell continues to lengthen in the form of a circular cylinder, continues to lengthen. The cell wall diameter is determined early in the growth cycle and is chiefly a genetic or varietal property.

The development of the cell into the cotton fibre takes place in two stages: cell elongation and cell wall thickening (Figure 2.1) [21](Thibodeaux et al, 1986). The elongation period lasts about 15 to 25 days after flowering (post-anthesis). The cell consists of primary wall filled with a semifluid, semitransparent substance (protoplasm in the central lumen) during the elongation phase. Secondary wall formation begins as the elongation ceases, [22](Ramey, 1988) and the fibre wall thickens by deposition of regular layers of secondary wall cellulose. After about five weeks, there is a significant secondary wall development, and most fibres terminate wall thickening between seven and nine weeks. Boll opening then commences, and the liquid material within and around the fibre evaporates [23](Thibodeaux et al, 1986).

On drying, the cylindrical wall collapses and actually twists or convolutes. The thickening of the secondary wall of the fibre, sometimes referred to as to its maturity, is extremely important during this stage. The presence of immature fibres can cause many problems during processing. Their reduced strength and resilience results in excessive damage and waste at ginning and carding, and weak and uneven yarns. Immature fibres also increase the tendency of fibres to tangle and form neps in the card web and finished yarn. Neps have a relatively low dye affinity due to low levels of cellulose and so they show up as imperfections or speckles in the finished fabric. They can lead to severe economic penalties for the manufacturer [24](Thibodeaux et al, 1986).

A number of related physical measures are used to specify the quality of harvested cotton fibre. These are summarised below along with their known impact on nep formation.

2.1 Fibre Fineness

Two definitions of fibre fineness are gravimetric fineness and biological fineness. Gravimetric fineness can be expressed as the mass per unit length of a fibre. The gravimetric or linear density of fibres is usually expressed in millitex or micrograms per meter. Biological fineness is defined either by the perimeter of the cross-section of the fibre or by the diameter of the cross-section of the fibre with that section assumed to be circular. Gravimetric fineness can be related to biological fineness if the wall thickness or maturity of the fibre is known [25](Ramey, 1988)

Fine fibres are desirable for strong yarns. The more fibres found in the cross-section of a yarn, the stronger the yarn. There are more fibres in the cross-section of a yarn constructed with fine fibres rather than coarse fibres. Fine cottons can also be spun at lower twist multipliers than coarse cottons of a given staple length. It is usually best to choose the finest cotton available [26](Marth et al, 1952). However, finer cotton fibres tend to form neps more easily than coarser fibres because the former are more easily bent, buckled, and entangled during mechanical manipulation. Several studies have shown that cottons with a lower micronaire (a general measure of maturity and fineness) produce neppy, low-grade yarn, whereas cottons with a higher micronaire produce less neppy, higher quality yarns [27](van der Sluijs, 1999).

Nep formation becomes more frequent and more detrimental in its consequences with the spinning of fine yarns from fine fibres. Neps are more noticeable in fine yarns because their size becomes comparable to that of the yarn diameter [28](Ramey, 1988).

2.2 Fibre Maturity

The term “fibre maturity” has not been standardized in the cotton industry. Common measures used [29, 30](Peirce and Lord, 1939; Lord and Heap, 1988) are: wall thickness, degree of thickening, maturity ratio, causticaire maturity index, and dye maturity. Wall thickness is the absolute value of the fibre wall thickness (μm). Degree of thickening (θ) is defined by area of fibre wall/area of circle having same perimeter. Maturity ratio is given by θ/0.577 and is the most widely used term in the literature. As a rough guide, immature fibres have a wall thickness below 2.7μm. Montalvo and Faught (1996) suggested a further measure called percent wall thickness.

Dead cotton consists of fibres that are very immature, where the secondary wall is completely missing. The fibres with intermediate development (between the dead and normal fibres) are described as thin walled; the dead and thin walled fibres may be classed together as immature. The mature cottons are fairly ridged and have a kidney bean shaped cross-section. The fibres collapse as the boll opens and immature fibres collapse to a ribbon-like section and are comparatively floppy. It is because of this lack of rigidity that the immature fibres tangle during processing [31](Midgley, 1933). These neps consist of mostly immature or dead fibres [32](Furter, 1992) that collapse into extremely flat ribbons, which are highly reflective and thus appear as white specks in the dyed fabric [33](Peter et al, 1989). These fibres are therefore called ‘shiny neps’.

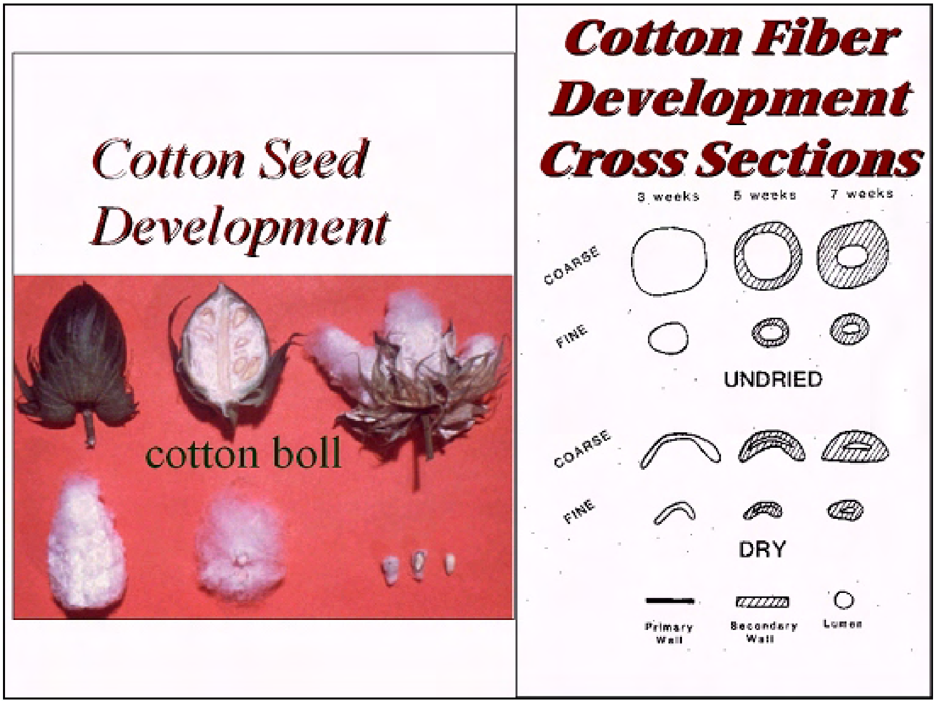


Figure 2.1: Cottonseed and fibre development (D. P. Thibodeaux and J. P. Evans, Textile Research Journal, February 1986).

Cellulose fills in the cell wall as the fibre develops and increases the maturity of the cotton. Mature fibre has a more circular in shape as illustrated in Figure 2.2 (a perfect circle would have θ = 1, while the smaller θ becomes, the less circular and the flatter the cross-section becomes). Cotton immaturity results when the normal wall thickening process is interrupted or slowed down by factors such as frost, bad weather, insects, drought stress, premature opening because of mineral deficiencies, plant diseases, injury to the foliage, stem or roots. [34](van der Sluijs, 1999).

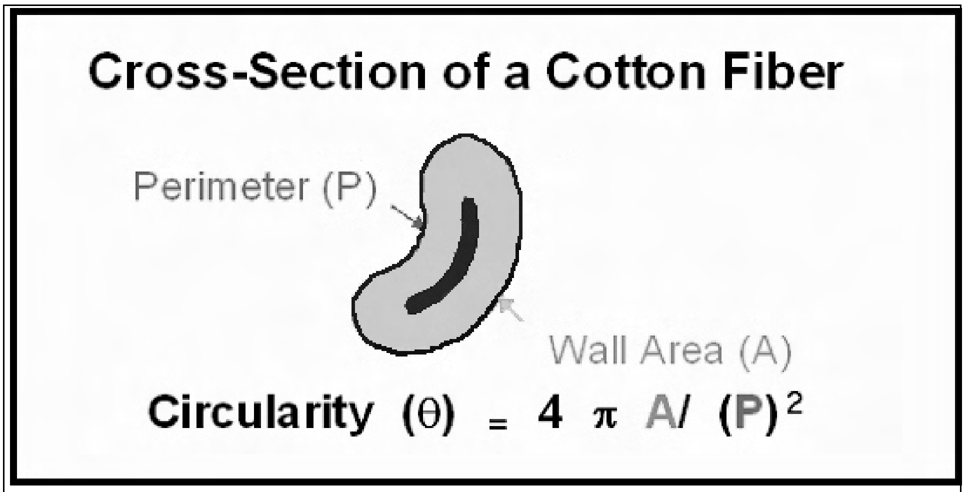


Figure 2.2: Maturity of the cotton fibre cross-section is dependent on its cell wall development (from Devron Thibodeaux).

Cottons of high fibre maturity are likely to give less neppy yarns than those of lower maturity. Fibre maturity is partly determined by genetic factors which may produce markedly consistent differences in cottons grown under varying environmental conditions, even when those conditions are uniformly favourable to a high degree of development of secondary thickening [35](Lord, 1948).

Immature fibres are finer, flatter, and more elastic than fully mature fibres of the same genotype because the fibre walls are thinner and the fibres are incompletely ‘filled’ with secondary wall cellulose. Consequently, immature fibres tend to stretch elastically, rather than break, when tension is applied. Upon release of tension, they can recoil into tangled snarls. The snarls and knots formed during fibre processing often contain entrapped mature fibres, and these tangled fibre masses appear in yarn and finished fabric as nep visible to the unaided eye. Furthermore, the lower cellulosic content of the cell walls of the immature fibre results in decreased dye uptake, which is seen as undesirable colour shadings or barré. When fibres of markedly different maturities are combined, ‘white specks” develop when the immature and mature fibres in a nep mass do not dye evenly and to the same degree [36](Bradow, 1998).

2.3 Fibre Length

The effect of the staple length on the tendency towards nep formation has been under debate. Some think that an increase in the tendency towards nep formation can be correlated with an increase in the staple length of the cotton, since a long-staple cotton frequently has a greater mean fibre fineness than a short-staple one [37](Wegener, 1980). Neps may also form due to the breaking of excessively long fibres, or lack of fibre orientation. However, a useful MSc dissertation by van der Sluijs, [38](van der Sluijs, 1996) showed that there was a low correlation between the cotton fibre length characteristics and neps, with the 50% (mean) span length playing a more significant role than the 2.5% (longest) span length [39](van der Sluijs, 1996).

2.4 Fibre Strength

Strong cottons usually exhibit fewer problems and fewer neps during processing than weaker cottons. Improvement in average strength reduces fibre breakage and therefore short fibre content and nep content; the same result can also be achieved by improving the uniformity of the cotton. Fibre tenacity is related to nep formation. Cotton with a low strength will result in the generation of fibre neps due to fibre damage in the carding process. A link between fibre strength and stiffness could also be reflected in a trend towards fewer neps[40] (van der Sluijs, 1999).

2.5 Fibre Elongation, Stiffness and Buckling Coefficient

An increase in fibre elongation tends to lead to an increase in nep formation with card and draw-frame sliver. At a constant fibre tenacity, an increase in fibre elongation is indicative of a decrease in fibre stiffness and an increase in buckling potential, and consequently of an increase in nep formation. Stiffer fibres form fewer neps. The stress build up and sudden release mechanism or Buckling Coefficient [41](Alon, 1978), which induces buckling along the fibre length, is probably a cause for the neps that are present in finished fabrics [42](van der Sluijs, 1999). Fibres, which are stretched during processing, accumulate elastic energy. If one end of the fibre is suddenly released from the tensile load, that energy is converted to kinetic energy. As the fibre cannot stand compressive stress, buckling results [43](Alon, 1978).

2.6 Fibre Impurities

The tendency towards nep formation increases with increasing amounts of impurities such as husk, leaf, stalk, and seed coat fragments. This is largely due to the fact that the higher the trash content, the greater the number of cleaning points required during ginning and opening, which in turn leads to more neps, fibre breakage and short fibre content, causing a deterioration in spinning performance and yarn quality [44](van der Sluijs, 1999).

2.7 Neps

The ASTM definition is “Neps are small knot-like aggregates of tightly entangled cotton fibres not usually larger than a common pinhead, which are difficult to remove. Neps usually appear to be more numerous in cotton after subjection to considerable handling and to some manner of processing, as certain ginning and manufacturing operations” [45](ASTM, 1947). A nep is therefore a small cluster of entangled fibres consisting either entirely of fibres (i.e., a mechanical or coalesced fibre nep) or of foreign matter (e.g., a seed-coat fragment) entangled with fibres. In most cases, fibrous neps are found to contain at least five fibres, with the average number being 16 or more [46](van der Sluijs, 1999). Neps are distinct from certain other imperfections found in cotton, including fibres still attached to parts of seeds. One of these imperfections is the "mote", which consists of a whole undeveloped seed of any size or age, covered with fuzzy and short fibres, certain of which bear mature lint fibres. Seed coat and mote fragments with lint or fuzz fibres attached are not neps. Neps are created during development, harvesting, ginning and yarn manufacturing phases of production [47](Mangialardi - a, 1985).

2.7.1 Nep Formation

Neps can be classified by the differences in formation. Biological neps are neps that contain foreign material, whether the material is a seed coat fragment, leaf, or stem material [48](Hebert, 1988). Mechanical neps are those that contain only fibres and have their origin in the manipulation of the fibres during processing [49](van der Sluijs, 1999). The coalesced neps make a third type of nep in that they are an intermediate between biological and mechanical neps (see 2.7.1.3), in that they are entirely formed from fibres, but biologically produced. In addition, most important to this research, is the fourth type of nep, white speck neps, which cause dye defects in the finished fabric.

2.7.1.1 Biological Neps

Biological neps are caused by biological components of the cotton plant forming contaminants in the fabric; two examples are shown in Figure 2.3. Undeveloped seeds, motes, small bits of seed coat, particles of leaf or bract can all be entangled in the cotton during harvesting or subsequent processing. They result in small dark specks in the greige (just off the loom without chemical finishing) fabric, but are generally removed by wet processing (scouring, bleaching, and dyeing).

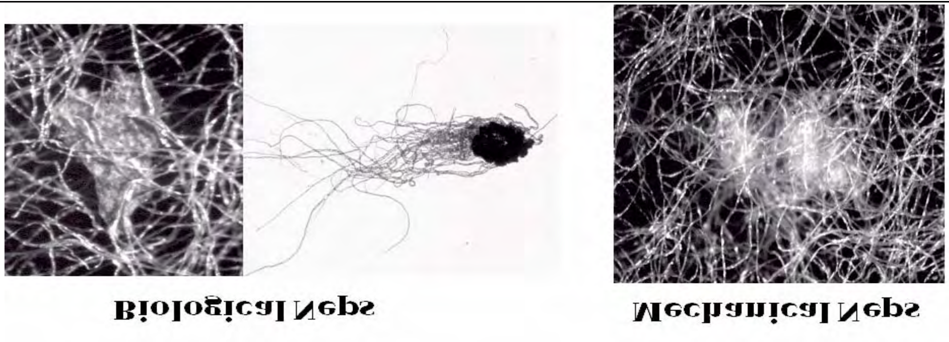


Figure 2.3: Fibre Entanglements -Biological Neps and Mechanical Neps.

2.7.1.2 Mechanical Neps

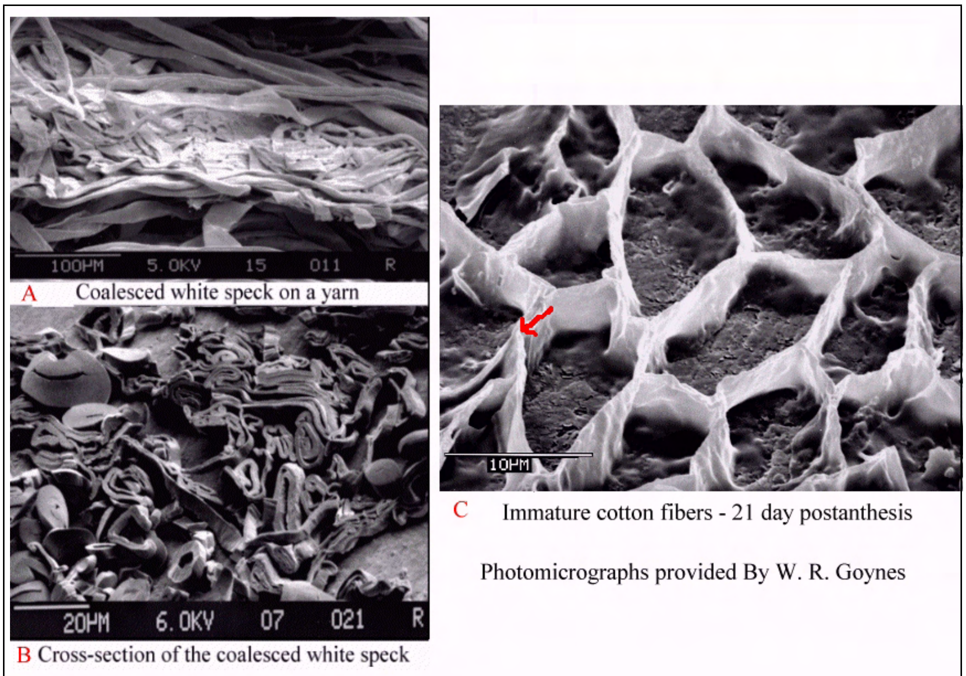
Mechanical neps are found in ginned lint, card web, yarns and cloth. Their numbers are strongly influenced by mechanical processing [50](Bel-Berger, 1998). They have been attributed to fibre properties such as immaturity, staple length, and fineness and to moisture content and handling methods in production such as over- or under-beating the fibres in the carding or ginning operations [51](Jakes, 1984). Other contributing factors may be harvesting methods, early frost, plant disease, and premature use of harvesting chemicals [52](Supak, 1992).

2.7.1.3 Coalesced Neps

Clumps of very immature fibre are the source of another type of biological nep. These clumps of highly entangled fibre can be found in seedcotton prior to mechanical processing. Typically, these neps are found in the unginned lint near malformed seed [53](Watson et al, 1991). These clusters of immature fibres probably come from motes, which are aborted or immature seed, ranging in size from small with little or no lint, to others slightly less than full size with long immature lint [54](Brown & Ware 1958). Mote fibres are commonly called “dead” fibres but in fact, all cotton fibres die when the bolls mature and open. Goynes defines a mote fibre as one that has defects emanating from arrested development and refers to it as a DEAD fibre [55](Goynes - a, 1995). These neps are formed from immature fibres that are damaged while there is still considerable biological material in the lumen or the boll. The biological material from the lumen adheres the immature fibres together, leaving a flat shiny clump of immature fibres.

Coalesced fibre entanglements (Figures 1.2 and 1.3 (in Chapter 1) and Figures 2.4 A & B) are created as a result of the contents of the lumen escaping or liquid from the boll adhering the dead or immature fibres together and result in “shiny” specks on the dyed fabric. The causes include premature harvesting or damage due to insects [56](Wegener, 1980) as well as genetic predisposition and growth conditions such as drought or cool temperatures and early frost, which slows down cell wall deposition [57](Ramey, 1988).

The photomicrograph in Figure 2.4C shows cross-sections of 21-day-old fibres that were part of a growth study by Goynes, Ingber and Triplett [58](Goynes - b, 1995). These fibres were fixed in a wet state, so have never collapsed as field harvested cottons would. The arrow indicates the area where the fibre mass is first beginning to separate into individual fibres. Figure 2.4A is a photomicrograph of a coalesced nep (removed from the outer edge of a yarn) that was clearly seen as a white speck on the dyed fabric. These fibres were dried in the field, processed through dyed fabric, and then fixed in a dry state, so they appear to be collapsed. In the cross-section of a coalesced nep shown in Figure 2.49B, many of the immature fibres seem to be “glued” together. The similarity between the two cross-sections results in the theory that dead immature fibres may be so immature that they have not yet separated into individual strands, or they may have died early in development and were “glued” together by the protoplasm in the boll. If the ultra-immature (biologically underdeveloped) or coalesced fibres have loose edges, they can entangle with mature fibres during processing, trapping the cluster in the yarn and appearing as white specks on the dye fabric (with out any dark foreign matter). Therefore, from this it can be seen that coalesced neps could also be considered mechanical or biological neps. They are also white speck neps, which are discussed in the next section.



A Coalesced white speck on a yarn

B Cross-section of the coalesced white speck

C Immature cotton fibers - 21 day postanthesis

Photomicrographs provided By W. R. Goynes

Figure 2.4: A) Coalesced nep on a dyed yarn and B) its cross-section. C) 21-day post anthesis cotton fibres from a growth study by Goynes et al, [59](Goynes –b, 1995).

2.7.1.4 White Speck Neps

White speck neps, referred to as “white specks” through the remainder of this dissertation, are the main focus of this project. Figure 2.5 has three different white specks highlighted with the matching photomicrograph so the structure may be seen. One is a mechanical nep and the other two are coalesced neps, but they all appear as white specks on the dyed fabric.

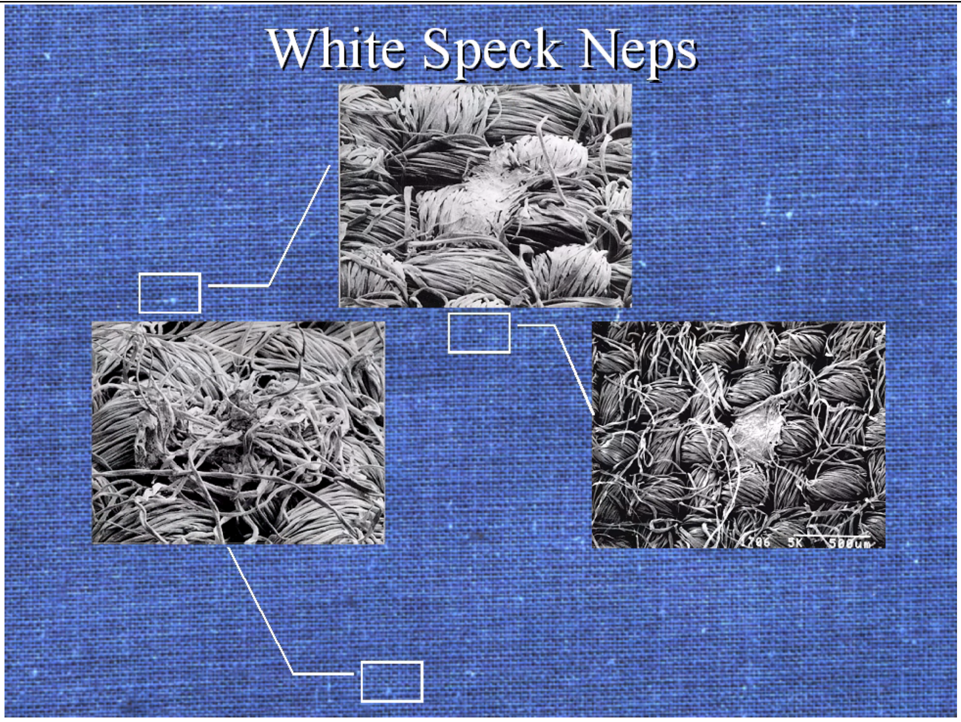


Figure 2.5: White specks as seen by the naked eye on fabric and magnified showing fibre entanglements or clusters of immature fibre

A shiny nep is found on the surface of dyed fabrics; they appear as light or white spots and occur only in the finished fabric [60](Hebert, 1988). Many people have called white specks “shiny neps” due to their reflective appearance (Figure 2.6). When immature fibres die, they collapse into flat ribbons. In dyed fabric, these flat ribbons are passed over steam cans, essentially polishing the already flat immature fibres to a high shine. This makes them even more reflective and the problem becomes even more obvious (Figure 2.6).

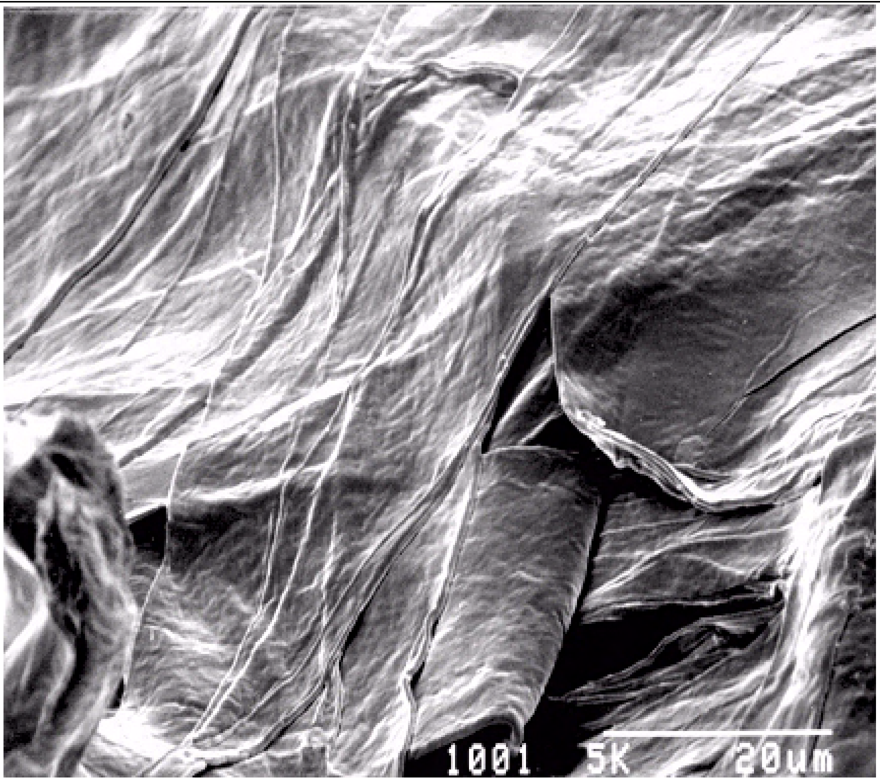


Figure 2.6: White speck - high magnification (photomicrograph by Bruce Ingber)

Goynes used a scanning electron microscope to study the fibre and confirmed that most neps are the result of underdeveloped cotton. "Neps can sneak up on mills: The money is spent to dye the fabric, and it comes out spattered with white specks where the dye didn't take," said Goynes [61](Stoneville, 1997) [62](Goynes et al., 1994). They reported that because of low cellulose content of the undeveloped fibres, these clumps of fibres do not accept dye. Therefore, when a fabric is dyed, the coalesced, mechanical and biological neps formed by immature fibres create undyed spots in the finished fabric. These undyed spots became known as white specks [63] (Goynes et al., 1994).

Not all neps are white specks, but all white specks are neps. Coalesced neps are composed solely of immature fibre clusters. They always appear white or light, and therefore are always white specks. Biological and mechanical neps can be white speck neps if they involve immature fibres, thus appearing white in dyed fabrics, but many of these neps have only mature fibres and appear as a thick and/or a dark spot on yarn and wouldn't be considered white specks. The more general term of "white specks" refers to all nep formations that appear white on the surface of the fabric (Figure 2.5).

2.8 Fibre Measurement Systems

High-speed fibre measurements are now being used to provide the main indication of crop quality. All US and Australian cotton is graded with the industry standard High Volume Instrumentation (HVI) system, which quantifies length, strength, trash, colour and micronaire. The candidate's previous work showed that little correlation could be established between any of these measurements and the degree of white speck nep potential, unless the processing history was known.

While HVI is the industry standard commercial instrumentation system, other systems are available. One commercially available instrument purchased by many textile mills is the Advanced Fibre Information System (AFIS). This machine can be fitted with an optional F&M (Fineness and Maturity) module, which provides the strongest fibre to white speck data relationships available to industry from high-speed measurement systems.

Lintronics FiberLab is the latest contender for commercial acceptance in the measurement of neps and maturity. It is different from the above systems in that it actually makes a web and attempts to simulate the real world conditions of the card.

High-speed near-infrared spectroscopy (NIRS) is another new and promising method of predicting the white speck potential of bale fibre, but it is still under development and not yet available commercially for fibre maturity measurements.

Part of the investigation described in this dissertation was intended to identify the high-speed systems that have the most potential for accurately predicting fabric quality from fibre quality. A large set of samples was required to do this. Samples with known ginning and growth environment history were needed to better establish the correlations with HVI, AFIS, NIRS, and other high-speed measurements of cotton fibre properties. Finally, the measured values are used to establish best-fit relationships between high-speed fibre data and fabric white specks.

3. HIGH SPEED FIBRE MEASUREMENT SYSTEMS

High-speed fibre measurement systems are beginning to influence the way cotton is being ginned in Australia and the U.S.A. The High Volume Instrumentation (HVI) system is well accepted in the Australian and North American ginning industries, while the advantages of several other systems are becoming increasingly well known. This chapter describes the HVI system and other high-speed fibre measuring systems and details the potential benefit of these systems for improving fibre quality.

3.1 HVI

Ginners are more conscious today of what is being done to cotton fibre during the ginning process following widespread acceptance of HVI measurements in recent years. The biggest offences in ginning have been over-drying and over-machination [64](Norman, 1991). Until recently, the grower and the ginner produced cotton “for the grade”. Ginning “for the grade” produces cotton that is visually appealing but gives less than optimum results in the spinning mill. Over-drying may result in reduced trash and a raised grade, but it breaks down large particles into pepper trash. It also makes neps, reduces average fibre length, increases “ends down” in spinning (number of broken ends/spindle hour), lowers yarn evenness, and lowers yarn strength. Cotton quality should be maintained or only minimally reduced during processing. A robust testing and marketing system would encourage breeding, variety selection and ginning for higher quality. Quality is the key, but what fibre qualities should be rewarded financially? Currently the marketing system tends to reward white, clean, but overprocesed cottons with qualities that can cause processing problems and defects in the mill. The grading system was based on hand picked cottons and was very valid in its day. However, today cottons are mechanically harvested and ginned at high speeds which affect cotton quality in ways that hand picking doesn’t. Mills would now rather pay for long, strong, fine, but mature cotton with large trash particles (easily removed in the mill) that process well, producing yarns and fabrics with low defects and high strength. Objective approaches to improving cotton quality are possible, based on:

1) Developing methods to measure all the important properties for textile processing (trash particle size and shape, short fibre content, colour [grey versus yellow], fibre maturity/ fibre fineness, and undyeable neps);
2) Adapting these methods for grading cotton; and
3) Developing ways to reduce damage in processing and so maintain the natural quality produced by the cotton plant; and make allowing the fibre as long and strong as possible [65](Werber, 1994).

The impact of HVI on the ginning process follows from the ginners becoming more aware of gin equipment and conditions that affect the HVI data on cottons that they ginned. The HVI measurements have heightened ginners’ awareness of the need to calibrate machinery controls: automatic calibration is available that allows for multiple temperature and /or moisture sensing inputs for improved process control. Lint cleaners at the gin are being bypassed for improved quality, and single stage lint cleaning is being discussed [66](Anthony, 1986). All these effects of the HVI grading system positively affect the cotton fibre and its associated nepping.

3.1.1 Instrumental Determinations [67](Cotton Program AMS USDA, 2001)

Measurements for the following quality factors are performed by high volume, precision instruments, commonly referred to as "HVI" (High Volume Instrumentation). The specifics outlined in this section are provided by the USDA publication “The Classification of Cotton” [68](Cotton Program AMS USDA, 2001).

3.1.1.1 Fibre Length

Fibre length is the average length of the longer one half of the fibres (upper half mean length). It is reported in 100ths, 32nds of an inch, or millimetres (see conversion chart below). It is measured by passing a "beard" of parallel fibres through a sensing point. The beard is formed when a clamp grasps fibres from a sample of cotton, then the beard is combed and brushed to straighten and parallelize the fibres.

The length of the fibre also influences the fineness of the yarn that can be successfully produced from given fibres. Excessive cleaning and/or drying at the gin may also result in shorter fibre length. Fibre length affects yarn strength, yarn evenness, and the efficiency of the spinning process.

Table 3.1: Standard length conversion chart for cotton classing systems:

Upland Length Conversion Chart

Inches	**32nds**	Millimetres
0.79 & shorter	24 & shorter	19.1 & shorter
0.80 - .85	26	20.6
0.86 - .89	28	22.2
0.90 - .92	29	23.0
0.93 - .95	30	23.8
0.96 - .98	31	24.6
0.99 -1.01	32	25.4
1.02 -1.04	33	26.2
1.05 -1.07	34	27.0
1.08 -1.10	35	27.8
1.11 - 1.13	36	28.6
1.14 - 1.17	37	29.4
1.18 - 1.20	38	30.2
1.21 - 1.23	39	31.0
1.24 - 1.26	40	31.8
1.27 - 1.29	41	32.5
1.30 - 1.32	42	33.3
1.33 - 1.35	43	34.1
1.36 & longer	44 & longer	34.9 & longer

3.1.1.2 Length Uniformity

Length uniformity is the ratio between the mean length and the upper half mean length of the fibres and is expressed as a percentage. If all of the fibres in the bale were of the same length, the mean length and the upper half mean length would be the same, and the uniformity index would be 100. However, there is a natural variation in the length of cotton fibres, so length uniformity will always be less than 100. Table 3.2 can be used as a guide in interpreting length uniformity measurements.

Length uniformity affects yarn evenness and strength, and the efficiency of the spinning process. It is also related to short fibre content (fibre shorter than one half inch). Cotton with a low uniformity index is likely to have a high percentage of short fibres. Such cotton may be difficult to process and is likely to produce low quality yarn.

Table 3.2: Degree of Uniformity as indicated by HVI Index

Degree of Uniformity	HVI Length Uniformity Index (Percent)
Very High	Above 85
High	83-85
Intermediate	80 - 82
Low	77 - 79
Very Low	Below 77

3.1.1.3 Fibre Strength

Strength measurements are reported in terms of grams per Tex. A Tex unit is equal to the weight in grams of 1,000 meters of fibre. Therefore, the strength reported is the force in grams required to break a bundle of fibres one Tex unit in size. Table 3.3 can be used as a guide in interpreting fibre strength measurements. Strength measurements are made on the same beards of cotton that are used for measuring fibre length. The beard is clamped in two sets of jaws, one-eighth inch apart, and the amount of force required to break the fibres is determined.

There is a high correlation between fibre strength and yarn strength. In addition, cotton with high fibre strength is more likely to avoid breakage during the manufacturing process.

Table 3.3: Degree of strength of cotton fibre as indicated by HVI measurements

Degree of Strength	HVI Strength
Very Strong	31 & above
Strong	29 -3 0
Average	26 - 28
Intermediate	24 - 25
Weak	23 & below

3.1.1.4 Micronaire

Micronaire is the most commonly used instrumental fibre-quality test [69] [70](Lord and Heap, 1988; Moore, 1996). Micronaire is a measure of fibre fineness and maturity combined. Micronaire is an indirect measure of fineness and maturity, but a direct measurement of the air-permeability. An airflow instrument is used to measure the air permeability of a constant mass of cotton fibres compressed to a fixed volume. The chart in Figure 3.1 can be used as a guide in interpreting micronaire measurements.

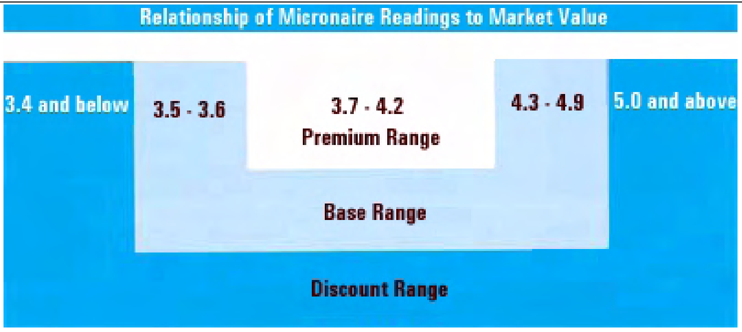


Figure 3.1: Relationship of micronaire readings to market value in standard cotton classing scheme.

Fibre fineness affects processing performance and the quality of the end product in several ways. In the opening, cleaning and carding processes, low micronaire, or fine fibre, cottons require slower processing speeds to prevent damage to the fibres. Yarns made from finer fibre result in more fibres per cross section, which in turn produces stronger yarns. Dye absorbency and retention varies with the maturity of the fibres. The greater the maturity, the better the absorbency and retention.

Figure 3.2: Cotton classing

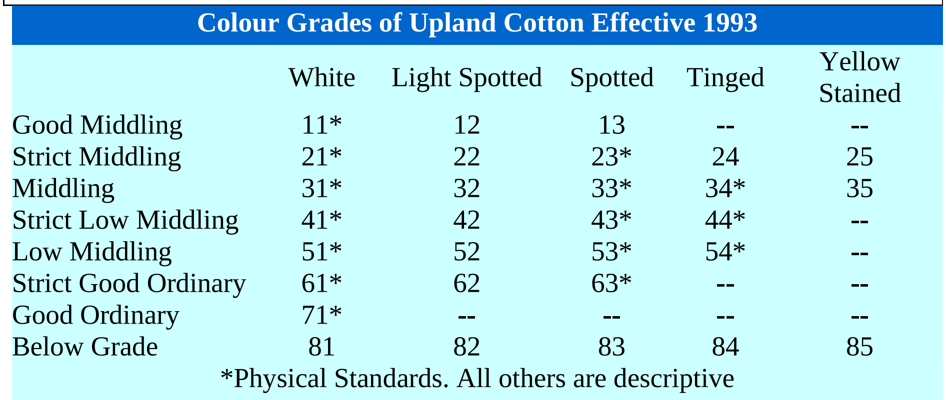
Samples are classed on an assembly-line arrangement utilizing the latest technology and equipment as shown in Figure 3.2. Fibre measurement results are electronically transmitted to the classing facility's computerized database.

3.1.1.5 Colour Grade

The colour grade is determined by the degree of reflectance (Rd) and yellowness (+b) as established by the official USDA standards and measured by the HVI. Reflectance indicates how bright or dull a sample is and yellowness indicates the degree of colour pigmentation. A three-digit colour code is used. The colour code is determined by locating the point at which the Rd and +b values intersect on the Nickerson Hunter cotton colorimeter diagram for Upland cotton (Table 3.4).

The colour of cotton fibres can be affected by genetics, rainfall, freezes, insects and fungi, and by staining through contact with soil, grass, or the cotton plant's leaf. Excessive moisture and temperature levels also can affect colour while cotton is being stored, both before and after ginning. As the colour of cotton deteriorates (greys) due to non-optimal environmental conditions, especially bacterial growth, the probable processing efficiency is reduced. Colour deterioration is an indication of the fibres' reduced ability to absorb and hold dyes and finishes.

Table 3.4: Colour Grades of Upland Cotton



Colour Grades of Upland Cotton Effective 1993

	White	Light Spotted	Spotted	Tinged	Yellow Stained
Good Middling	11*	12	13	--	--
Strict Middling	21*	22	23*	24	25
Middling	31*	32	33*	34*	35
Strict Low Middling	41*	42	43*	44*	--
Low Middling	51*	52	53*	54*	--
Strict Good Ordinary	61*	62	63*	--	--
Good Ordinary	71*	--	--	--	--
Below Grade	81	82	83	84	85

*Physical Standards. All others are descriptive

There are 25 official colour grades for American Upland cotton, plus five categories of below grade colour, as shown in the tabulation below. The USDA maintains physical standards for 15 of the colour grades. The others are descriptive standards.

3.1.1.6 Trash

Trash is a measure of the amount of non-lint material (such as leaf and bark from the cotton plant) in the cotton. The surface of the cotton sample is scanned by a video camera and the percentage of the surface area occupied by trash particles is automatically calculated. Although the resulting trash determination is not the same as classer's leaf grade, there is a correlation between the two as shown in Table 3.5

below.

Table 3.5: Relationship of trash measurement to classer's leaf grade

Relationship of trash measurement to classer's leaf grade

Trash Measurement (4-yr. Avg.) (% Area)	Classer's Leaf Grade
0.12	1
.20	2
.33	3
.50	4
.68	5
.92	6
1.21	7

3.1.2 Classer Determinations

Although the official USDA colour grade is measured by HVI, and an HVI trash measurement is provided, the traditional method of classer determination for leaf grade and extraneous matter continues to be included as part of USDA's official cotton classification.

3.1.2.1 Leaf Grade

The classer's leaf grade is obtained by a visual estimate of the amount of cotton plant leaf particles in the cotton. There are seven leaf grades, designated as leaf grade "1" through "7", and all are represented by reference samples. In addition, a "below grade" designation is descriptive. Plant variety, harvesting methods, and harvesting conditions affect leaf content. The amount of leaf remaining in the lint after ginning depends on the amount present in the cotton before ginning, and on the type and amount of cleaning and drying equipment used. Even with the most careful harvesting and ginning methods, a small amount of leaf remains in the cotton lint. From the manufacturing standpoint, leaf content is all waste, and there is a cost factor associated with its removal. In addition, small particles cannot always be successfully removed and these particles may detract from the quality of the finished product.

3.1.2.2 Preparation

Preparation is a term used to describe the degree of smoothness or roughness of the ginned cotton lint. Various methods of harvesting, handling, and ginning cotton produce differences in roughness or smoothness of fibre (preparation) that sometimes are very apparent. Abnormal preparation in Upland cotton has greatly diminished in recent years due to improvements in harvesting and ginning practices, and now occurs in less than one-half of 1 percent of the crop. If the cotton has abnormal preparation, that is noted under extraneous matter on the classification record.

3.1.2.3 Extraneous Matter

Extraneous matter is any substance in the cotton other than fibre or leaf. Examples of extraneous matter are bark, grass, spindle twist, seed coat fragments, dust, and oil. The classer notes the kinds of extraneous matter, and an indication of the amount (light or heavy), on the classification document.

In 1993, the classer grading system was changed. Under the old system of grading, the classer determined a composite grade of colour and trash content. Bales that contained bark and grass were reduced one or more grade levels. Under the current system, the classer determines a colour grade, a leaf (trash) grade and notes whether there is bark or grass present in the bale, factors that do not influence the grade. Each colour grade percentage will include all levels of leaf [71](Cotton Program AMS USDA, 2001).

3.2 Other High-Speed Maturity Measurements.

Fast methods of high-speed maturity measurements other than the HVI (High

Volume Instrument) include the Fineness and Maturity Tester (FMT), Lintronics FiberLab and the Advanced Fiber and Information System (AFIS). The FMT is based on airflow resistance to cotton (Lord and Heap, 1988). Lintronics measurements of micronaire, fineness, and maturity are based on double compression airflow resistance and are made by image analysis of data from the web that the system makes and analyses for neps and seed coat fragments. AFIS is based on the amount of radiation (NIR) sensed by two detectors as a single cotton fibre moves across the incident beam [72](Gordon et al., 1997). Benchmark analysis speeds, exclusive of sample preparation, for FMT, FiberLab and AFIS are, respectively 20, 55 and 60 seconds [73](Mor, 2003). Although, these are high-speed systems, industry does not consider them high volume instrumentation.

3.2.1 FMT

The first dual-compression airflow instrument for estimating both fibre fineness and fibre maturity from airflow rates through untreated raw cotton was the Arealometer, developed by Special Instruments Laboratories Inc (Knoxville, TN)[74, 75](ASTM, 1976; Lord and Heap, 1988). The Arealometer provides an indirect measurement of the specific surface area of loose cotton fibres, that is, the external area of fibres per unit volume (approximately 200-mg samples in four to five replicates). Empirical formulae were developed for calculating the approximate maturity ratio and the average perimeter, wall thickness, and weight per inch from the specific surface area data. The precision and accuracy of Arealometer determinations were sensitive to variations in sample preparation, to repeated sample handling, and to previous mechanical treatment of the fibres, e.g., conditions during harvesting, blending, and opening. The Arealometer was never approved for acceptance testing, and the ASTM method was withdrawn in 1977 without replacement [76](Bradow, 2000).

The variations in biological fineness and relative maturity of cotton fibres cause the porous plugs used in air-compression measurements to respond differently to compression and, consequently, to airflow [77](Lord and Heap, 1988). The IIC-Shirley Fineness/Maturity Tester (Shirley FMT), a dual-compression instrument, was developed to compensate for this plug-variation effect [78](ASTM, 1994). The Shirley FMT is considered suitable for research, but is not used for acceptance testing (grading) due to low precision and accuracy. Instead of fineness and maturity, the combination micronaire value has become the standard estimate in the USDA-AMS classing offices.

The need continues for a reliable reference method that can analyse, in about 30 seconds, several grams of cotton for fineness and maturity. The Shirley Developments LTD. Micromat Fineness and Maturity Tester (FMT) provides a reference method that meets this need. The method is based on the resistance to air flowing through cleaned cotton in a short pipe. Montalvo et al. [79](1995) identified a number of biases in data produced by the FMT and performed experiments to define acceptable limits. Montalvo and Faught [80] [81](1998; 1999) developed the theory and reduced to practice physical standards for calibrating, control and elimination of drift in the FMT. To calibrate the upgraded FMT (Figures 3.3 and 3.4) with cotton, a dozen new FMT standard cottons were produced, analysed by a combination of independent reference methods including image analysis [82](Montalvo et al., 2001). Combining data from independent methods is the approach used by the National Institute of Standards and Technology (NIST) in developing certified reference materials [83](Schiller and Eberhardt, 1991).

Figure 3.3 The Shirley Developments LTD. Micromat Fineness and Maturity Tester (FMT), a dual-compression instrument [84](ASTM, 1994). Photo supplied by J. Montalvo [85](Montalvo, 2002).

Instrumentation for the rapid measurement of cotton maturity and fineness must be calibrated before it can give accurate results. Calibration is based on results from a reference method that gives accurate and precise analyses of cottons. Unfortunately, the FMT instrument readings are subject to drift so the data can be unsuitable for calibration. In Montalvo's work, the FMT is modified including headspace resistance standards (HRS) and leak detector module (LDM) (Figure 3.4) to produce consistent results. The FMT measures maturity and fineness based on the principle of air permeability through a fixed mass of fibres. To keep the FMT readings from drifting, high precision physical standards were developed. The physical standards create a precise permeability when air is drawn through the device. The technology is being transferred to the industry by commercialisation of Agricultural Research Service (ARS) research [86](Montalvo, 1998).

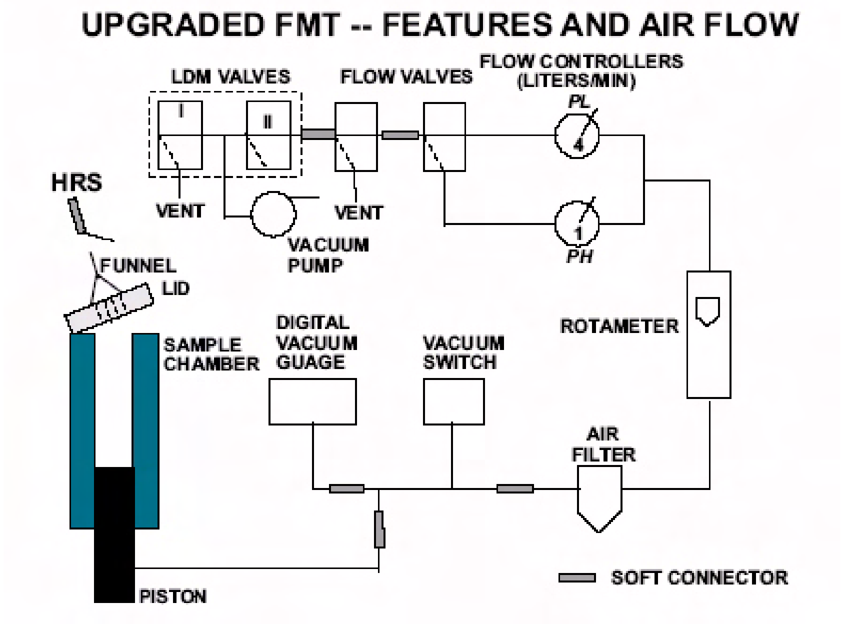


Figure 3.4 Upgraded Micromat at the Southern Regional Research Center includes headspace resistance standards (HRS) and leak detector module (LDM) and airflow. *PL* and *PH* are the initial and second stage pressure drops, respectively. [87](Montalvo, 2002)

In order to clarify the meaning of the micronaire values, the **Shirley FMT** tester was used to estimate the maturity and fineness of each of the cottons; these measurements are shown in the bottom two rows of Table 3.6. Results indicate that the HS-200 cotton sample is of comparable maturity with the other two cottons, but that it is a finer fibre than the other two. Therefore, the low micronaire reading for the HS-200 cotton is due primarily to fibre fineness, rather than to immaturity.[88](*Cole*, 1997)

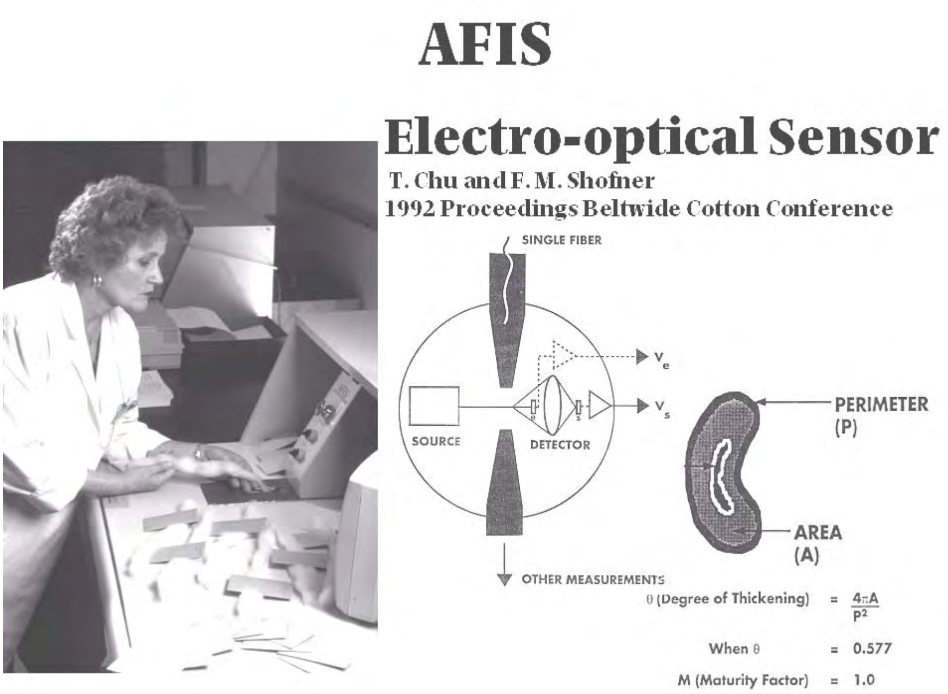
Table 3.6: HVI and FMT Fibre Data show that Micronaire is an indirect estimate of fibre fineness and maturity [89](Montalvo, 1989).

Properties	HS-200	DPL-5409	Acala
Micronaire (mg/in)	3.2	4.2	4.7
FMT Maturity (%)	80.6	78.8	84.1
FMT Fineness (mtex)	142	184	192

3.2.2 AFIS - Advanced Fiber Information System

In 1988, Shofner at Schafner Technologies Inc., Knoxville, USA, developed the AFIS-N, which included two measuring modules. Module T measures the number and size of trash and dust particles while module L & D measures the length and the diameter of individual fibres as well as short fibre content. Subsequent adaptations were made to the AFIS-N to allow Seed Coat Fragments (SCFs) to be counted separately from fibrous neps and to measure cotton fineness (F) and maturity (M) on a single fibre basis [90](van der Sluijs, 1999). Maturity measurements made by the AFIS have been compared with image analysis of fibre cross sections. The correlation diminishes with later versions of AFIS [91](Thibodeaux et al., 2003).

AFIS, now manufactured by Zellweger Uster, mechanically processes a sample of cotton to give a “cloud” of individualized fibres suspended in an air stream. The air stream transports individual fibres into a narrow diameter tube for optical analysis (Figure 3.5). Gordon et al. [92](1997) collaborated in theoretical and experimental work to probe into AFIS data distribution from a set of commercial cottons. Their results did not agree with that predicted by theory and suggest that the physical process by which the instrument measures maturity is not yet understood.



AFIS

Electro-optical Sensor

T. Chu and F. M. Shofner

1992 Proceedings Beltwide Cotton Conference

θ (Degree of Thickening) = $\frac{4\pi A}{P^2}$

When θ = 0.577

M (Maturity Factor) = 1.0

Figure 3.5: AFIS, by Zellweger Uster, utilized an electro-optical sensor to detect fibre properties and their distributions.

Sampling requires the hand generation of five half-gram slivers, approximately thirty centimetres (12in) in length, of fibres pulled from various points in the bale. Separating trash from lint is done using aerodynamic methods similar to carding which individualizes fibres. The aeromechanical processor separates the sample into individual fibres, neps, and trash. The trash particles are collected in the trash trap. The fibres and neps are picked up by an air stream and transported through an electro-optical sensor. Trash is removed through counter flow slots and then measured with the trash sensor. The five thousand fibres are then passed before an optical sensor where they produce characteristic voltage versus time waveforms. The individual neps produce ‘spike’ waveforms whose magnitude and duration are related to the size of the neps. The resulting signals are analysed for length, diameter, maturity and fineness.

The F & M module, currently unavailable to industry, enabled the fineness and maturity measurements to be undertaken at SRRC (Versions 2 and 4) and Zellweger (Version 5). Five repetitions of the five slivers were utilized on these systems to calculate the mean, standard deviation, and percent coefficient of variation for each parameter. The parameters relevant to this project include Micronafis (similar to micronaire), which measures fineness and maturity in micrograms of one inch of fibre, and Theta (θ), which represents the circularity, or the degree of thickening, as, calculated by the equation:

$$\theta = 4\pi \frac{A}{P^2}.$$

Where A = the cross-sectional area, and

P = perimeter of the fibre cross section

Most importantly, Immature Fibre Fraction (IFF) measured the percentage of fibre with values of theta less than 0.25. In every case, there was an inverse correlation between the fraction IFF and Micronafis, and Theta. An increase in IFF resulted in a decrease in the values of Micronafis and Theta. Since white specks are primarily immature fibre clusters, % IFF was seen as a possible prediction tool for indicating a potential white speck problem.

3.2.3 Lintronics

FiberLab (Figure 3.6 shows the combination of FCT (Fibre Contamination Tester) and FQT (Fibre Quality Tester)) works at ginning production speeds, and is very easy to operate. FiberLab is designed to measure impurities such as neps and to test the stickiness of cotton.

Figure 3.6: Lintronics FiberLab measures length, strength stickiness, trash, seed coat fragments and neps [93](Mor, 2003).

3.2.3.1 FQT

FiberLab FQT system employs technologies in fibre testing that include:

1. Automatic feeding by a cassette that self reverses for its second cycle.
2. Length and strength measurements by a fully automated beard-sampling device.
3. Micronaire & Maturity are measured using a unique automatic system for blending the cotton sample. It employs standard single and double compression technology using blended cotton. It produces well-blended samples at very high speeds (55 seconds) - vital for testing maturity accurately.
4. Colour is measured automatically. This module self-calibrates for every sample.

3.2.3.2 FCT

The Fibre Contamination Tester (FCT) [94](Mor, 2003); manufactured by Lintronics measures neps, seed coat fragments (SCF and trash by means of unique image processing techniques and algorithms that enable it to test for stickiness, neps, SCF and trash. Its major advantage is its ability to test contradicting quality parameters. FCT is in fact a simulator a spinning process. A sample of cotton (from raw to roving) is taken as a bundle and entered into a self-cleaning micro-carding device inside the FCT (Figure 3.7). It produces about10 meters of transparent web that exposes the impurities and contaminants. About one square meter per sample (at the same density as used in the spinning mill process) is tested. The web is analysed by machine vision, in real time, for trash, neps and seed-coat fragments and then pressed between two "stickiness" crush rolls, similar to the crush rolls in commercial cards. The cotton web is then removed by vacuum. The deposits that remain on the stickiness crush rolls are evaluated by a laser signal analysis system to determine stickiness (amount and size). One sample takes 40 seconds to test, including its cleaning cycle between samples.

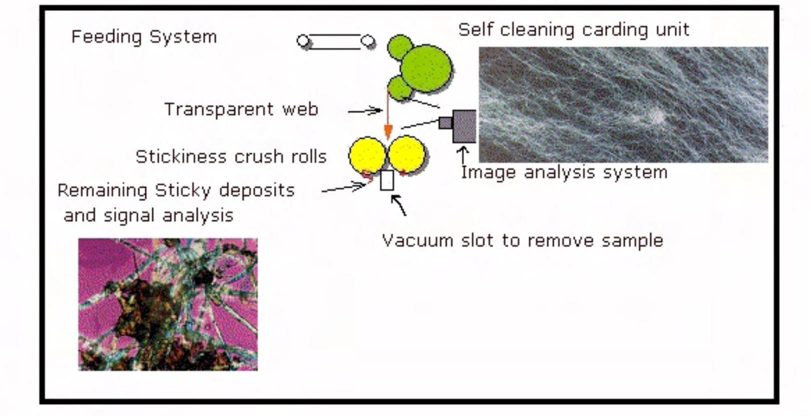


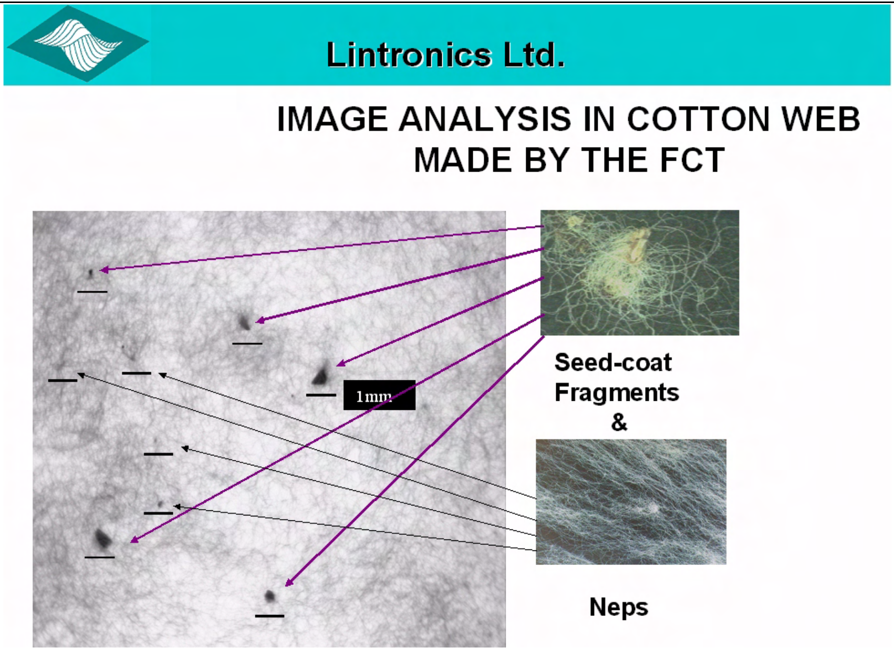
Figure 3.7: FCT testing schematic [95] (Mor, 2003).

Neps in Webs **-** Neps can also be measured by digital image processing (Figure 3.8). Using an image analysis program, webs can be examined automatically with regard to their disruptive particle content. The size of the area to be examined can be freely selected. Type and form classes determined during the course of an examination, as well as the sizes of the disruptive particles, are recorded.

These data can be statistically evaluated to determine:

Number and size of particles per type class (i.e., Neps, Fibrous seed coat fragments, Wood, Leaf fragments, and Extraneous non-cotton fibres)

The disruptive particles are allotted to size classes and the corresponding frequency distribution is determined [96](Wulfhorst, 1989).



Lintronics Ltd.

IMAGE ANALYSIS IN COTTON WEB
MADE BY THE FCT

Figure 3.8: Lintronics measures mechanical neps and seed coat fragments, which are detected using image analysis on the web it generates from the cotton sample [97](Mor, 2003).

In a comparison of nep determination by card web neps, Agricultural Marketing Services (AMS) nep test machine, and yarn neps (Uster), Harrison, (1986) found each method delivered similar results and concluded that a good prediction of yarn neps can be obtained from card web neps [98](Harrison, 1986).

3.3 Hand count

Although hand counting neps is not a high-speed system, it is described here as a means to acquire baseline data for use with the high-speed systems. In the ASTM

D3216 - 78 method (Grading Cotton Card Webs for Appearance), specimens of a web are placed on a dark background, with particular care taken to preserve the original condition of the web, as it would be immediately after leaving the web-detaching device on the card. The web specimens are compared with photographs of web representing five levels of web quality. The grade is based on the appearance and nep content of the specimens in comparison to the photographs [99](ASTM Codes, 1978).

For the manual counting method, specimens of web are extracted on flat supports and covered with templates containing a number of small holes or cells of equal cross-sectional area. For each specimen a count is made of the number of cells containing neps. The average number of cells with neps per template is converted into neps per unit area of web on the assumption that neps follow a Poisson distribution. Templates should be no larger than 150mm x 300mm and should contain 20 to 40 holes each of 1 square inch in area [100](Verschraege, 1989).

4. IMAGE ANALYSIS SYSTEMS
AND
THE U.S. EXTREME VARIETY WHITE SPECK STUDY

This chapter sets out the experimental work and analysis undertaken to develop and validate a system for reliably quantifying the amount of white specks in a woven fabric. An automatic system was required to enable the collection of a large number of measurements so that adequate amounts of data could be obtained in the work described in subsequent chapters.

4.1 Introduction

It has been estimated that 40% of white specks are caused by processing and 30% by the cotton variety [101](Bragg, 1992). Varietal tests indicate that cotton varieties that have a strong tendency to nep usually have high levels of immature fibre. Varieties mature at different rates. Some mature quickly and there is only a limited “tail” (the time period when most bolls have fully matured but some are still maturing). Others mature more slowly, and the “tail” drags out longer. These differences increase the range of maturities in harvested bolls. It was concluded that nep formation is heritable; and that nep levels are influenced by fibre fineness and maturity [102](Miravelle, 1984).

The genotype influences the tendency of fibres to form neps and the occurrence of seed coat fragments (SCF) and motes. Motes are found in genetically disposed cultivars that have expressed, to some extent, a defect in the pollination process or environmental conditions at anthesis [103](van der Sluijs, 1999). White specks, although primarily immature fibre neps, may also result from seed coat fragments that have short fibres attached that resist dye. Often, these seed coats appear as dark specks in the dyed fabric with white specks around the SCF, due to their attached short, immature fibres. These SCFs are portions of immature or mature seeds that have disintegrated during mechanical processing. In addition, the seed coat has a weakness at the chalazal (point at which the nucleus and seed coat of an ovule are united) portion of the seed. This portion easily peels and is generally believed to be the source of the seed coat fragment problem. SCFs are produced by cultivars that have a high fibre-to-seed attachment force, a strong shank and loose tissue at the chalazal end of the seed.

Some individual varieties have particularly strong tendencies to produce high levels of immature cotton. It is likely that in the future this tendency will have a greater importance in the selection of new varieties. Breeding programs have been geared to producing longer, stronger and finer cottons, but other elements often change without control while the breeder seeks the desired property. Breeders could reduce the nep formation potential of cotton by selecting for further development those varieties and fibre properties that are consistently associated with low nep count and seed coat fragment levels in ginned lint, yarn and fabric.

The two varieties shown in Figure 4.1 are from a breeding program in California where the EAC-30 variety was bred to mature early from the EAC-32 line. The cottons were grown in the same field, and were harvested and ginned identically. These photomicrographs show that the EAC-32 cotton has a much higher level of immature fibres than the EAC-30. EAC-32 produced very high levels of white specks (see Figure 4.5) in the dyed fabric while the EAC-30 had minimal levels. This is not surprising when fibre properties such as the cell wall thickness and Buckling

Coefficient (Figure 4.2) are considered. Two varieties (both Acalas) have similar perimeters but the EAC-30 has a much thicker cell wall and would be stiff in comparison to the thin-walled EAC-32. Hence, it would be less prone to nepping during processing and should have very good dye retention due to the level of cellulose found in the thicker cell wall. Conversely, the thin-walled EAC-32 fibres would be very prone to nepping and be dye resistant due to the lack of cellulose, thereby appearing as white specks in the dyed fabrics.

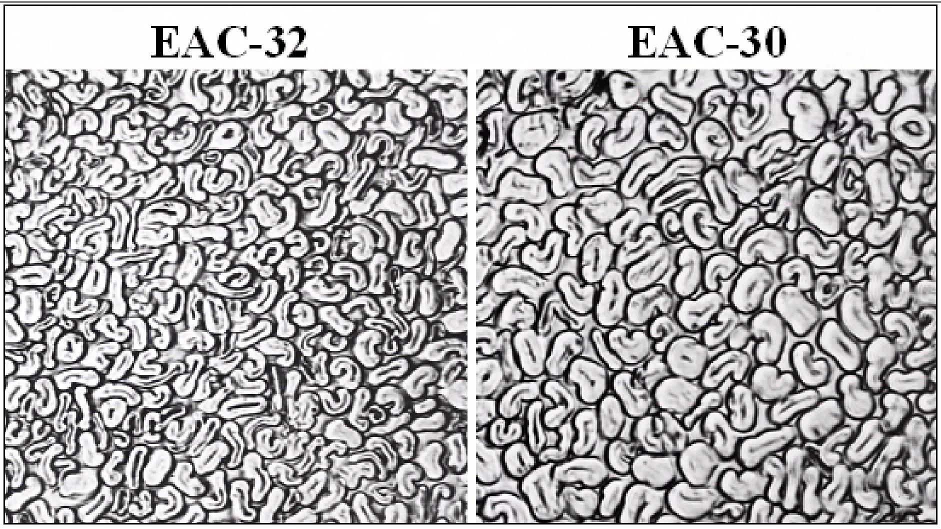
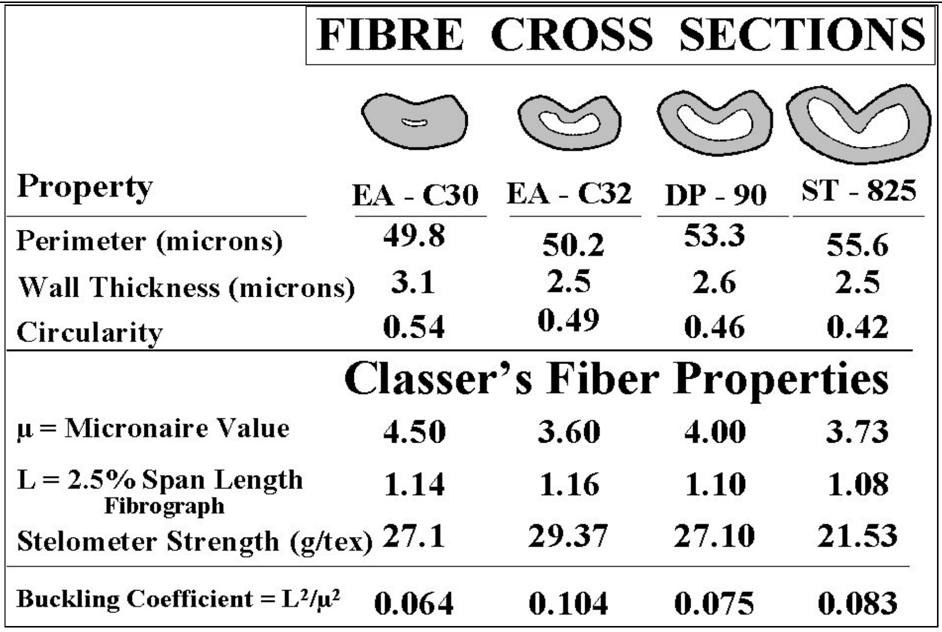


Figure 4.1: The two varieties are from a breeding program where the EAC-30 was bred to mature early. (Note: High level of flat, immature fibres in EAC-32). Hardy cross-sections and photomicrographs provided by Jarrel Carra (SRRC).

Hebert [104](1988) found that 96% of all neps studied contained immature fibres, and 50% of the examined neps were entirely immature fibres. The dead or undeveloped fibres have virtually no secondary wall and are exceedingly flat. The dead fibres collapse into flat ribbons that highly reflect light and thus appear as white specks in the dyed fabric [105](Peter et al, 1989). The shortness of the path of light through the extremely thin walls of the immature and dead fibres of the dye resistant nep accentuate the light coloured or white appearance of the nep. In addition, the immature fibres have an accelerated rate of sorption and desorption as compared to mature fibres and thus dispel dye more easily [106](Cheek, Wilcock, 1988).

4.2 Extreme Variety Experimental program

The white speck phenomenon is an industry-wide problem, so it is important to be able to predict this phenomenon from high-speed measurements of fibre properties. Before such predictions can be made, however, it is necessary to find a method for accurately quantifying the level of white specks on fabrics. This section describes an experimental program undertaken to develop a system to accurately quantify the level of white specks in fabric. It sets out the field and laboratory development work in related experimental programs.



FIBRE CROSS SECTIONS

Property	EA - C30	EA - C32	DP - 90	ST - 825
Perimeter (microns)	49.8	50.2	53.3	55.6
Wall Thickness (microns)	3.1	2.5	2.6	2.5
Circularity	0.54	0.49	0.46	0.42
Classer's Fiber Properties				
μ = Micronaire Value	4.50	3.60	4.00	3.73
L = 2.5% Span Length Fibrograph	1.14	1.16	1.10	1.08
Stelometer Strength (g/tex)	27.1	29.37	27.10	21.53
Buckling Coefficient = L^2/μ^2	0.064	0.104	0.075	0.083

Figure 4.2: Fibre properties of the four EVS cottons. Illustration based on cross-sectional data.

An initial field study was designed to produce sample fabrics with extreme levels of white specks. It was named the U.S. Extreme Variety Study (EVS). Varietal influences on white specks were examined to eliminate as many confounding variables as possible, such as weathering, soil conditions and maturity. Standard processing was employed from field to fabric and full warps were made for each variety, so the final fabrics reflected varietal differences only.

For the EVS study, four extremely different U.S. cotton varieties were grown under irrigated conditions in the same field in the San Joaquin valley in California. The cottons included two typically rain grown and two irrigated varieties. DP-90 is a commercial Delta Upland fibre, while ST-825 is a Mississippi hybrid variety. EAC30 (experimentally bred to mature early from the EAC-32 line) and EAC-32 (Prema) are Acala cottons (Figure 4.2).

4.2.1 EVS Processing Methodology

Full size production equipment was used throughout the study. The EVS cottons were spindle picked and then ginned, to remove the seeds, at Mesilla Park, NM, with the lint cleaned by two saw-type lint cleaners. Three bales were produced for each variety. The bales were opened and processed into yarn and then woven into fabric and dyed. See Appendix A - Figure A1- 1) Samples of the fabric were dyed and the white specks were counted both manually and with image analysis systems. All of these processes were standardized as much as possible to allow future comparisons with the EVS results. The ginned fibre samples were evaluated using the following: Fibrograph, Stelometer, Arealometer, Peyer, microscopic cross sections with image analysis, and the complete ranges of HVI (Motion Control 3500 and Spinlab 9000), AFIS and Lintronics tests. Figure 4.2 shows some of the results from these measurements.

4.2.1.1 Mill Processing

The cotton was processed using mill equipment at the USDA, Southern Regional Research Center (SRRC). Three bales were used for each variety. Equal amounts were taken from each of the three bales to make four lots of equal weight per variety for processing. All sixteen lots underwent the same opening process. They passed through a hopper, Superior Cleaner, and two beater sections of the picker and then were chute fed to the cards. Two of the four lots from each variety were single carded, while the other two were tandem carded. The international cotton industry uses non-standard, U.S. units of measurement, and so these units have been adopted in this dissertation. SI units are also provided where appropriate throughout the dissertation. A 30 Ne, 30/1 or 30’s yarn all indicate a 30 cotton count yarn, which means that it would take 30 x 840 yards or 25,200 yards to weigh one pound. ASTM has identified tex yarn number as the standard measure of yarn. Tex determines the yarn number by determining the weight in grams of 1 kilometre (1000 meters) of yarn [107](Joseph, 1986). For clarity, both cotton count and tex will be given.

The first drawing had eight doublings to 55 grains/yard (3.99g/m) and the second drawing had eight doublings to 55 grains/yard. (3.99g/m) Roving was 1.25 hank (472 tex) with medium soft twist. Both 30’s (19.7 tex) and 40’s (14.8 tex) yarns with a 3.8 T.M. (twist multiplier - the ratio of turns per inch to the square root of the yarn count) were spun on a Roberts Arrow 240 spindle spinning frame with spindle speed of 9500 rpm. Warp yarns with a 4.2 T.M. 30’s (19.7 tex) were also spun for fabrics with 40’s (14.8 tex) filling for all varieties.

4.2.1.2 Dyeing Procedure for Fibre Evaluation

Fibre dyeing (Goldwaithe[108] maturity test, using red dye portion only) allowed the overall number of neps and the white specks in the fibre to be identified. A 0.2 g sample was sandwiched between two pieces of 160cm^2 (25 in^2) fibreglass screening and clamped tightly within a 100 cm (4 in) diameter polymer embroidery hoop (or tambour frame). The webs were opened up slightly by hand before mounting in the screening to minimize fibre clumping. This ensured free access of the dye liquor to the fibre without any possible loss of fibre through the web.

The web in its tambour frame was submerged in a 250 ml (cc) dyebath in a 15 cm diameter pan. CI Direct Red 81 was selected for this dyeing procedure due to a known lack of affinity for immature fibres [109, 110] (Mangliardi, 1990 and Bragg, 1992) and poor coverage of immature fibre neps in fibre and fabric. The dyeing pan was placed on a hotplate equipped with a magnetic stirrer and a thermistor probe. The dyebath included 0.015% (owb [on weight of bath]) dye, 0.1% owb NaCl, and 0.01% of non-ionic surfactant (Triton X-100, Rohm and Haas). Dyeing was carried out at 60°C for one hour with constant stirring, with the salt added in equal portions at three 15-minute intervals.

The dried web was spread out on a 25 x 10 cm panel of clear Plexiglas, and the fibres teased into a thin layer of uniform density as shown in Figure 4.3. A second panel of Plexiglas was put on top of the fibres, rendering them immobile. The composite assembly was then put onto a piece of black velvet fabric and examined under a magnifying lamp (Figure 4.3). The number of undyed neps on each 0.2 g web was counted. Five webs were examined for each fibre variety and the total counts were recorded as the number of white specks per gram.

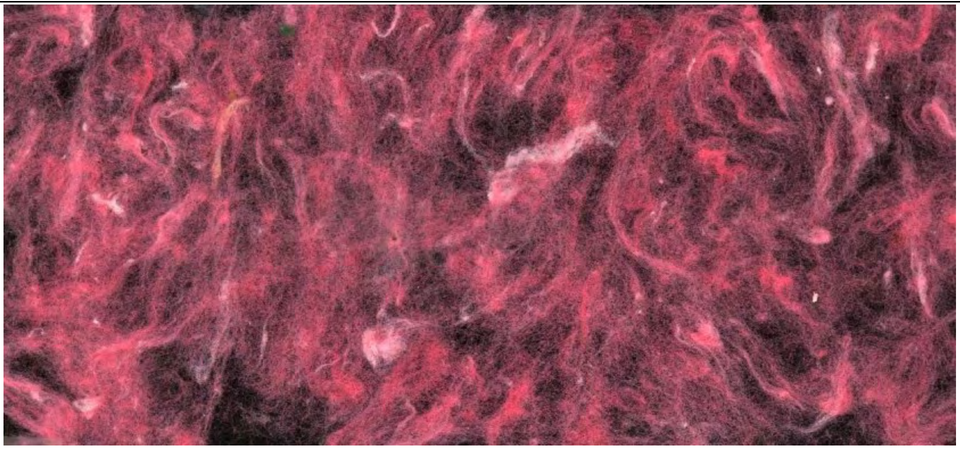


Figure 4.3: Sample of bale cotton fibres dyed red from Goldthwait's maturity dye test and spread out on black velvet. Immature fibre is present as small and large clumps. Mature fibres absorb dye, while the immature fibres remain white.

4.2.1.3 Dyeing Procedure for Fabric Evaluation

The scouring and dyeing procedures were standardized for use throughout this project. The fabric is finished with a 0.1% Prechem 70, 0.3% T.S.P.P. boil-off, a caustic scour of 1.1% Prechem SN, 1.1% Mayquest 80, 0.1% Prechem 70 and 0.7% sodium hydroxide (caustic soda), followed by the same boil-off procedure. The fabric was then bleached (0.1% Prechem 70, 0.5% Mayquest BLE and 3.0% peroxide (Albone 35)) followed by an acid scour (0.1% acetic acid) and dyed with 4% Cibacron Navy F-G Blue, 0.5% Calgon, 8% Sodium Chloride, 0.8% Na_2 Co_3 (soda ash) and 0.5% Triton Tx-100. This dye has a high propensity for highlighting white specks in finished fabrics.

Four 130cm^2 (20 square inch) fabric samples were evaluated by two technicians for each of the eight conditions of the EVS study. The number of white speck neps on each 4 inch by 5 inch dyed fabric was counted. From the examination of four fabrics (for each fibre carding treatment), the overall total number of such white specks per square meter was found.

4.2.2 White Speck Evaluation

After the processing was completed, the tandem carded fabrics had a visibly higher level of white specks than the single carded fabrics. It was suspected that the new tandem card (this was the first study run) had not been properly set when it was installed. Investigations showed that the second card cylinder was left in its shipping position. The cylinder was high on the left side and so the fibres tended to roll across it to the area of least resistance when they hit that cylinder, causing the number white specks to increase considerably as seen in Figure 4.4.

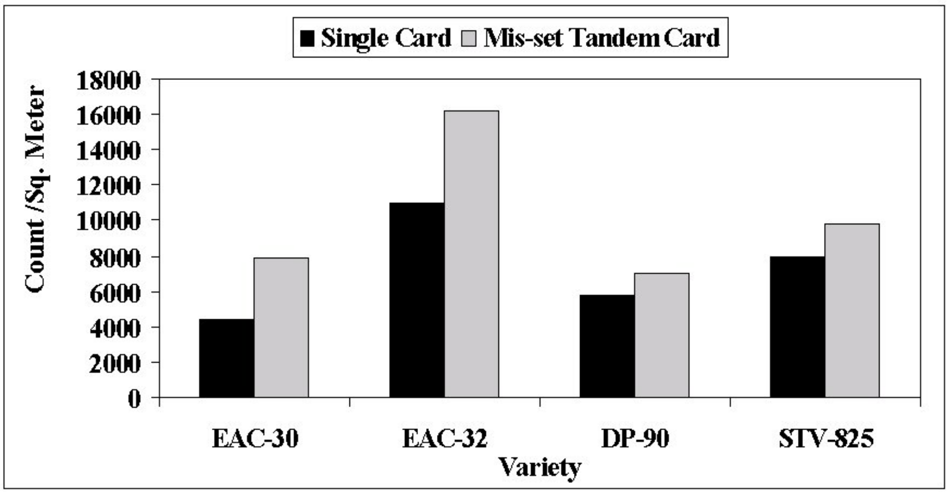


Figure 4.4: Card settings significantly affect the level of white specks on dyed fabrics.

As it turned out, the error had the beneficial effect of producing fabrics with a broader range of white speck than would otherwise have been the case. Subsequent comparisons of the performance of image analysis systems used these EVS fabrics as test specimens. The EVS fabrics provided visibly different levels of white specks as seen in the scans of the single carded fabrics in Figure 4.5.

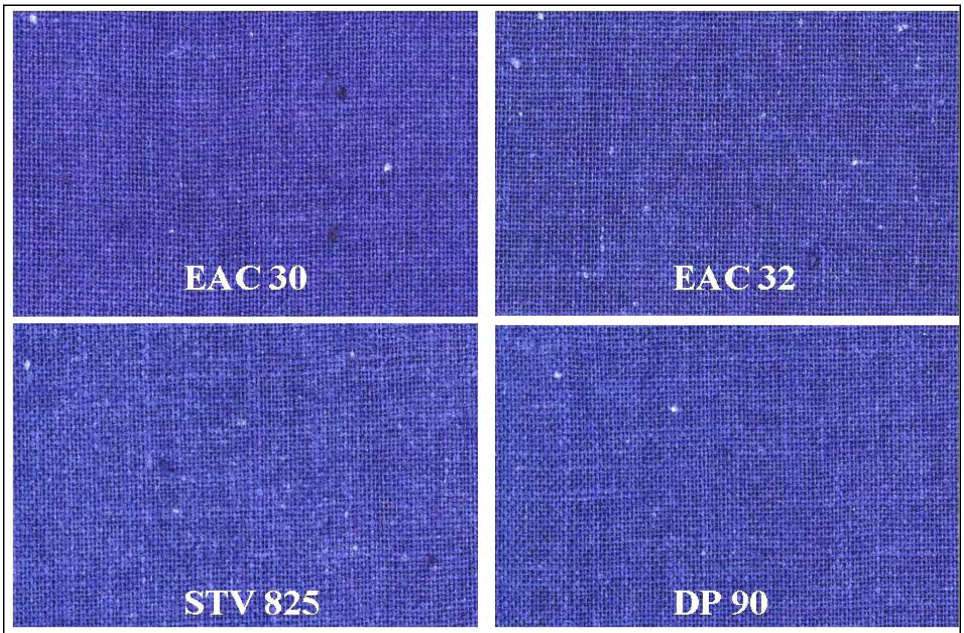


Figure 4.5: Four Varieties grown to show different levels of white specks on fabric.

Two technicians independently counted white specks on four samples (64.5 cm^2 = 10in^2 in size) for each of the eight fabrics. Counts were recorded as the number of white specks per square meter and compared with counts from the. Cotton Inc., Cambridge, Optimas 4.0 & 5.2 and Xu's AutoRate image analysis systems as explained later in this chapter.

Hand counting white specks, as described above, is an extremely time consuming process, and is only practical for a small number of samples. Many samples were required in order to meet the objectives of this study, and so a high-speed system for analysing neps on the fabric was required in order to complete the project. The hand-counted values of white speck provide a benchmark to test a range of image analysis systems that are described below. Figure 4.6 shows a typical set-up for image analysis.

4.2.2.1 Cotton Incorporated's Image Analysis system

Cotton Incorporated provided an existing image analysis system that was evaluated for usefulness in counting white speck in dyed fabric. The Cotton Incorporated procedure for Dye Resistant Nep (White Speck) Analysis **[111]**(Von Hoven, 1996) in fabrics incorporated a Cohu 4912 CCD monochrome camera, a copy stand, a monitor, a computer, a Coreco 3000 Image Processing Board and a fluorescent ring light. The camera was mounted so that the lens went through the centre of the fluorescent ring light. The edge of the light fixture and the lens were 380mm (15 inches) from the sample surface. The viewing area in this configuration covered 77cm^2 (12 in^2) of sample. Specific processing software was developed by a Cotton Incorporated consultant for this system.

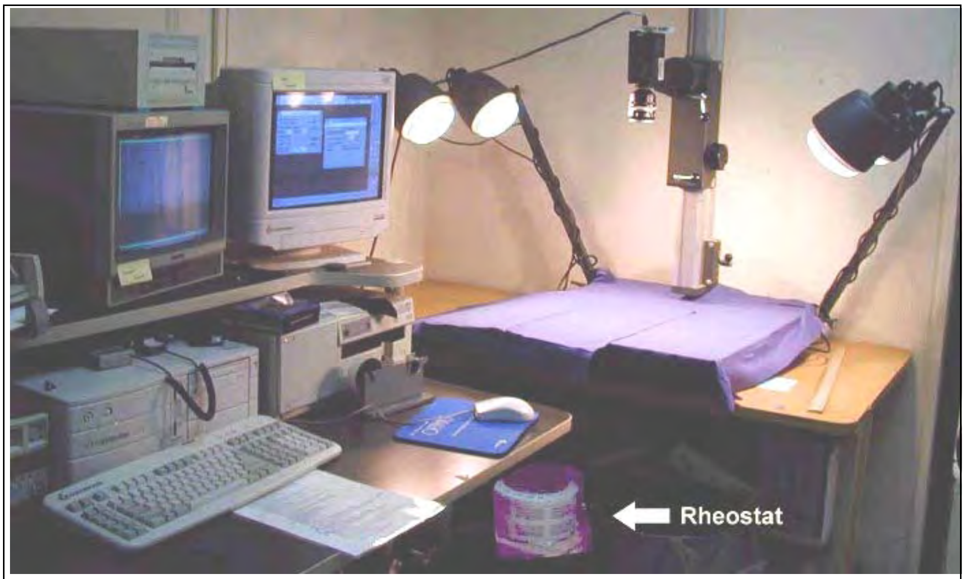


Figure 4.6: Typical image analysis system: camera with uniform lighting or scanner to capture image, computer with program to evaluate fabrics and monitor to visually evaluate images.

During operation, the software threshold was adjusted by placing a representative sample under the camera and acquiring the image on the computer screen. The threshold function created a binary (black=0, white =1) image. The threshold was manually adjusted until all of the white specks were visible to the operator, with a minimum amount of noise in the image. Once the threshold was set, the minimum size (in pixels) was determined visually to differentiate between white specks and noise. The threshold and minimum pixel size were set and maintained throughout the duration of the testing to remove noise from the image, leaving the white specks highlighted. The number of "events" was then automatically counted with the number of pixels determining the size of each "event". The count per square meter and “% white" (the actual percent of the fabric that was white rather than dyed blue) were calculated. Twenty-four readings were taken from each of the fabrics. The samples were manipulated so that there was no overlap of the sample viewing area. Cotton Incorporated tested the samples and then the system was shipped to SRRC for further evaluation. It must have been damaged in shipping because a drift was noted in the data when the system was used at SRRC. The system was focused on one fabric, which was taped into place, then tested every half hour with the same settings to see if there was any change over time. The recorded number of white speck increased significantly over an 8-hour period. The problem could not be resolved and it started the search for other imaging systems to evaluate white specks. Only one complete data set for this study using this image analysis system was gathered at Cotton, Inc. when the fabrics were sent there for analysis. This data, was used for comparison purposes to compare % White values obtained by the other systems evaluated.

4.2.2.2 Cambridge Instruments Quantimet 970[112] (Von Hoven, 1996)

The fabrics were also analysed using a Cambridge Instruments Quantimet 970 at SRRC. Before testing, the operator determined the camera settings for the Cambridge Instruments’ Chalnican camera, which resulted in a sharp image of the white speck fabric. The Cambridge Instruments Chalnican camera was placed on the arm of a Cambridge Instruments stand fifteen inches above the surface of the stand, thus the camera was twelve and one half inches above the fabric sample. A ring light was used in order to provide uniform lighting and was placed eight and one half inches above the fabric sample. The equipment was then allowed to equilibrate for approximately an hour to permit stabilization of lighting and equipment. The room was blackened so that the only source of light was that of the Image Analysis system. After stabilization, shading correction was implemented to eliminate any unevenness in lighting. Acceptance values were set to place size limits on what was to be detected as a white speck while eliminating noise or false positives that were typically smaller than white specks. These parameters were set once, and all tests were performed consecutively under the same conditions so that reliable comparisons and correlations could be made. The system was calibrated at the start of every analysis procedure to ensure correct measurements.

The equipment was programmed to sample seven approximately 60cm^2 (9 square inch) sections of fabric, measure the size and area of the white specks, and count the number of specks detected in that area. The image size was 600 by 500 pixels, with one pixel edge equivalent to 0.138mm^2 (0.00543 in^2). An average size, count and area were determined for each of the seven samples. The tests were then replicated five times. The same operator tested all samples on the same day, to eliminate any operator or lighting variation influencing the results. The operator manipulated the fabric sample to avoid detecting the same area more than once [113](Von Hoven, 1996).

4.2.2.3 Optimas 4.0 and the Upgraded Optimas 5.2 Image Analysis System

Two versions (4.0 and 5.2) of the Optimas system for image analysis were also evaluated for use in the project. The Optimas system used a Gateway 2000 P5-75 computer with a dual monitor set up with a Sony Trinitron RGB Monitor and an Imaging Technologies frame grabber. A Microimage Video Systems RGB/YC/NTSC colour camera was mounted on a camera stand. The F-stop on the camera was set to a value of four, and the lens was located 47cm (18.5 in) above the fabric surface.

The original setup (Version 4.0) used a low level of lighting with only two 15 W fluorescent lamps. This was subsequently revised to use a brighter and more uniform light source using four tungsten 120 V 300W flood photography lights that could be adjusted by a rheostat. A digital light meter was used to measure luminance (visible flux density). The light sensor was mounted over the lens of the video camera and pointed towards the fabric. The rheostat was adjusted until the light meter luminance reading was 234±1 lm/m^2 (234±1 Lux). For white speck measurements, the lights were set on high and the rheostat was used to maintain a constant reflected light measurement of 11 EV with ASA set at 800. This is the lighting procedure used for the data reported for both Versions of Optimas.

Thirty different sections, regions of interest (ROI), of the fabric were analysed with a total area of $2320cm^2$ ($360\ in^2$) of fabric. The operator manipulated the fabric sample so that the same area was not tested more than once and area covered was sequential.

4.2.2.3.1 Optimas 5.2 Image Analysis System –White Speck Size

To determine which system was most accurately measuring the size of the white specks, forty photomicrographs were taken of white specks from each of the eight EVS fabrics and measured using the area protocol from Optimas version 5.2.

Optimas was developed for medical purposes and is considered very accurate for measuring cell areas. A Bausch & Lomb stereomicroscope fitted with a Hitachi KP-D50 colour digital camera with an extension tube (which increased the magnification) RS Photometric's CoolSNAP was used to create digital photomicrographic images of white specks. Most of the white specks were photographed at a magnification of four, but some larger white specks had to use a magnification factor of three.

The Optimas system also changes the scale of the photomicrograph, depending on the monitor size, and the image appears as shown in Figure 4.7. The system is calibrated and then:

1) The scanned photomicrograph is opened,
2) The operator draws the perimeter of the white speck using the mouse and
3) Optimas determines the sizes of the white speck in square microns.

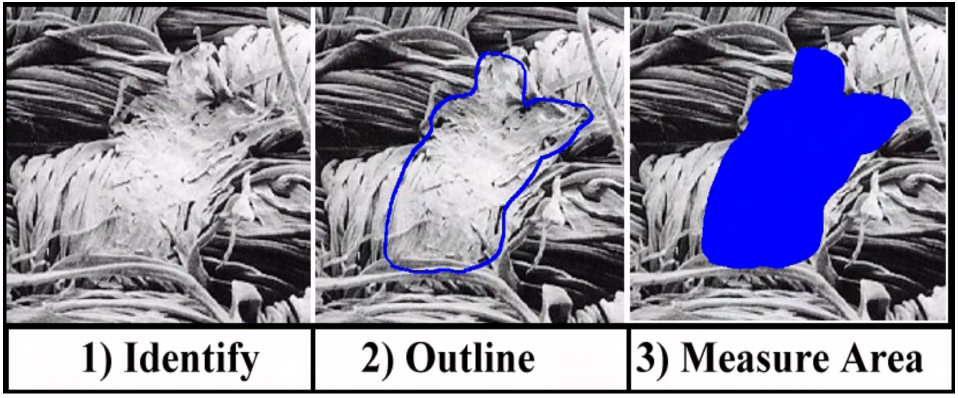


Figure 4.7: Measuring white speck size using Optimas Version 5.2.

4.2.2.4 Xu Image Analysis System

The AutoRate System was designed and developed by Dr. Bugao Xu of the University of Texas at Austin specifically to measure white specks. The candidate assisted Dr Xu throughout this development process. Initially, we used a camera and lighting set-up (as reported for Optimas) with this system but found that it was very sensitive to lighting and picked up “hot spots” for each of the four lamps. Next, a scanner was used to acquire an image. It gave the uniform lighting necessary for this imaging system. The reset control tool of the HP Scan Jet 6300C flatbed scanner was used to reset all tools except dimensions to their automatic settings. The scanning Region of Interest (ROI) was set at 5 inches by 5 inches with four adjacent fabric images analysed to give a total viewing area of 100 square inches. The images were converted into pixels by the AutoRate program Version AR-02-03 (February 2003). The scanner contrast was found to drift slightly over time, so brightness was adjusted to 120 in the AutoRate program so the images would be consistent. A minimum size of three pixels was adopted to differentiate between real white specks and anomalies. The contrast setting was used to dictate what is detected as white and so it affects the percent white of the sampled area. The contrast can be set for each fabric. If the fabrics were all dyed and scanned in a batch, the contrast usually remained the same, but each dye batch is slightly different. Figure 4.8 shows the original scan of a fabric and the altered image after it was brightened and analysed. In this case, the operator found that a contrast of 20 was good for all of the EVS fabrics. The analysis results in two values: white speck count and area that is white in pixels. The size of the white specks and the percent white on the fabric are calculated.

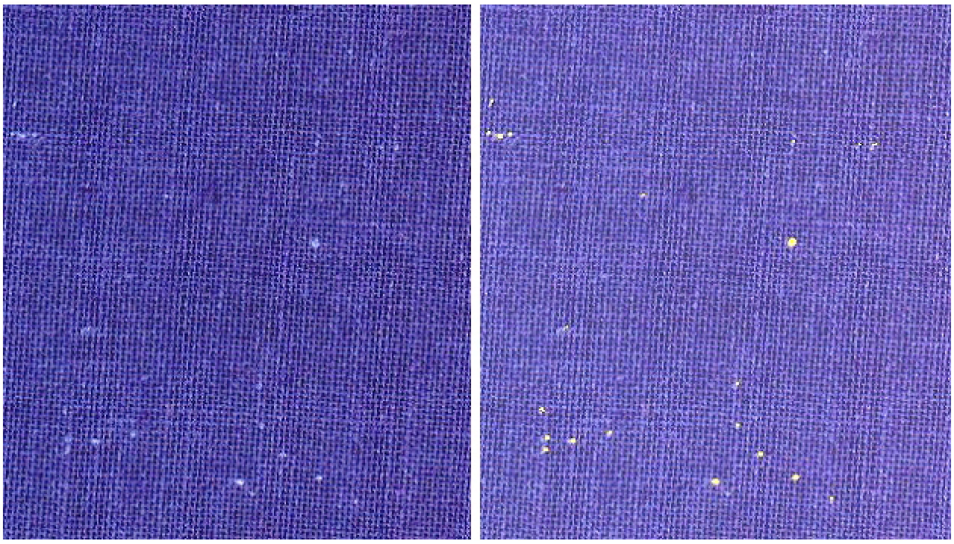


Figure 4.8: Four 5" x 5" fabrics are scanned (image on left). The image is converted into pixels, and then adjusted to 120 Brightness in Xu's AutoRate program; minimum size is set to three pixels. Fabrics are measured and analysed resulting in white speck count, size and % white (image on right).

The current version of AutoRate is only semi-automated, but development of this system continues as a separate project. So far, the candidate has evaluated twelve versions of the AutoRate system during the period 1998 - 2003. With AutoRate, fabric scans can be checked for brightness level and contrast. The brightness can be adjusted from its initial value (eg 99) to 120. However, the internal contrast that changes the visual appearance of the scan is set by a slide control instead of a numeric value. This means that the contrast varies depending on the depth of dye and variations in the scanner. Contrast and pixel size can be set numerically to determine what the system views as white specks. My testing determined that, with the scan's brightness adjusted to 120 and minimum pixel size 3 (minimum number of pixels for inclusion as white speck event), the contrast can be set between 19 and 39 for the wide range of fabrics I have tested in this study. The contrast setting is currently the only variable that is set by the operator.

Future research will be aimed at eliminating any operator intervention on the settings by determining the internal contrast level (in the same manner as the brightness setting was developed). That will make the digital images uniform. Then the contrast evaluation setting will be determined (in the same manner number of pixels was determined) so that white specks can be consistently evaluated without an operator's input.

4.2.3 EVS Results

Figure 4.2 illustrates average cross-sections for the four varieties along with the cross-section and basic classers data. All four cottons were similar in grade. The Acala varieties (EA-C30 and EA-C32) were generally long, strong, small perimeter fibres. The DP-90 was a medium length, strength, and perimeter fibre. The STV-825 was coarser, slightly shorter, and was similar in cell wall thickness of the EA-C32 and the DP-90. A thicker cell wall results in EA-C30 being more circular than EA-C32. The STV-825 is the least circular. Micronaire readings show the Acalas contrast strongly with each other. The EA-C30 variety had the highest micronaire value while EA-C32 had the lowest.

Alon and Alexander [114](1978) pointed out that fibre processing tends to produce buckling along the fibre length through a stress build-up/sudden release mechanism. They developed an equation for a buckling coefficient[115] (Alon et al, 1978) included in Figure 4.2. In essence, the longer and finer the fibre, the more prone it is to "buckle" and entangle with itself or with other fibres during processing. The buckling coefficient does an excellent job of rating these fibres with EAC-32 having the highest propensity to nep and appear as white specks, followed by ST-825, DP-90 and EAC-30 being the least likely to have white specks. The Acalas were two

32nds (inches) longer that the DP-90 and ST-825 (Table 3.1). Strength varied between the varieties with EAC-32 rated as strong, EAC-30 and DP-90 as average and ST-825 as weak (Table 3.3). Both Acalas and ST-825 were rated as base grade for micronaire (mic) and the DP-90 was rated as premium (Figure 3.1). The following sections of the dissertation present results from the eight EVS fabrics (the varieties are referred to by their numeric component and S or T indicate Single or Tandem carding).

4.2.3.1 Hand Counting and Cotton Incorporated's Image Analysis System

The initial data from the Cotton Incorporated image analysis system tracked the hand counted white speck values fairly well (see Figure 4.9). However, the results drifted over time. The fabric was taped into place and the analysis run every hour resulting in a false increase in white speck count as explained in Section 4.2.2.1.

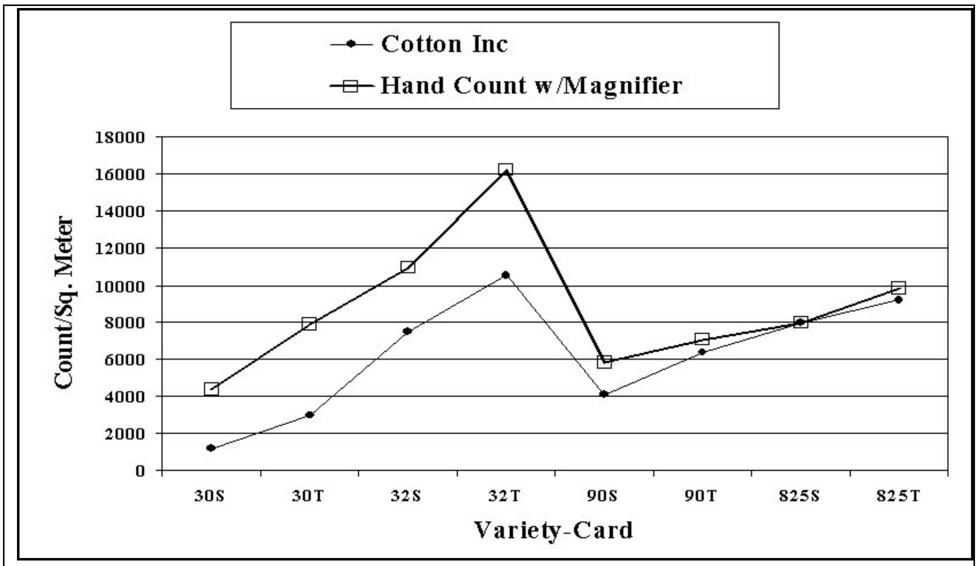


Figure 4.9: Image Analysis by Cotton Incorporated's System tracks hand counted white specks

4.2.3.2 Cambridge Image Analysis System

The image analysis results for the Cambridge system were characterised by a lack of consistency. Figure 4.10 shows the variation found with five different test dates.

This system was found to be extremely sensitive to the surrounding environment; even the colour of the garments worn by the operator altered the readings. It was noted that, as the operator leaned forward to evaluate a fabric, the reflectance off her white shirt altered the reading. Following this discovery, each test was performed in a blackened room in which the image analysis system provided the only source of light. The operator wore black clothing to reduce reflectance. The Cambridge system was designed for high magnification work and is apparently not suitable for macro applications such as white speck analysis.

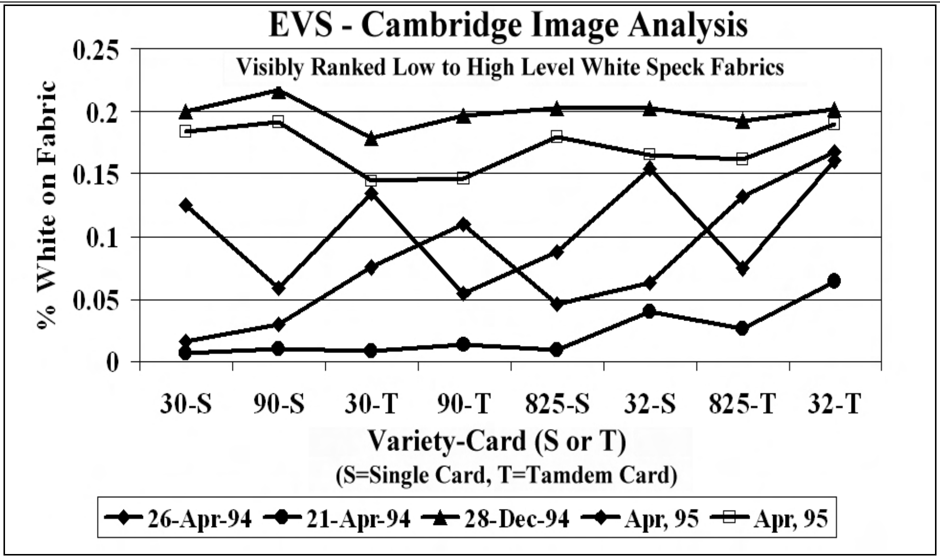


Figure 4.10: EVS results by Cambridge % White values for five test dates.

4.2.3.3 Optimas Image Analysis System

The Optimas system provided more consistent results than the Cambridge system. The readings were much more repeatable and consistent from day to day, with the tandem carded fabrics showing a higher white speck count and a larger size of neps than was measured on their single carded counterparts. This result is expected, given that the tandem card was mis-set as described in section 4.2.2 and Figure 4.4.

EA-C30S had the lowest white speck content in all measurement replications, followed by the DP-90S, EAC-30T, DP-90T, STV-825S, EA-C32S, STV-825T, with the EA-C32T having the highest % white, as shown in Figure 4.11 and Table 4.1. Results obtained with the Optimas 4.0 system are shown in the graph. The data from version 5.2 of Optimas is shown as the last testing date. The results from the two versions of Optimas are in close agreement.

Table 4.1: EVS results by Optimas % White Values for Four Test Dates (Versions 4.0 and 5.2)

% White Values	***Opt 4.0***	***Opt 4.0***	***Opt 4.0***	***Opt 5.2***
	July 95	Jan 96	Feb 96	July 96
EAC-30-S	0.01418	0.01171	0.01339	0.01188
EAC-30-T	0.01832	0.0192	0.01893	0.02037
EAC-32-S	0.02871	0.02807	0.02755	0.0292
EAC-32-T	0.04646	0.04195	0.04264	0.0494
DP-90-S	0.05099	0.04573	0.0468	0.04922
DP-90-T	0.06168	0.05393	0.05643	0.06226
ST-825-S	0.07744	0.06607	0.0673	0.069
ST-825-T	0.13473	0.10122	0.11039	0.11675

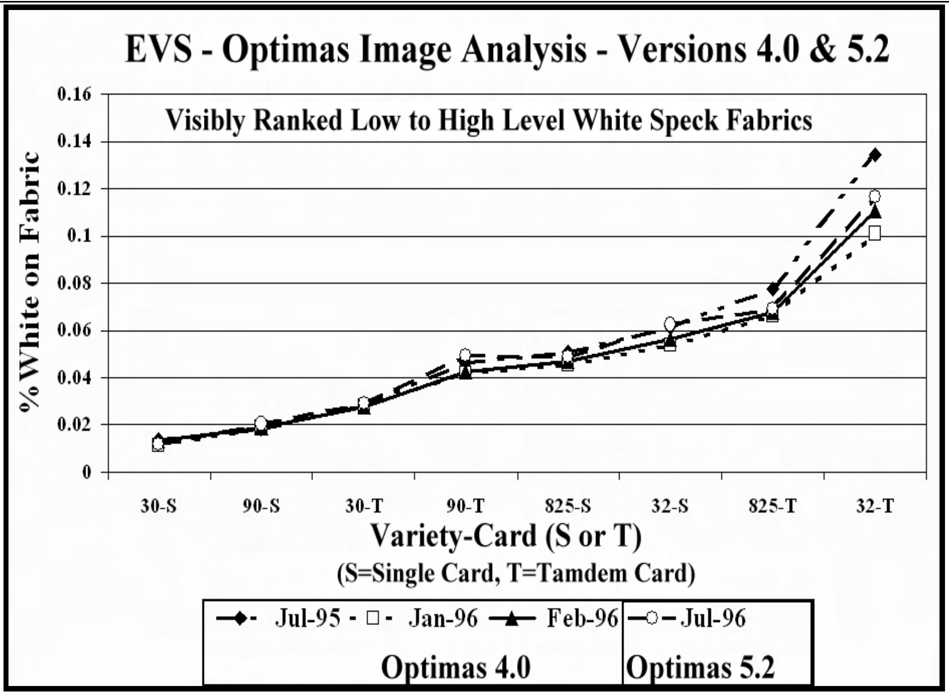


Figure 4.11: EVS results by Optimas % White values for four test dates.

4.2.3.4 AutoRate Image Analysis System

Results from four image analysis systems are presented for comparison in Figure 4.12. The AutoRate system was compared to past systems and generally was found to track the level of white specks, although a few points were higher than the other systems (with the exception of the Cambridge system which is completely inconsistent).

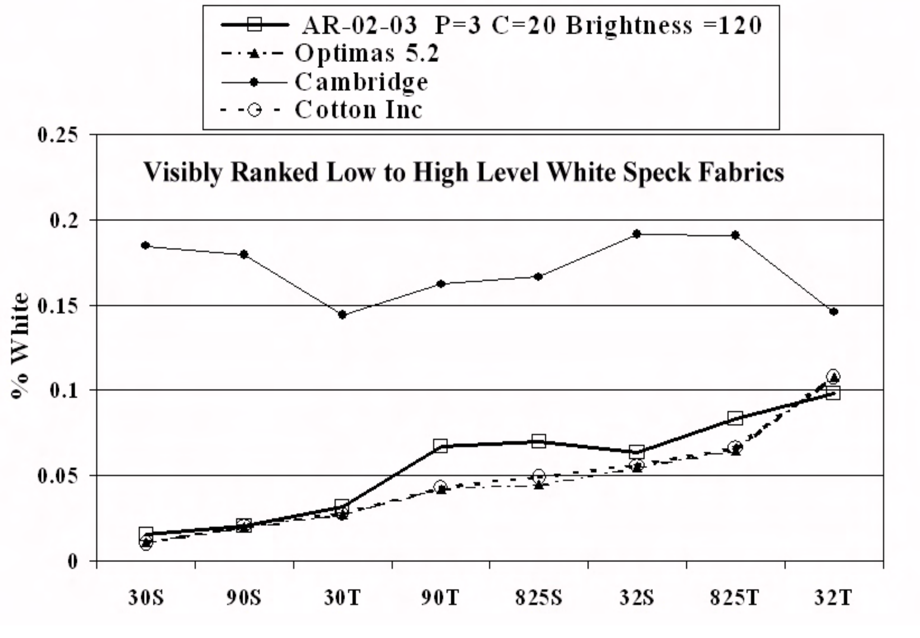


Figure 4.12: White specks (%White) measured on four image analysis systems.

In Figure 4.13, the White speck count/square meter values from AutoRate, Optimas 5.2 and Cotton Incorporated's systems are compared to hand counting. The human eye is much more discerning than any of the imaging systems and many tiny white specks are counted that may appear as noise to an image analysis system. All of these systems have a general upward trend similar to hand counting, but none of the electronic systems counts are as high, because at some level for each system, false white specks are picked up when trying to account for the smallest white specks, so size limits are used to avoid anomalies. The Cotton Incorporated system tracks closest to AutoRate. Optimas has an upward trend, but seems to give much lower counts than the other systems.

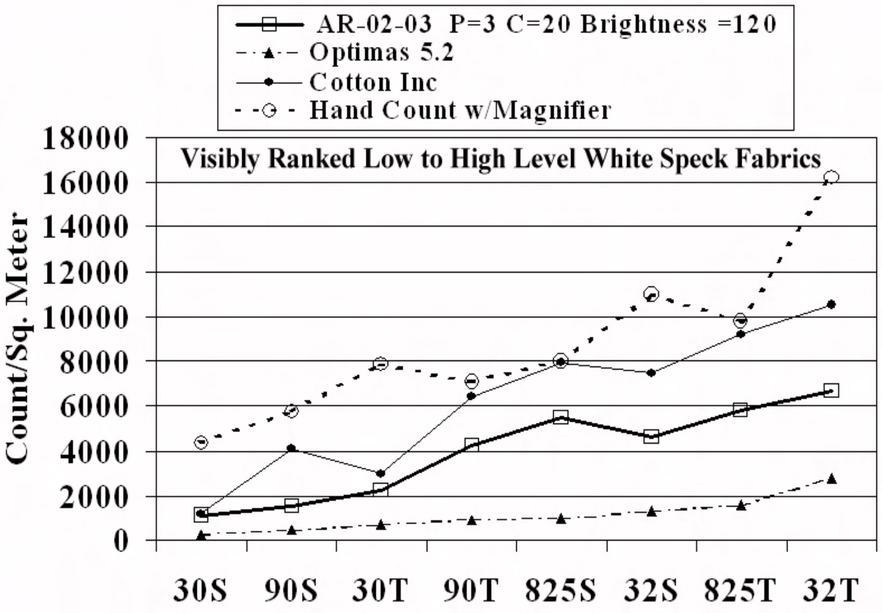


Figure 4.13: White speck count per square meter measured on three image analysis systems and compared to hand counting

The next concern is accuracy of measured size. The Cotton Incorporated system reported the size in pixels and a conversion was not possible to square microns. While evaluating different aspects of the imaging systems, it was noticed that some changes could make the white specks appear extremely large. The larger the size of the white speck appeared on the monitor, the higher the % white became, resulting in a false size measurement and reduced accuracy. The sizes of white specks were also measured using a scanning electron microscope and then related back to the available imaging systems, Optimas and AutoRate.

When the panel (made up of SRRC & Cotton Incorporated personnel) that rated the fabrics were questioned, they agreed that the three middle fabrics (DP-90T, STV-825S and EAC-32S) were the hardest to rate because they were the most similar. One member stated that the DP-90 was hard to rate because it had much larger white specks than the other fabrics, so she felt she had to balance the lower count she saw with the larger size, giving it a higher rating for white specks. These observations relate well to the microscope and the AutoRate measurements that both show DP-90 white specks to be the largest (Figure 4.14).

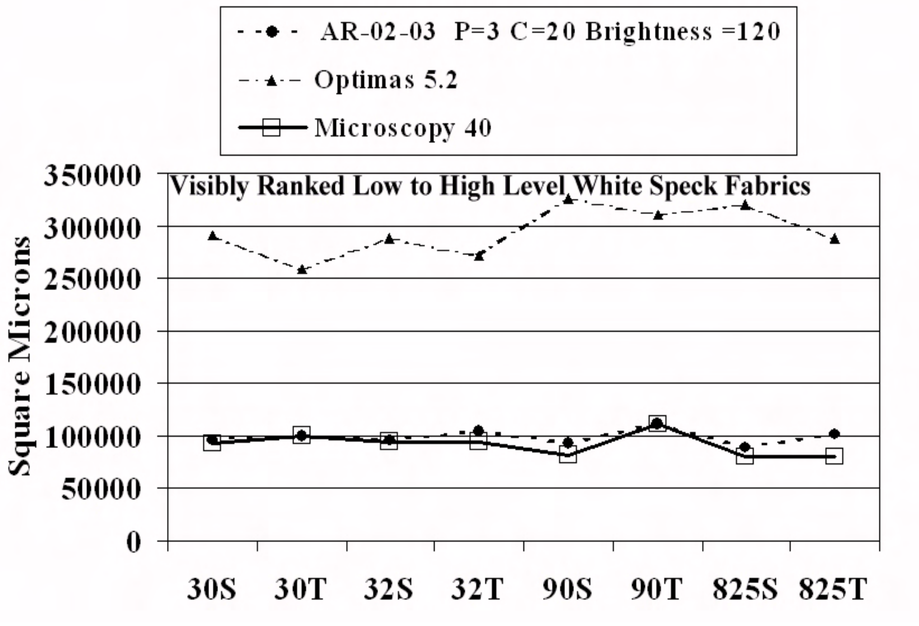


Figure 4.14: Accuracy of white speck size measurements.

It is concluded that the AutoRate system is currently the only one that can provide an accurate measurement of white speck size (Figure 4.14) when benchmarked against the manually obtained microscopic measurements using a magnification of 40. Since all of the fabrics were run at the same settings on the more stable AutoRate system, there should be less operator influence on the white speck count and size. Visually, the counts from the AutoRate system appear realistic, while the Optimas system appears to undercount and significantly oversize the white specks. The combination results in very similar % white for both systems, but the AutoRate system obviously measures size more accurately than the Optimas system. Testing fabrics for white specks can take as much as an hour per fabric using the manual Optimas system. The candidate reduced the required time to ten minutes per fabric with the current AutoRate system. A fully automated system should result from Dr. Xu's current work and this would further reduce this time significantly.

Only data from the latest version of AutoRate (AR-02-03) are presented in the remainder of this dissertation using the adopted configuration (fabrics scanned using the reset control tool, minimum pixel size = 3, brightness =120 and contrast varied as needed), which seemed visually most accurate.

5. LARGE SCALE VARIETY WHITE SPECK STUDIES AND PROCESSING EFFECTS ON WHITE SPECK LEVELS

Both Australia and the U.S. mechanically harvest and gin their cottons and both countries are perceived by buyers to have nep problems. White specks are the most expensive nep defect problem. Many growing regions (usually small areas but sometimes whole countries) are often avoided by individual cotton buyers if the previous year produced high white speck problems for their mills. This project was undertaken at sites in the U.S. and Australia to provide baseline data on the level of white specks in Australian and U.S. cotton. Previously published studies do not cover fabric neps but focus on yarn quality, which makes it particularly important to determine the factors that affect white speck levels in fabrics. After all, cotton is ultimately valued in fabric form. This chapter sets out the experimental work and analysis undertaken in U.S. and Australian field studies. The AutoRate system was used to evaluate the large number of fabric samples. Processing effects on the level of white specks in the dyed fabrics are also described.

5.1 Large scale variety white speck studies

Several field studies in the U.S. and Australia were used to investigate varietal differences as well as processing influences on white speck levels. The U.S. Leading Variety Study (LVS) consisted of 26 bales from across the U.S. cotton belt and were part of an annual variety study conducted by AMS (Agricultural Marketing Service). Two years of field studies in Australia with known harvesting and ginning were used to derive more information about processing effects on white speck levels. This was followed by an investigation of 21 varieties from three states in the U.S. All of these studies had the same mill processing.

5.1.1 Neps result from growth, harvesting or ginning and processing [116](Wegener, 1980)

Imperfections in lint cotton, particularly neps and seed coat fragments, reduce processing efficiency in the textile mill and detract from appearance of yarns and fabrics, ultimately causing financial losses. Breeders can help to reduce the nep formation potential of cotton by selecting for further development those varieties with fibre properties that are consistently associated with low nep count and seed-coat fragment levels in ginned lint, yarn and fabric. Neps are often the result of immature fibre growth as influenced by climate, over-watering, coalescence, and pests. These growth neps contain predominantly dead and immature fibres. Fibres damaged by insects will no longer mature and the escaping lumen cellular fluid causes these immature fibres to coalesce [117](Wegener, 1980). If a plant is stressed during certain critical periods, for example by a shortage of water, some of the immature seeds within a boll are aborted. The immature fibres attached to those seeds have the primary wall laid down, but lack secondary wall that other living seeds on the plant produce. Growth period, which is related to growing conditions prior to harvest, has an impact on the number of neps and other imperfections found in ginned lint, yarn and fabric [118](Mangialardi, 1987). It is possible that a crop of cotton that “just makes it” through a bad season may not have “made it” at all, and a white speck problem is likely to occur.

The susceptibility of cotton to form neps is dependent upon the nature of the cotton itself. Fibre properties such as fineness and maturity determine to a large degree the amount of nepping that occurs during mechanical processing [119](Hunter, 1996). Since immature fibres have little secondary wall, the stiffness of the fibres is severely limited, which allows them to tangle easily, or form a nep during mechanical processing such as ginning [120](Chellamani, 1999). Fibres are stretched during processing, accumulating elastic energy. When one end of the fibre is suddenly released from the tensile load, the energy is converted to kinetic energy, if the fibre is free to move. As the fibre cannot withstand compressive stress, buckling results [121](Alon, 1978). During textile processing, these colonies of immature fibres are separated and divided into smaller segments, which are ultimately responsible for the white specks of the dyed fabric [122](Watson, 1991). Forty percent of white specks are caused by processing [123](Bragg, 1992).

It is common knowledge that cotton in the boll has few, if any, mechanical neps and that neps are formed to varying degrees during the mechanical handling and processing which the cotton undergoes during harvesting, ginning, opening, cleaning, carding, combing, etc., from field to fabric. Neps first form when the cotton boll opens and the fibres "blow up", dry, convolute and collapse [124](Verschraege, 1989). Harvesting cotton blends the immature fibres with mature fibres and this usually causes neps during further processing. In addition, the aborted seed is usually too small to be removed by the gin saws, and persists through processing to produce a biological nep and/or a white speck. However, growers, ginners, and mill operators can influence, to some degree, the number of imperfections that are created during harvesting, ginning, and spinning by controlled use of the processing machinery [125](Mangliardi, 1990).

5.1.2 Harvesting and Ginning

Harvesting and ginning can cause neps through fibre damage [126](Wegener, 1980). Harvesting methods affect nep formation. Hand picking gives the lowest number of neps, strip picking the highest number. Mechanical cotton pickers suit the industry well, but they lack the selectivity of manual workers. Mechanical picking removes almost all bolls regardless of maturity. Unambiguously immature bolls are removed by the rock and green boll trap early in the ginning process, but other partially mature bolls may be knocked open during the extraction of trash. When this happens, the immature fibre in those bolls mixes with mature fibres and usually results in neps during further processing. This effect is particularly bad in "second pick" seedcotton, when the farmer undertakes a secondary harvesting operation.

Generally, cotton harvested early in the season will produce yarn and fabric containing a lower number of imperfections than cotton harvested late in the season in the same field. This can be attributed to higher micronaire cotton in the earlier harvest, associated with more mature fibres than the later harvested cotton. Sometimes, in the face of impending wet weather or other picking problems, farmers will choose to pick earlier than is desirable from an agronomic point of view. At other times, wet weather prevents picking operations for a time. Both of these situations affect the quality of fibre arriving at the gin. Early picked cotton contains more immature bolls than cotton allowed to mature properly. Late picked cotton is even worse, for two possible reasons. The bolls that are maturing in the "tail" of the process may be marginal bolls with a higher proportion of aborted seeds and immature fibre. In addition, lint exposed to sunlight and moisture becomes weaker and more susceptible to damage by later mechanical processing [127](Bel-Berger, 1995).

Figure 5.1: Different types and levels of trash seen in spindle picked and stripper picked cotton.

Figure 5.1 shows samples of spindle-harvested, conventionally grown cotton (left) and stripper-harvested cotton. Cotton harvested with a stripper harvester contains more stems and leaves [128](Greb , 2000) than spindle picked cotton.

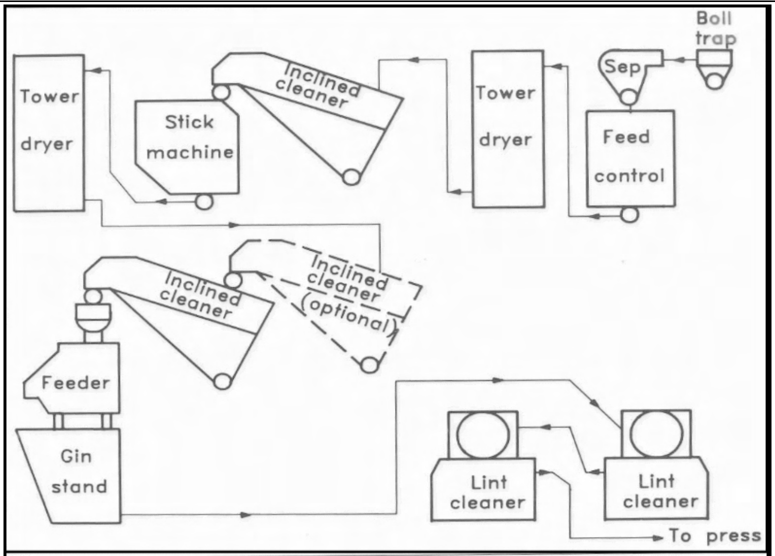
Figure 5.2: Spindle picking cotton[129](Nance, 2002). Cotton stripper harvesting cotton[130](Wright, 2000).

Figures 5.2 compares the field impacts of the two types of cotton harvesting machines. There is very little cotton left in the field behind the stripper harvester, emphasizing that all of the cotton is taken by the stripper, both mature and immature.

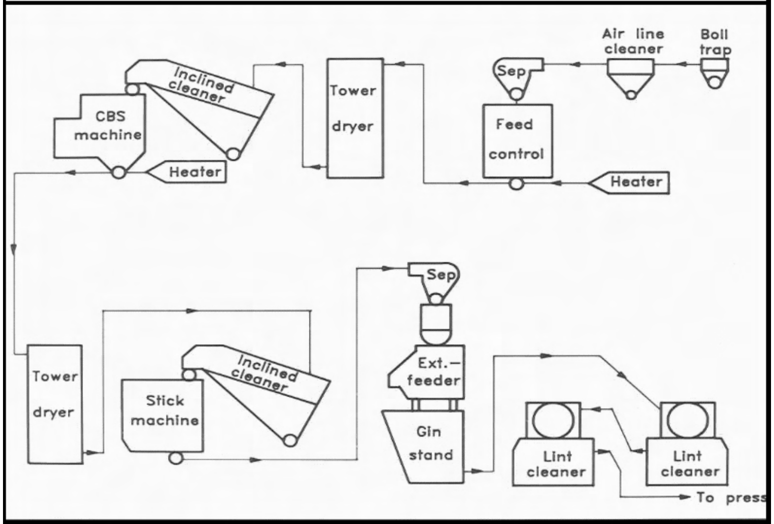
Figure 5.3 depicts the processing sequence followed by seedcotton from module to bale. Many stages can be bypassed or heat levels changed at the discretion of the ginner. Ginning increases the number of neps, saw-ginning more so than roller ginning. The more violent the ginning method, the more neps and seed coat fragments are formed [131](Mangialardi, 1987).

The ginner’s job is to remove the lint from the seed and to clean the cotton (Figure 5.4) in order to get the best price for the grower for his cotton based on the grading system. The grading system was set up on hand picked cotton and discounts heavily if the cotton is not “white and clean”, as this was a major indication of quality problems in the days of hand picked cotton.

The gin stands and saw cylinder lint cleaners are major points of cleaning and formation of neps. Using three saw cylinder lint cleaners in the ginning sequence instead of one lint cleaner can increase the number of neps by 54% [132](Mangialardi - b, 1985). Lint cleaning in the gin does take out motes and seed coat fragments (SCF), but the cleaning efficiency depends somewhat on the differential weight between cotton and trash, so the heavier, larger motes and seed coat fragments are more likely to come out than smaller, pinhead motes. As the severity of the machining is increased, the smaller motes are just as likely to be broken up and scattered through the lint rather than being removed [133](Hughs, 1988). The number of neps also increases with increased SFC and coefficient of length variation [134](Frydrych, 2001), both of which are good indicators of excessive ginning conditions.



Maximum amount of gin equipment for spindle picked cotton



Recommended gin equipment for stripper picked cotton

Figure 5.3: Typical saw ginning system for spindle and stripper picked cottons (Anthony, 1994).[135]

Excessive heat or lint cleaning increases the short fibre content and length variability of the baled cotton. The final nep level after ginning is also greatly influenced by the nature of the cotton itself. Fibre fineness and maturity determine to a large degree the amount of nepping that occurs during the ginning process. Immature, fine-fibre cottons tend to nep more readily than do mature fibres or coarse fibres [136](Anthony, 1986).

Figure 5.4: Seedcotton and Ginned Cotton - Cotton on the right has been ginned and is ready for conversion into yarn at a textile mill [137](Agriculture Research Service Image Gallery, 2003).

The AFIS instrument can quantify the effect of multiple stages of saw-type lint cleaners. Its analysis indicates the rise in neps, reduction in trash particle count, and size as the number of lint cleaners increase. Some spinning mills are now buying cotton direct from the gin and specifying the use of only one lint-cleaner [138](Yankey, 1996).

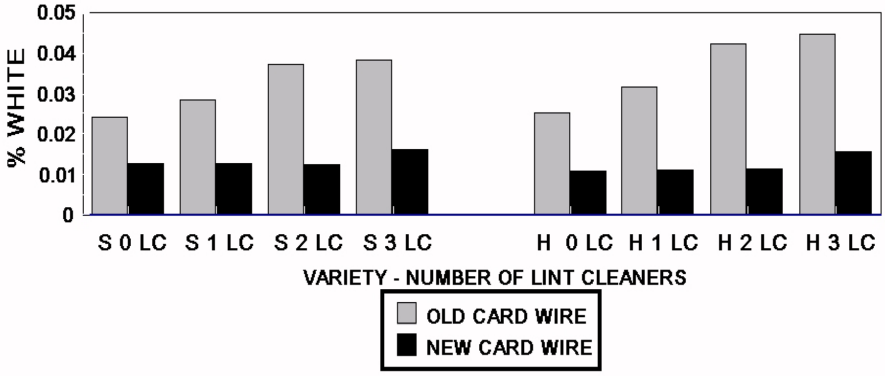


Figure 5.5: Card wire and levels of lint cleaning in the gin affects the white speck content in dyed fabrics [139](Bel-Berger, 1997).

White speck levels in dyed fabrics are also increased with the level of lint cleaning as shown in Figure 5.5, which shows two varieties (S=Smooth-leaf and H=Hairy-leaf) each with 0, 1, 2 & 3 lint cleaners used at the gin. The study was run on a card just before and after it was rewired. The effect is minimal if the mill’s cards have new or sharp wire, but if the wire is worn, which is inevitable at some point, the lint cleaner effect is dramatic.

5.1.3 Mill Processing

Neps in the spinning mill are caused by the entanglement and hooking-together of fibres during various mechanical processes. If a fibre breaks during processing, it often rolls up on itself and/or wraps around other fibres, thus forming a nep [140](Wegener, 1980). In the spinning mill, neps can be eliminated, or nep formation prevented, or at least reduced, by general practices such as maintaining an even feed to beaters; keeping machines in good condition; and ensuring that teeth on beaters are sharp and straight [141](van der Sluijs, 1999).

5.1.3.1 Carding

Multiple bales are opened and fibres are suctioned off to the opening line in the mill where very coarse trash is removed. The opened fibres are chute fed to the card where the main cleaning operation occurs. The stock fed to the card is processed into a thin mist-like sheet, or web, which is then formed into a loose rope-like strand of fibres known as card sliver.

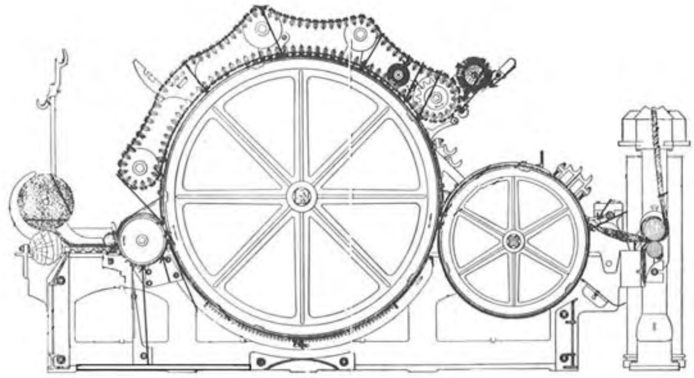


Figure 5.6: Carding in the Mill [142](Marvin, 1973).

A single card is depicted in Figure 5.6; a tandem card is similar except that it uses two large cylinders in tandem to increase cleaning. Tandem carding provides superior yarn and fabric quality to single carding. Verschraege [143](Verschraege, 1989) found that the use of tandem carding over single carding reduces the number of neps by 50%. This benefit was not obtained in my project though, in the case of the mis-set tandem card discussed in Chapter 4, which caused an increase in white specks in the dyed fabrics (Figure 4.4). In carding, a low nep count is directly related to the sharpness and thickness of the points of the cylinder wire, carding segments and wire flats. The results shown in Figure 5.5 established that new card wire produced, on average, 61% fewer neps (a range of 48% to 73% reduction depending on variety and level of lint cleaning) than blunt teeth (van der Sluijs, 1999). The same experiments established that the percentage of immature fibres is a major contributor to the number of white specks for both the single and tandem carded samples. The lengths of the fibres influence the size of the white specks for the tandem carded samples.

More neps are eliminated on the card than are newly formed if the wires are sharp and properly set, but the nep-reducing effect is diminished as the card clothing fills up. The number of neps in the card web shortly before the card clothing is cleaned can often be double that in the card web shortly after cleaning the card clothing. The use of a tandem card or a second passage through the card is advantageous for eliminating as many neps as possible. In addition, the use of calendering rollers (take-off roller at end of card which press and polish the fibres) will reduce the nep content considerably [144](Wegener, 1980).

To examine whether and to what extent the neps can be opened without destruction of the fibres during their opening, neps were taken from the lap (fibres after opening before carding), the flat strips, the cylinder strips and the card sliver, and they were opened by means of two marking pins under a stereoscope. This manner of opening is comparable to the treatment of neps by the card clothing. A nep was regarded as non-openable if it could not be taken apart without destruction of the fibres. The results showed that, in the lap, about 75% of the neps could be opened, whilst about 20% could not be opened and about 5% could be only divided into several still smaller non-openable knots.

The neps were examined for their composition at the same time. About 60% of the neps had very fine short fibres (immature and dead fibres) in the centre, about 35% were composed of normal fibres, and only about 5% had seed coat residues in their centres. In the card sliver, flat strips and cylinder strips the percentage of the not-openable neps was slightly smaller, namely:, flat strips and cylinder strips the percentage of the not-openable neps was slightly smaller, namely:

Openable about	60%
Non-openable	35%
Openable into small knots	5%

The compositions of the neps were similar to that of the neps in the lap.

These experimental results are in agreement with the idea that the card opens the neps. Since only the openable neps can be drawn out, the percentage of non-openable neps must increase in the card wastes [145](Kaufman, 1964).

5.1.3.2 Combing

While carding cleans the fibres, removes some short fibres, and partially parallelizes them, combing (Figure 5.7) obtains a better separation of the fibres and a better removal of impurities and contaminants than carding alone and reduces the number of neps and seed coat fragments in the yarn [146](Verschraege, 1989). By removing the short fibres and neps (mostly clusters of immature fibres), combing resulting in stronger, smoother, and more uniform and lustrous yarns, consequently reducing the percent white of the fabrics.

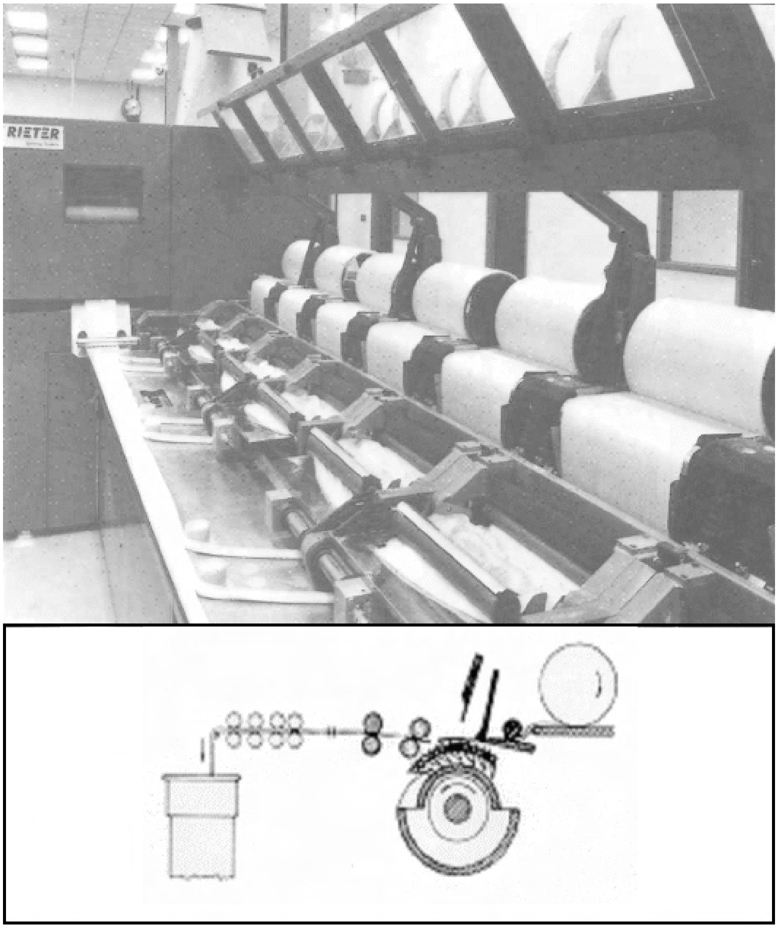


Figure 5.7: Combing at the Mill [147](Anthony, 1994).

In general, combing reduces yarn neps by 30 to 50%, with the impact being less for rotor (open-end) spinning. Nep removal is also influenced by the setting of combers, such as the number of needles on the cylinder and top comb, setting of halflap, unicomb and top comb, and maintenance routine of all these settings. The combing process appears to be better at removing neps than seed coat fragments [148](van der Sluijs, 1999).

5.1.3.3 Spinning

High quality cotton is traditionally spun using the ring spinning system (Figure 5.8) at a typical speed of 20 metres per minute. This produces high quality, fine yarns with excellent mechanical properties and a soft, smooth feel. The other technology commonly used in cotton processing, the open end (OE) spinning system (also known as rotor spinning) (Figure 5.9), has a productivity in the region of 150 metres per minute and is more suited to coarser yarns. By comparison, the new Murata Vortex Spinning (MVS) (Figure 5.10) system produces 400 metres per minute and can produce fine yarns of high quality, similar to that of a ring spun yarn. Based on the quantity of yarn produced, open end spinning dominates. Even though there are only one-third as many positions of rotors installed, rotor spinning is so much faster that they spin three times more yarn than ring spinning [149](Naylor, 2002).

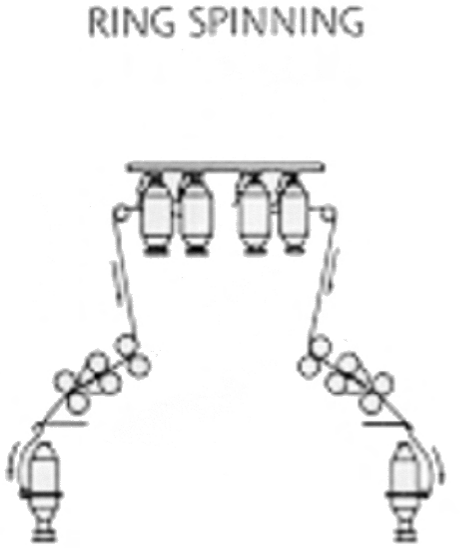


Figure 5.8: Ring Spinning –roving is drawn out into a tiny strand of fibres and twisted into a yarn.

In ring spinning, in order to obtain a good parallelization and the desired number of fibres, card lint is drawn down to roving (a very coarse and loosely twisted fibre assembly) which in turn is further drawn and twisted during ring spinning. During drawing, neps are pulled apart. One nep can be pulled into individual fibres or split into two or more neps, much as Kaufman [150](Kaufman, 1964) described in hand opening card sliver. Large seed coat fragments (SCFs) break into smaller pieces, increasing their number. During drawing, an equal number of neps in a roving will be dispersed in a shorter or longer piece of yarn depending on the size of the spun yarn. In fine yarns, the number of neps will be more visible than in course yarns where they may be hidden inside the yarn [151](Verschraege, 1989).

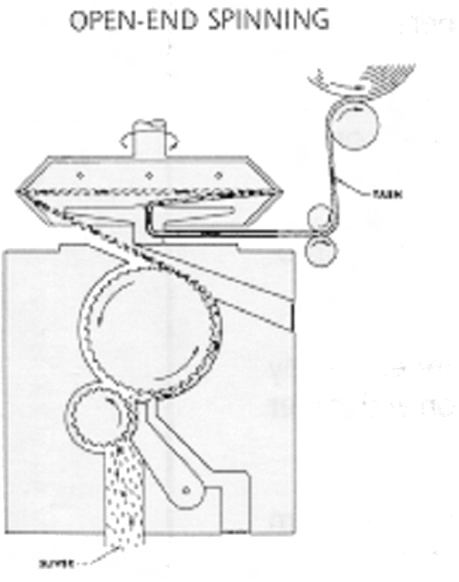


Figure 5.9: Open End Spinning – card sliver is opened, cleaned, and reduced into individualized fibres that are laid into the groove of the rotor and twisted into a yarn as it leaves the rotor.

In OE spinning, the sliver passes through the opening roller mechanism of the spinning machine (Figure 5.9). This mechanism separates the fibres from most of the seed coat fragments, neps and other contaminants, much like combing. The nep count increases rapidly with increased rotor speed and rotor diameter. Strength in OE yarn is about 20 % lower than ring spun yarn. The difference in strength is much reduced with waste mixing, which means that OE spinning is more advantageous when fibre length is short. There is substantial reduction in Uster irregularity and imperfection levels in the yarn with OE spinning, even at the highest rotor speeds used in the studies [152](Monahar, 1983).

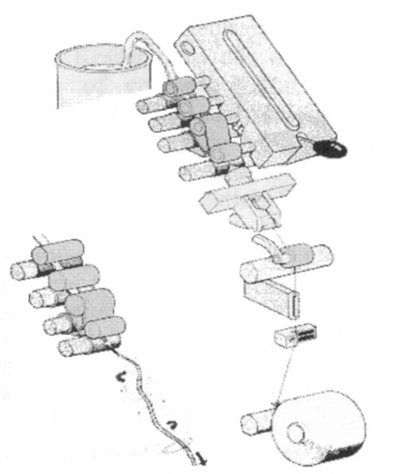


Figure 5.10: Vortex Spinning – drawn sliver is reduced to a small continuous strand of fibres and fed through an air-jet nozzle with rotating jets of air which twists the fibres together and form a yarn.

The major marketing feature of Murata Vortex Spinning (MVS) is that it is capable of spinning uncombed cotton slivers into acceptable yarns at significantly higher speeds than with any other system. The yarn structure is different from jet-spun yarn with many more wrapper fibres, and in some ways, the vortex yarn resembles a two-fold yarn. There were concerns regarding excessive fibre loss using this spinning machine. Even though the fibre loss may be about 8 percent, most of this is short fibre, which would not contribute to yarn quality [153](Naylor, 2002). While there is a loss of predominantly short fibre at the spinning frame - in the neighbourhood of 4 to 7% - it is 'almost like' performing a combing enhancement. This shows up in the sheen of the fabric and strength of yarn, even though a carded sliver is being fed to the spinning frame [154](Schreiner, date unknown).

5.13.4 Winding

Yarns intended for the warp (lengthwise element of the woven fabrics) are processed through the winder (Figure 5.11) to obtain the proper size package for warping. The winder is also used to package yarns for shipping. Van der Sluijs [155](1999) found that, at a winding speed of 600 m/min, the winding process increases yarn neps by about 20%. This could be due to the tension applied to the yarn during winding; fibres may slip, and later, when the tension is released, certain fibres may move together and form small knots. Nep formation is also influenced by winding elements such as tensioners and yarn guides, and the overall condition of those machine parts that come into direct contact with the yarn [156](van der Sluijs, 1999).

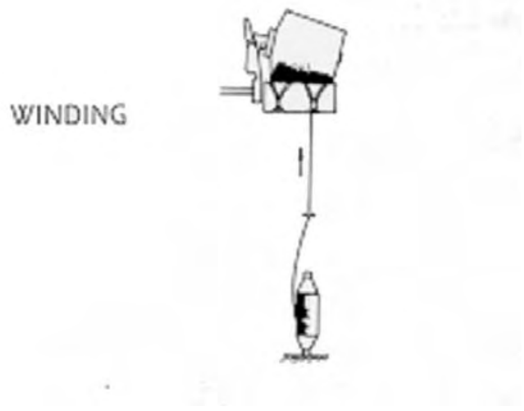


Figure 5.11: Winding in the Mill

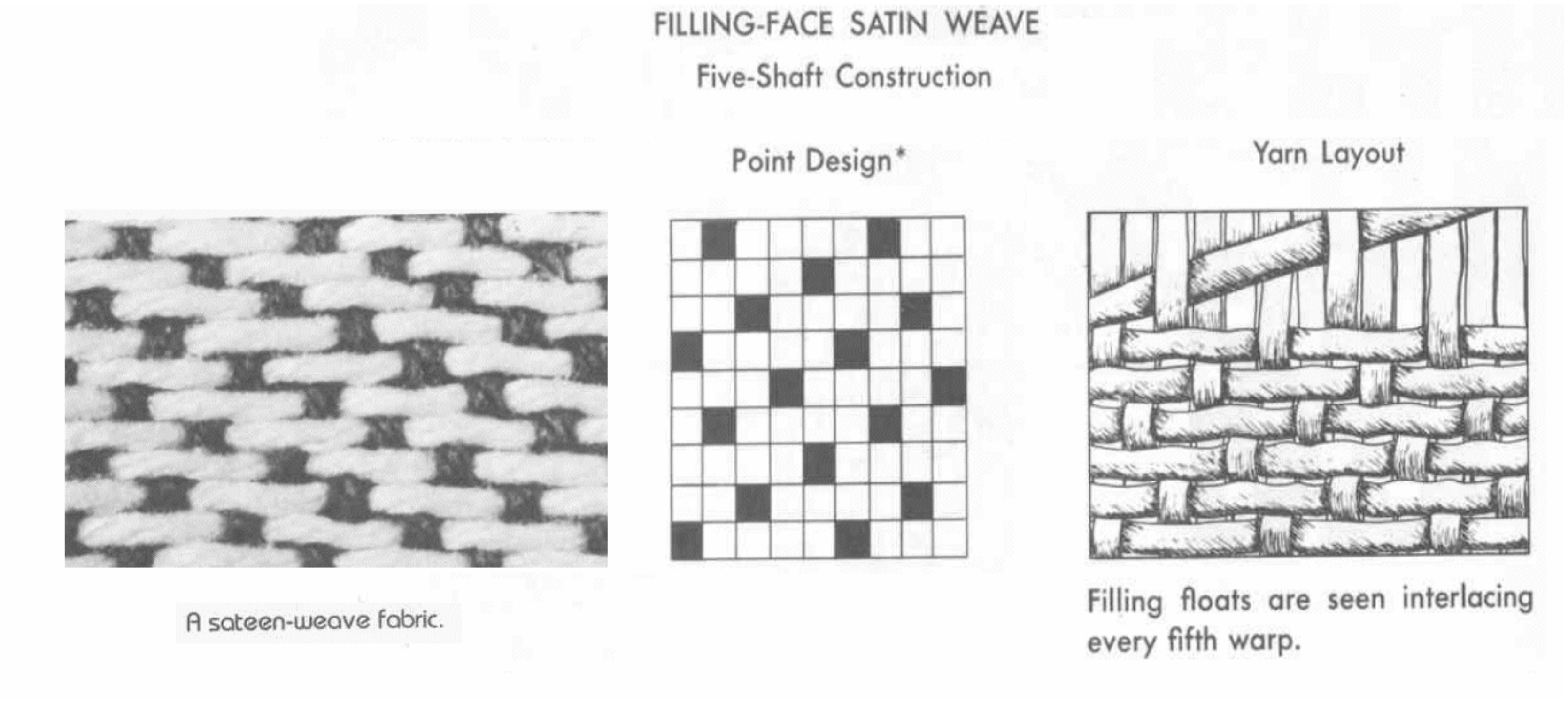
5.2 White Speck Variety studies Methodology

The first experimental study conducted with AMS (USDA's Agricultural Marketing Service) retained little history about the bale, except the region where it was grown, the variety, the gin used, and the general processing levels (number of lint cleaners) at the gins. The last three studies exercised greater control over the cotton and ginning. Samples were identified in the field and agronomic data were collected. The samples were then ginned under certain settings, and samples of lint were collected from the bale press. Fibres were evaluated by classing, HVI, FMT, AFIS, Lintronics and cross-section image analysis. The mill processing for these three studies followed the same protocols as the first study except for yarn size. In addition, the final study increased carding production from 70 lbs/hour to 150 lbs/hour to be more in line with industrial standards. The yarns for all of these studies were woven into a common combed warp, producing a filling faced sateen fabric at SRRC (Figure 5.12). The experimental yarns cover approximately 84% to 92% of the fabric surface, a factor that is considered when comparing studies (Figure 5.13). The fabrics were dyed and image analysed for white specks at SRRC using the AutoRate Program (Version AR-04-03 [April 2003]) as described at the end of Chapter 4. Most studies do not cover fabric neps, they usually conclude with yarn quality, which makes these studies unusual in design, as the primary results are fabric appearance.

Dyeing of Fabric

The fabric was finished with a 0.1% Prechem 70, 0.3% T.S.P.P. (tetrasodium phosphate) boiloff, a caustic scour of 1.1% Prechem SN, 1.1% Mayquest 80, 0.1% Prechem 70 and 0.7% sodium hydroxide (caustic soda), followed by the same boiloff procedure. It was then bleached (0.1% Prechem 70, 0.5% Mayquest BLE and 3.0%

Peroxide (Albone 35) and dyed with 4% Cibacron Navy F-G Blue 184 (owf-on weight of fabric), 0.5% Calgon, 8% NaCl, 0.8% Na^2CO^3 (soda ash) and 0.5% Triton X-100. This reactive dye (Colour Index Reactive Blue184) effectively highlights white specks in finished fabrics.



FILLING-FACE SATIN WEAVE

Five-Shaft Construction

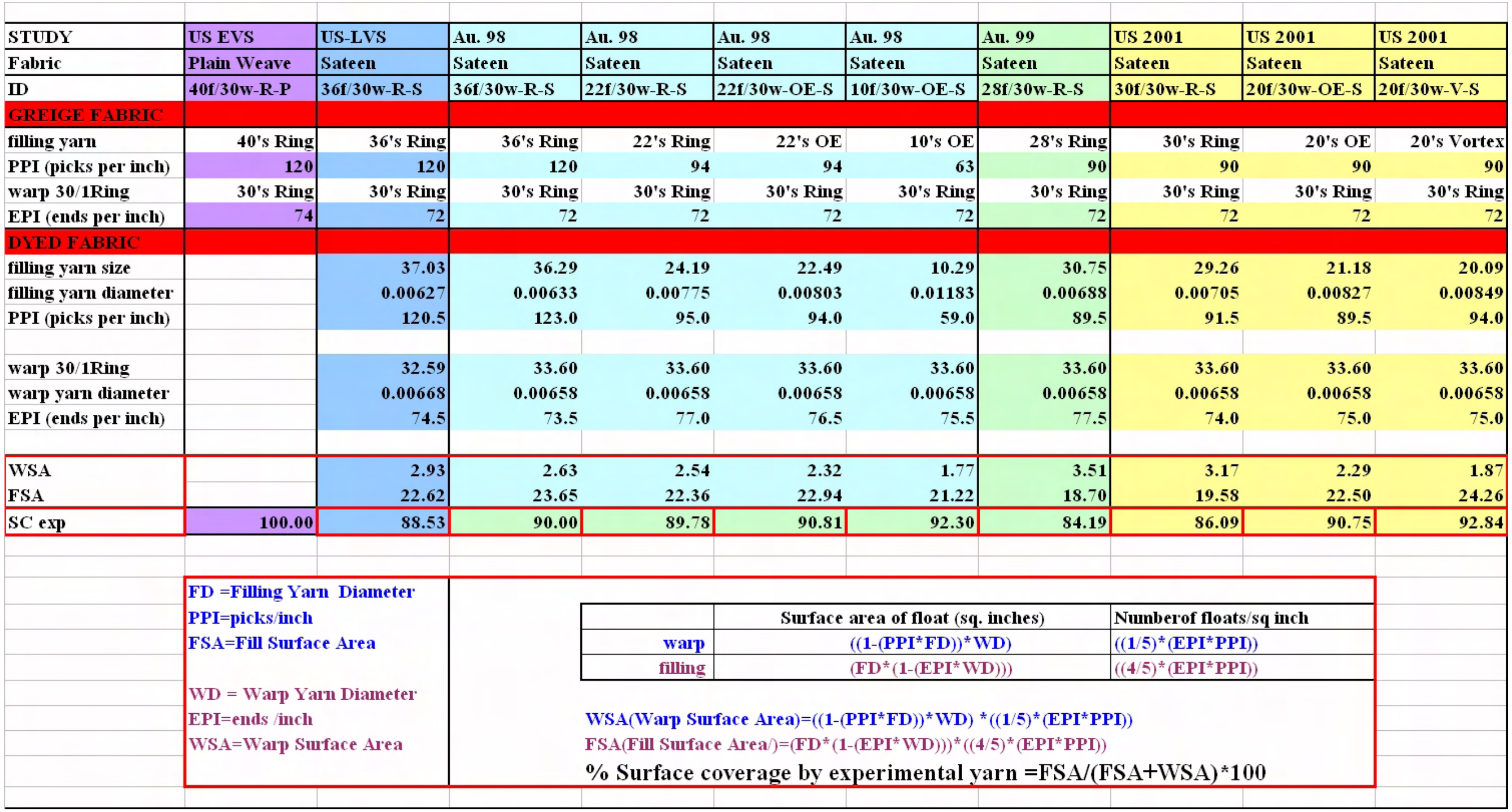
A sateen-weave fabric.

Point Design*

Yarn Layout

Filling floats are seen interlacing every fifth warp.

Figure 5.12: Five harness, filling-face sateen fabric construction [157] (Potter, 1967).



STUDY	US EVS	US-LVS	Au. 98	Au. 98	Au. 98	Au. 98	Au. 99	US 2001	US 2001	US 2001
Fabric	Plain Weave	Sateen	Sateen	Sateen	Sateen	Sateen	Sateen	Sateen	Sateen	Sateen
ID	40f/30w-R-P	36f/30w-R-S	36f/30w-R-S	22f/30w-R-S	22f/30w-OE-S	10f/30w-OE-S	28f/30w-R-S	30f/30w-R-S	20f/30w-OE-S	20f/30w-V-S
GREIGE FABRIC										
filling yarn	40's Ring	36's Ring	36's Ring	22's Ring	22's OE	10's OE	28's Ring	30's Ring	20's OE	20's Vortex
PPI (picks per inch)	120	120	120	94	94	63	90	90	90	90
warp 30/1Ring	30's Ring	30's Ring	30's Ring	30's Ring	30's Ring	30's Ring	30's Ring	30's Ring	30's Ring	30's Ring
EPI (ends per inch)	74	72	72	72	72	72	72	72	72	72
DYED FABRIC										
filling yarn size		37.03	36.29	24.19	22.49	10.29	30.75	29.26	21.18	20.09
filling yarn diameter		0.00627	0.00633	0.00775	0.00803	0.01183	0.00688	0.00705	0.00827	0.00849
PPI (picks per inch)		120.5	123.0	95.0	94.0	59.0	89.5	91.5	89.5	94.0
warp 30/1Ring		32.59	33.60	33.60	33.60	33.60	33.60	33.60	33.60	33.60
warp yarn diameter		0.00668	0.00658	0.00658	0.00658	0.00658	0.00658	0.00658	0.00658	0.00658
EPI (ends per inch)		74.5	73.5	77.0	76.5	75.5	77.5	74.0	75.0	75.0
WSA		2.93	2.63	2.54	2.32	1.77	3.51	3.17	2.29	1.87
FSA		22.62	23.65	22.36	22.94	21.22	18.70	19.58	22.50	24.26
SC exp	100.00	88.53	90.00	89.78	90.81	92.30	84.19	86.09	90.75	92.84

FD =Filling Yarn Diameter
PPI=picks/inch
FSA=Fill Surface Area

WD = Warp Yarn Diameter
EPI=ends /inch
WSA=Warp Surface Area

	Surface area of float (sq. inches)	Numberof floats/sq inch
warp	((1-(PPI*FD))*WD)	((1/5)*(EPI*PPI))
filling	(FD*(1-(EPI*WD)))	((4/5)*(EPI*PPI))

WSA(Warp Surface Area)=((1-(PPI*FD))*WD) *((1/5)*(EPI*PPI))

FSA(Fill Surface Area/)=(FD*(1-(EPI*WD)))*((4/5)*(EPI*PPI))

% Surface coverage by experimental yarn =FSA/(FSA+WSA)*100

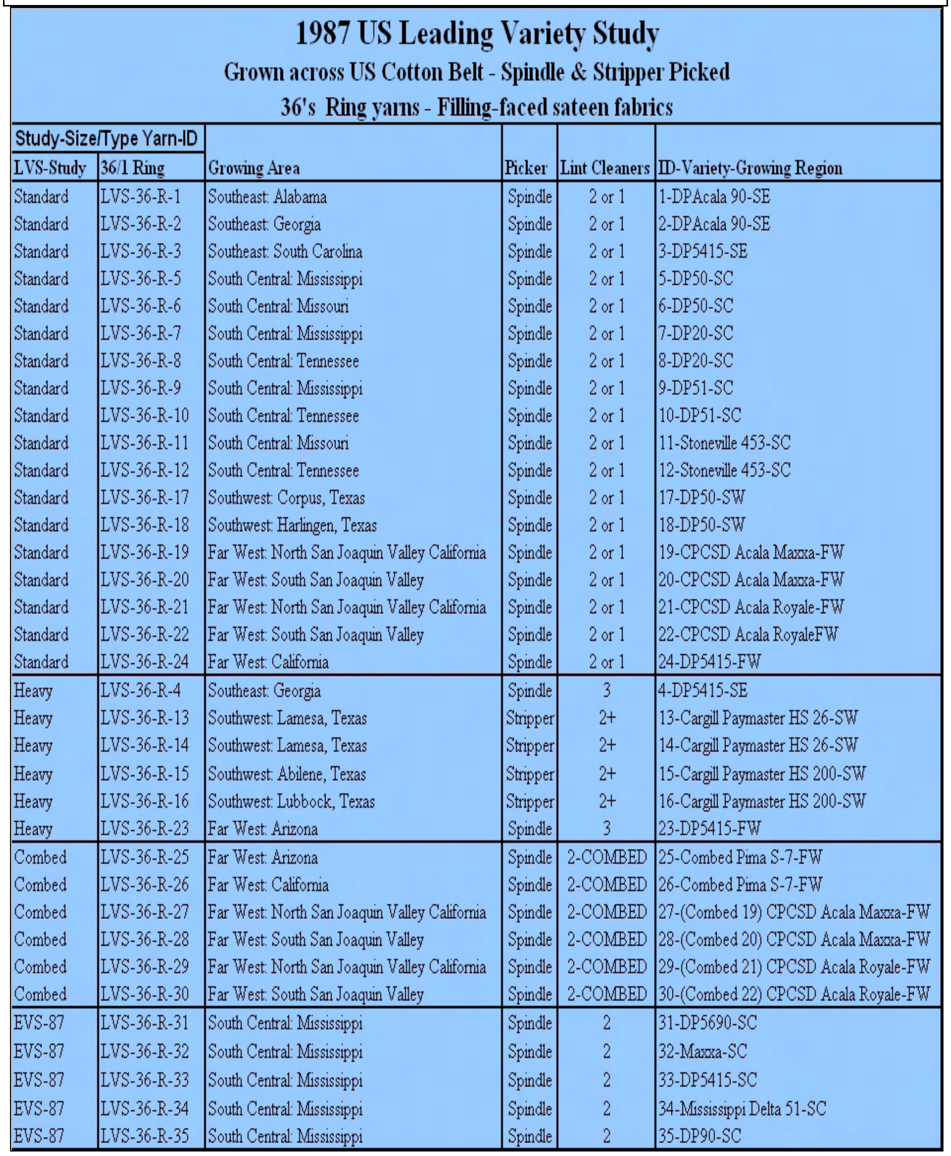
Figure 5.13: Calculating surface coverage of the experimental yarns.

5.2.1 US Leading Variety Study – (LVS)

The 1993 US LVS study was undertaken to quantify the impact of different processing regimes on white speck formation. Twenty-six bales of cotton (24 upland and 2 American Pima selected by H. H. Ramey Jr. of AMS), were purchased to represent leading varieties commercially grown in the United States in the test program, Five additional varieties were specifically grown to give a range of white specks as recommended by W. R. Meredith. Those five varieties were all harvested from the same rain grown field in Stoneville, Mississippi and processed identically to the 26 varieties mentioned above. The fibres were ginned using two lint cleaners. All 150 pounds of each sample were processed in the same manner [158](USDA, AMS, 1994) at CQRS (Cotton Quality Research Center) in Clemson, SC, USA. See flow chart in Appendix A - Figure A1- 2.

Table 5.1 describes the varieties and the growing areas used. All of the cottons were single carded at CQRS at a rate of 70 lbs/hour. The ring-spun 36's yarns gave 88.53% surface coverage on the dyed fabrics. The U.S. LVS were divided into several sub-groups to reflect the mechanical processing. In the first sub-group are standard US cottons with standard ginning and mill processing. The second group had heavy cleaning at the gin because the cotton was stripper harvested or because three lint cleaners were the standard for that gin. Standard mill processing was used for this group. The third group had standard ginning, but the cottons were combed in the mill. The Acala cottons, sample numbers 19 to 22, were both carded and then combed before ring spinning. The combed versions of these cottons were 27 to 30. The Pima cottons, 25 and 26, were only combed, as these varieties typically are combed. The fourth group is the 1987 EVS study, similar to the original EVS study in Chapter 4. In addition to the carded cottons, a combing study was included as part of the LVS (ID numbers 25 to 30).

Table 5.1: US LVS has several subgroups. Standard US cottons, cottons with heavy cleaning at the gin, combed cottons and the 1987 EVS cottons. The second column identifies each cotton (Study -yarn size and type- ID number).



1987 US Leading Variety Study

Grown across US Cotton Belt - Spindle & Stripper Picked

36's Ring yarns - Filling-faced sateen fabrics

Study-Size/Type Yarn-ID					
LVS-Study	36/1 Ring	Growing Area	Picker	Lint Cleaners	ID-Variety-Growing Region
Standard	LVS-36-R-1	Southeast: Alabama	Spindle	2 or 1	1-DPAcala 90-SE
Standard	LVS-36-R-2	Southeast: Georgia	Spindle	2 or 1	2-DPAcala 90-SE
Standard	LVS-36-R-3	Southeast: South Carolina	Spindle	2 or 1	3-DP5415-SE
Standard	LVS-36-R-5	South Central: Mississippi	Spindle	2 or 1	5-DP50-SC
Standard	LVS-36-R-6	South Central: Missouri	Spindle	2 or 1	6-DP50-SC
Standard	LVS-36-R-7	South Central: Mississippi	Spindle	2 or 1	7-DP20-SC
Standard	LVS-36-R-8	South Central: Tennessee	Spindle	2 or 1	8-DP20-SC
Standard	LVS-36-R-9	South Central: Mississippi	Spindle	2 or 1	9-DP51-SC
Standard	LVS-36-R-10	South Central: Tennessee	Spindle	2 or 1	10-DP51-SC
Standard	LVS-36-R-11	South Central: Missouri	Spindle	2 or 1	11-Stoneville 453-SC
Standard	LVS-36-R-12	South Central: Tennessee	Spindle	2 or 1	12-Stoneville 453-SC
Standard	LVS-36-R-17	Southwest: Corpus, Texas	Spindle	2 or 1	17-DP50-SW
Standard	LVS-36-R-18	Southwest: Harlingen, Texas	Spindle	2 or 1	18-DP50-SW
Standard	LVS-36-R-19	Far West: North San Joaquin Valley California	Spindle	2 or 1	19-CPCSD Acala Maxxa-FW
Standard	LVS-36-R-20	Far West: South San Joaquin Valley	Spindle	2 or 1	20-CPCSD Acala Maxxa-FW
Standard	LVS-36-R-21	Far West: North San Joaquin Valley California	Spindle	2 or 1	21-CPCSD Acala Royale-FW
Standard	LVS-36-R-22	Far West: South San Joaquin Valley	Spindle	2 or 1	22-CPCSD Acala RoyaleFW
Standard	LVS-36-R-24	Far West: California	Spindle	2 or 1	24-DP5415-FW
Heavy	LVS-36-R-4	Southeast: Georgia	Spindle	3	4-DP5415-SE
Heavy	LVS-36-R-13	Southwest: Lamesa, Texas	Stripper	2+	13-Cargill Paymaster HS 26-SW
Heavy	LVS-36-R-14	Southwest: Lamesa, Texas	Stripper	2+	14-Cargill Paymaster HS 26-SW
Heavy	LVS-36-R-15	Southwest: Abilene, Texas	Stripper	2+	15-Cargill Paymaster HS 200-SW
Heavy	LVS-36-R-16	Southwest: Lubbock, Texas	Stripper	2+	16-Cargill Paymaster HS 200-SW
Heavy	LVS-36-R-23	Far West: Arizona	Spindle	3	23-DP5415-FW
Combed	LVS-36-R-25	Far West: Arizona	Spindle	2-COMBED	25-Combed Pima S-7-FW
Combed	LVS-36-R-26	Far West: California	Spindle	2-COMBED	26-Combed Pima S-7-FW
Combed	LVS-36-R-27	Far West: North San Joaquin Valley California	Spindle	2-COMBED	27-(Combed 19) CPCSD Acala Maxxa-FW
Combed	LVS-36-R-28	Far West: South San Joaquin Valley	Spindle	2-COMBED	28-(Combed 20) CPCSD Acala Maxxa-FW
Combed	LVS-36-R-29	Far West: North San Joaquin Valley California	Spindle	2-COMBED	29-(Combed 21) CPCSD Acala Royale-FW
Combed	LVS-36-R-30	Far West: South San Joaquin Valley	Spindle	2-COMBED	30-(Combed 22) CPCSD Acala Royale-FW
EVS-87	LVS-36-R-31	South Central: Mississippi	Spindle	2	31-DP5690-SC
EVS-87	LVS-36-R-32	South Central: Mississippi	Spindle	2	32-Maxxa-SC
EVS-87	LVS-36-R-33	South Central: Mississippi	Spindle	2	33-DP5415-SC
EVS-87	LVS-36-R-34	South Central: Mississippi	Spindle	2	34-Mississippi Delta 51-SC
EVS-87	LVS-36-R-35	South Central: Mississippi	Spindle	2	35-DP90-SC

5.2.2 Australian Field Study 1998 (AU98)

Two series of field studies were conducted in Australia to complement the US LVS studies. They are named the AU98 and AU99 studies in this dissertation. The objective of these studies was to isolate variety and environmental effects from machinery effects on nep formation.

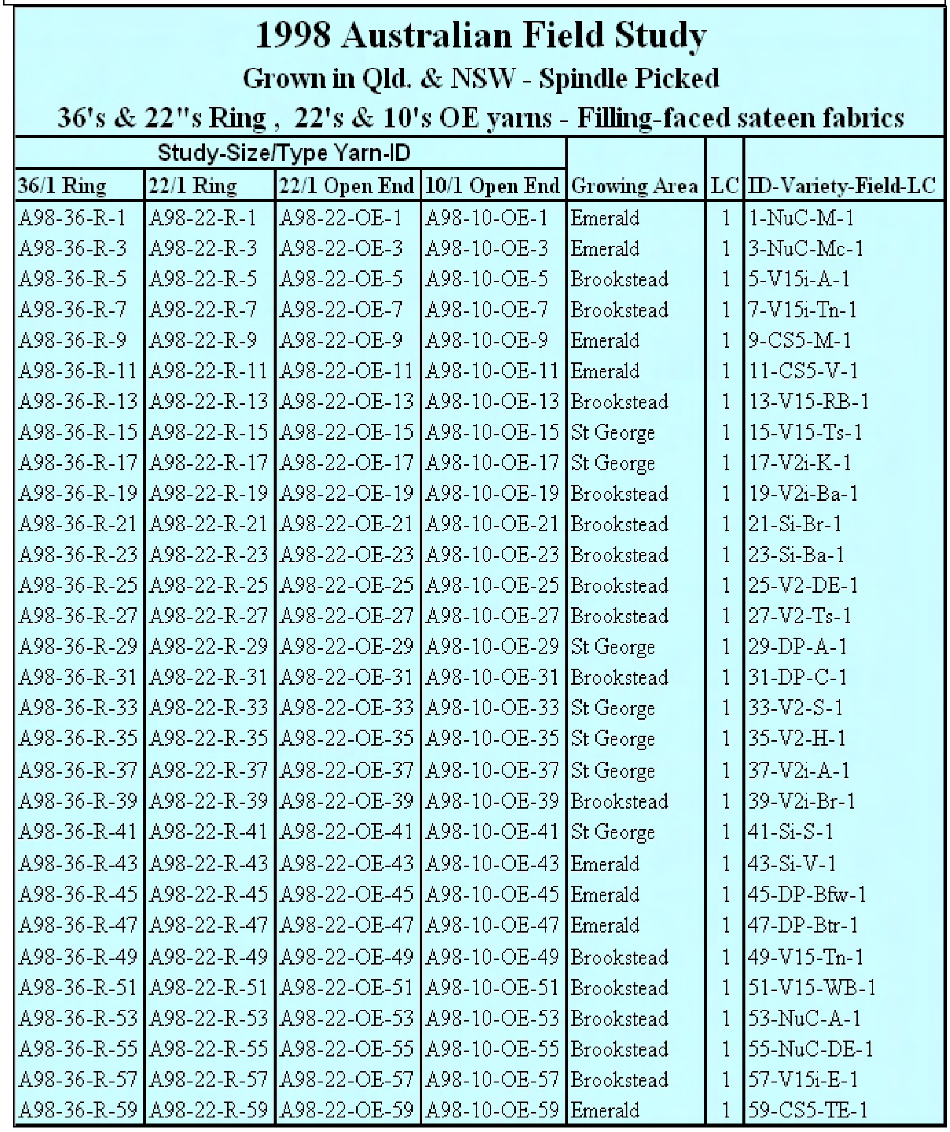
The AU98 study was conducted first, and 30 cotton samples were collected from across Australia to include eight different Australian varieties, with four locations or irrigation conditions (two varieties only have three locations, due to timing problems). Each sample had a known history regarding variety and growing issues such as drought, flood, cloud cover, high-low temperatures, or specific field problems. For example, if the white speck data for one variety has lower values at one location than another, the field history would show if the high white speck data were influenced by drought, flooding, or low sun days. It would be obvious that it was a weather problem rather than a varietal problem. For the purposes of quantifying the tendency of the variety to form white specks, the low white speck data would be used, but both the high and low white speck data are used for the fibre to fabric prediction study detailed in Chapter 6. By using all of the fibre data, including field conditions that increased immature fibre production, useful information could be obtained to help reduce white specks in the future and prediction equations for yarns and fabrics from fibre properties without processing interactions can be determined.

Thirty samples of seedcotton, each 1500 kg in weight, were baled using a small wool bale press in the field. Each sample was split into two 750 kg samples at Queensland Cotton’s Emerald Gin and ginned (approximately 5 bales/hr to assist in sampling; normal gin production is about 6 bales/hr) using one lint cleaner on one set and two lint cleaners on the second set of samples. All of the samples were processed through one gin in one line with common equipment settings, preserving the individual identities of the lots. The bulk of the ginned cottons were sold, reserving 50 lbs. of each of the 60 samples, which were sent to CQRS (Cotton Quality Research Station, Clemson SC, US). The 60 cotton bale samples were processed into 36's and 22's ring yarns and 22's and 10's OE yarns using the same processing protocol as the U.S LVS program. The full-scale equipment at CQRS is able to handle a minimum of 50 lbs. See flow chart in Appendix A - Figure A1- 3.

Cotton Seed Distributors (CSD) in Wee Waa furnishes 90% of seed planted in Australia and Deltapine provide 10% of the seed planted in Australia. Ninety % of CSD's sales come from five lines - SiCala V2 and V2i, SiOkra V15 and V15i, and SiCot 189. Deltapine seed is mostly Delta Pearl. These were included in the study together with an Inguard line of genetically modified cotton called NuCOTN.

One CSD variety, CS50, tends to have low micronaire, depending on the growing season. It is a long season variety that yields well, but our crop experienced a cold start to the growing season. One CS50 sample in Emerald experienced heavy rainfall twice following irrigation, so the urea fertiliser leached down slope. As a result, the upper end of the field ran out of nitrogen in early January. We would expect that cotton from the upper end would have the worst problem with white speck.

Table 5.2: Identification of the Au 98 cottons using one lint cleaner (LC) at the gin.



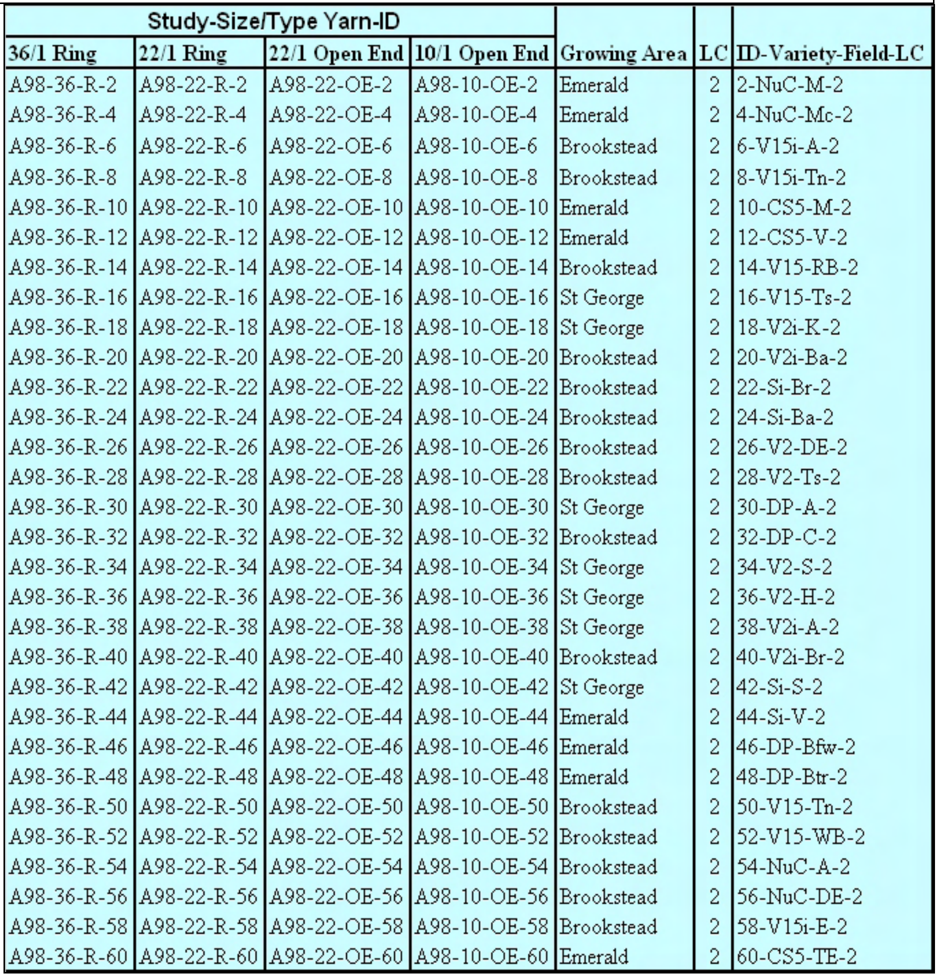
1998 Australian Field Study

Grown in Qld. & NSW - Spindle Picked

36's & 22"s Ring , 22's & 10's OE yarns - Filling-faced sateen fabrics

Study-Size/Type Yarn-ID						
36/1 Ring	**22/1 Ring**	**22/1 Open End**	**10/1 Open End**	**Growing Area**	**LC**	**ID-Variety-Field-LC**
A98-36-R-1	A98-22-R-1	A98-22-OE-1	A98-10-OE-1	Emerald	1	1-NuC-M-1
A98-36-R-3	A98-22-R-3	A98-22-OE-3	A98-10-OE-3	Emerald	1	3-NuC-Mc-1
A98-36-R-5	A98-22-R-5	A98-22-OE-5	A98-10-OE-5	Brookstead	1	5-V15i-A-1
A98-36-R-7	A98-22-R-7	A98-22-OE-7	A98-10-OE-7	Brookstead	1	7-V15i-Tn-1
A98-36-R-9	A98-22-R-9	A98-22-OE-9	A98-10-OE-9	Emerald	1	9-CS5-M-1
A98-36-R-11	A98-22-R-11	A98-22-OE-11	A98-10-OE-11	Emerald	1	11-CS5-V-1
A98-36-R-13	A98-22-R-13	A98-22-OE-13	A98-10-OE-13	Brookstead	1	13-V15-RB-1
A98-36-R-15	A98-22-R-15	A98-22-OE-15	A98-10-OE-15	St George	1	15-V15-Ts-1
A98-36-R-17	A98-22-R-17	A98-22-OE-17	A98-10-OE-17	St George	1	17-V2i-K-1
A98-36-R-19	A98-22-R-19	A98-22-OE-19	A98-10-OE-19	Brookstead	1	19-V2i-Ba-1
A98-36-R-21	A98-22-R-21	A98-22-OE-21	A98-10-OE-21	Brookstead	1	21-Si-Br-1
A98-36-R-23	A98-22-R-23	A98-22-OE-23	A98-10-OE-23	Brookstead	1	23-Si-Ba-1
A98-36-R-25	A98-22-R-25	A98-22-OE-25	A98-10-OE-25	Brookstead	1	25-V2-DE-1
A98-36-R-27	A98-22-R-27	A98-22-OE-27	A98-10-OE-27	Brookstead	1	27-V2-Ts-1
A98-36-R-29	A98-22-R-29	A98-22-OE-29	A98-10-OE-29	St George	1	29-DP-A-1
A98-36-R-31	A98-22-R-31	A98-22-OE-31	A98-10-OE-31	Brookstead	1	31-DP-C-1
A98-36-R-33	A98-22-R-33	A98-22-OE-33	A98-10-OE-33	St George	1	33-V2-S-1
A98-36-R-35	A98-22-R-35	A98-22-OE-35	A98-10-OE-35	St George	1	35-V2-H-1
A98-36-R-37	A98-22-R-37	A98-22-OE-37	A98-10-OE-37	St George	1	37-V2i-A-1
A98-36-R-39	A98-22-R-39	A98-22-OE-39	A98-10-OE-39	Brookstead	1	39-V2i-Br-1
A98-36-R-41	A98-22-R-41	A98-22-OE-41	A98-10-OE-41	St George	1	41-Si-S-1
A98-36-R-43	A98-22-R-43	A98-22-OE-43	A98-10-OE-43	Emerald	1	43-Si-V-1
A98-36-R-45	A98-22-R-45	A98-22-OE-45	A98-10-OE-45	Emerald	1	45-DP-Bfw-1
A98-36-R-47	A98-22-R-47	A98-22-OE-47	A98-10-OE-47	Emerald	1	47-DP-Btr-1
A98-36-R-49	A98-22-R-49	A98-22-OE-49	A98-10-OE-49	Brookstead	1	49-V15-Tn-1
A98-36-R-51	A98-22-R-51	A98-22-OE-51	A98-10-OE-51	Brookstead	1	51-V15-WB-1
A98-36-R-53	A98-22-R-53	A98-22-OE-53	A98-10-OE-53	Brookstead	1	53-NuC-A-1
A98-36-R-55	A98-22-R-55	A98-22-OE-55	A98-10-OE-55	Brookstead	1	55-NuC-DE-1
A98-36-R-57	A98-22-R-57	A98-22-OE-57	A98-10-OE-57	Brookstead	1	57-V15i-E-1
A98-36-R-59	A98-22-R-59	A98-22-OE-59	A98-10-OE-59	Emerald	1	59-CS5-TE-1

Table 5.3: Continuation of the identification of the Au 98 cottons - two lint cleaners (LC) at the gin.



Study-Size/Type Yarn-ID						
36/1 Ring	22/1 Ring	22/1 Open End	10/1 Open End	Growing Area	LC	ID-Variety-Field-LC
A98-36-R-2	A98-22-R-2	A98-22-OE-2	A98-10-OE-2	Emerald	2	2-NuC-M-2
A98-36-R-4	A98-22-R-4	A98-22-OE-4	A98-10-OE-4	Emerald	2	4-NuC-Mc-2
A98-36-R-6	A98-22-R-6	A98-22-OE-6	A98-10-OE-6	Brookstead	2	6-V15i-A-2
A98-36-R-8	A98-22-R-8	A98-22-OE-8	A98-10-OE-8	Brookstead	2	8-V15i-Tn-2
A98-36-R-10	A98-22-R-10	A98-22-OE-10	A98-10-OE-10	Emerald	2	10-CS5-M-2
A98-36-R-12	A98-22-R-12	A98-22-OE-12	A98-10-OE-12	Emerald	2	12-CS5-V-2
A98-36-R-14	A98-22-R-14	A98-22-OE-14	A98-10-OE-14	Brookstead	2	14-V15-RB-2
A98-36-R-16	A98-22-R-16	A98-22-OE-16	A98-10-OE-16	St George	2	16-V15-Ts-2
A98-36-R-18	A98-22-R-18	A98-22-OE-18	A98-10-OE-18	St George	2	18-V2i-K-2
A98-36-R-20	A98-22-R-20	A98-22-OE-20	A98-10-OE-20	Brookstead	2	20-V2i-Ba-2
A98-36-R-22	A98-22-R-22	A98-22-OE-22	A98-10-OE-22	Brookstead	2	22-Si-Br-2
A98-36-R-24	A98-22-R-24	A98-22-OE-24	A98-10-OE-24	Brookstead	2	24-Si-Ba-2
A98-36-R-26	A98-22-R-26	A98-22-OE-26	A98-10-OE-26	Brookstead	2	26-V2-DE-2
A98-36-R-28	A98-22-R-28	A98-22-OE-28	A98-10-OE-28	Brookstead	2	28-V2-Ts-2
A98-36-R-30	A98-22-R-30	A98-22-OE-30	A98-10-OE-30	St George	2	30-DP-A-2
A98-36-R-32	A98-22-R-32	A98-22-OE-32	A98-10-OE-32	Brookstead	2	32-DP-C-2
A98-36-R-34	A98-22-R-34	A98-22-OE-34	A98-10-OE-34	St George	2	34-V2-S-2
A98-36-R-36	A98-22-R-36	A98-22-OE-36	A98-10-OE-36	St George	2	36-V2-H-2
A98-36-R-38	A98-22-R-38	A98-22-OE-38	A98-10-OE-38	St George	2	38-V2i-A-2
A98-36-R-40	A98-22-R-40	A98-22-OE-40	A98-10-OE-40	Brookstead	2	40-V2i-Br-2
A98-36-R-42	A98-22-R-42	A98-22-OE-42	A98-10-OE-42	St George	2	42-Si-S-2
A98-36-R-44	A98-22-R-44	A98-22-OE-44	A98-10-OE-44	Emerald	2	44-Si-V-2
A98-36-R-46	A98-22-R-46	A98-22-OE-46	A98-10-OE-46	Emerald	2	46-DP-Bfw-2
A98-36-R-48	A98-22-R-48	A98-22-OE-48	A98-10-OE-48	Emerald	2	48-DP-Btr-2
A98-36-R-50	A98-22-R-50	A98-22-OE-50	A98-10-OE-50	Brookstead	2	50-V15-Tn-2
A98-36-R-52	A98-22-R-52	A98-22-OE-52	A98-10-OE-52	Brookstead	2	52-V15-WB-2
A98-36-R-54	A98-22-R-54	A98-22-OE-54	A98-10-OE-54	Brookstead	2	54-NuC-A-2
A98-36-R-56	A98-22-R-56	A98-22-OE-56	A98-10-OE-56	Brookstead	2	56-NuC-DE-2
A98-36-R-58	A98-22-R-58	A98-22-OE-58	A98-10-OE-58	Brookstead	2	58-V15i-E-2
A98-36-R-60	A98-22-R-60	A98-22-OE-60	A98-10-OE-60	Emerald	2	60-CS5-TE-2

5.2.3 Australian Field Study 1999 (AU99)

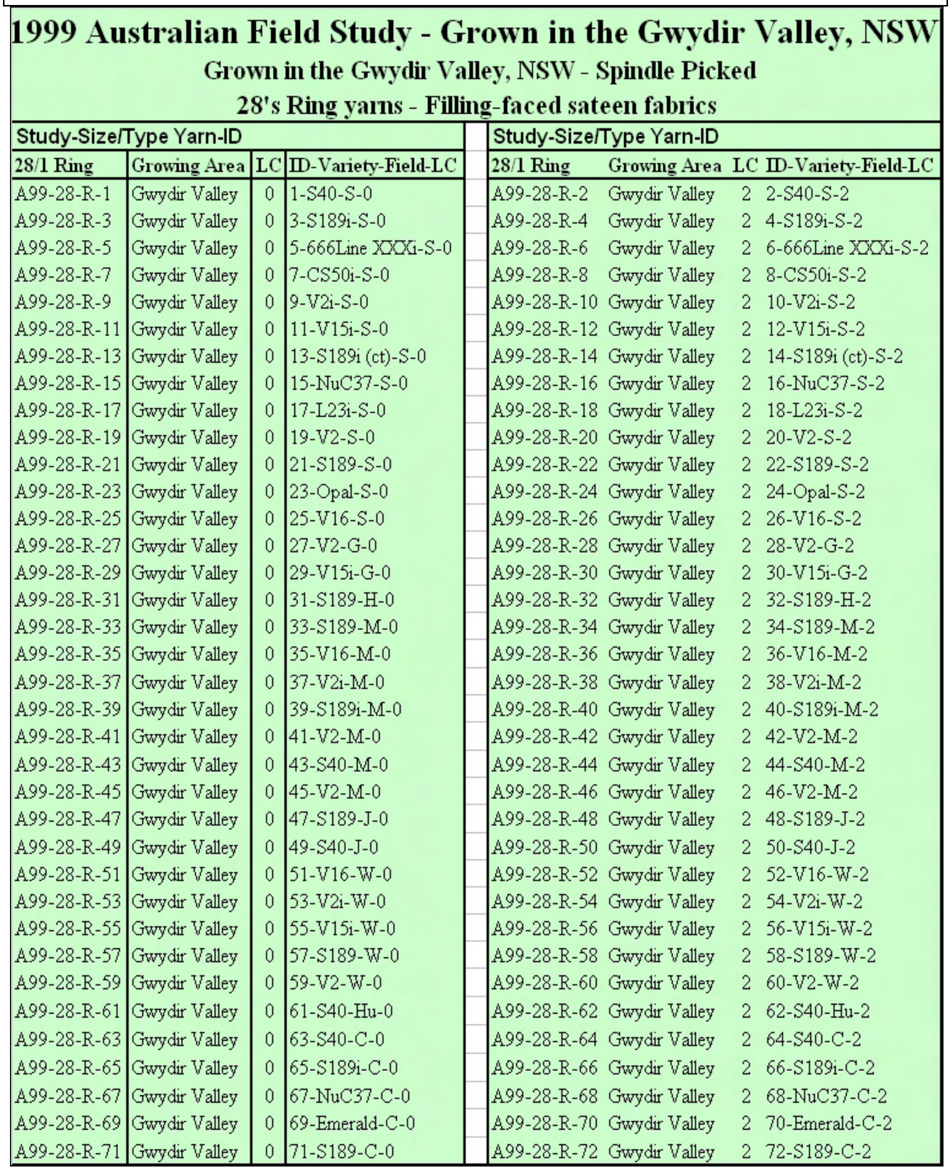
The second Australian field trial was based on module size cotton samples from the 1999 Crop. This meant that it was restricted by freight costs to the 'catchment' of one gin. It was not possible to have equal numbers of a selected group of varieties in this study because there were not enough prospective samples from which to choose. This meant that certain varieties were represented by many samples and other varieties by single samples. The decision was taken to accept the statistical constraints on comparisons between varieties in order to get the benefits of having more samples overall for wider comparisons. Namoi Co-op's Wathagar gin, east of Moree was selected for processing the samples. Cotton was selected in the field, and harvested normally by spindle picking. At harvest, the cotton was specially tagged and diverted to stand with the other sample modules until a suitable time. The 36 modules comprised 540 tonnes of seedcotton and required about 20 hours running time for the Wathagar gin. A rain front arrived after the first 12 hours of ginning, changing the ambient atmospheric conditions. The decision was then made to break the ginning after the 13th sample module. This was done assuming that fewer problems would be caused by the break in continuity than were likely to be caused by ginning under markedly different atmospheric conditions. The ginning of the remaining 23 sample modules resumed 21 days later under conditions similar to those existing for the first 13. All ginning was done during a 'day' shift, which is 12 hours from 8 a.m. to 8 p.m. The equipment was being used in the main run of the season's cotton at the time the samples were ginned. No changes were made for the sample modules except for the number of lint cleaners brought into use.

In this AU99 trial, the gin’s operation had to be continuously managed. The first half of each module was ginned using two lint cleaners, which was standard for that gin in that season. The flow of seedcotton from the module feeder was then stopped, and a bale of cotton fibre was pressed. A lint sample was taken at this time and adjustments were made to the equipment so that both lint cleaners were by-passed. The flow of seedcotton was resumed until a second bale was pressed. A sample of this 'zero lint cleaner' cotton was then removed in the same way as the previous sample, and the two lint cleaners were brought back into use. The flow of seedcotton then resumed to complete ginning of that module and start the sequence again with the next sample module. Each 25kg lint sample was weighed, and then pressed into woolpacks (small bales) in a nearby wool press. Four samples were pressed into each woolpack. The lint samples in woolpacks were transported and stored for further processing. Smaller lint samples were taken for laboratory analysis. After ginning, the lint was freighted to the International Fibre Centre (IFC), Melbourne, Victoria, Australia, to be spun on a ring spinning frame to a nominal yarn size of 30's Ne (19.7 Tex). The spinning specifications were set up to match the U.S. LVS mill processing protocol. See flow chart in Appendix A - Figure A1- 4.

The processing of yarns from this study into fabrics experienced technical problems. Initially, the yarns were woven and dyed by ITC, International Textile Center, Lubbock, Texas, U. S., for a fee, using a common combed warp, in a filling faced sateen for dyeing and white speck evaluation. The yarns were backwound before weaving and there was a large amount of “fly” in the air during rewinding. The fabrics all appeared relatively free of white specks. When the fabrics were tested on AutoRate, there was no significant difference among these fabrics for white speck, even though the fibre data indicated it should be significant. The yarns were sent to USDA and rewoven on the same warp as was used in previous studies. The fabrics were visibly different as can be seen in the results section (Figure 6.5).

All of the cottons from this trial were CSD and DP smooth leaf Upland varieties. Varieties with “i” as the last letter in their variety name are Inguard varieties, single BT gene (same as US Bollguard™). The 666 and Line XXXi are alternative names for an experimental variety from CSD. S189i (ct) distinguishes that module from another S189i module, both from Statham. The former was grown amongst a range of conventional varieties and was sprayed when they were sprayed. The latter was grown amongst a range of Inguard varieties and had the same field treatments as the Inguard varieties.

Table 5.4: Identification of the Au 99 cottons using 0 & 2 lint cleaners (LC) at the gin.



1999 Australian Field Study - Grown in the Gwydir Valley, NSW

Grown in the Gwydir Valley, NSW - Spindle Picked

28's Ring yarns - Filling-faced sateen fabrics

Study-Size/Type Yarn-ID				Study-Size/Type Yarn-ID			
28/1 Ring	Growing Area	LC	ID-Variety-Field-LC	28/1 Ring	Growing Area	LC	ID-Variety-Field-LC
A99-28-R-1	Gwydir Valley	0	1-S40-S-0	A99-28-R-2	Gwydir Valley	2	2-S40-S-2
A99-28-R-3	Gwydir Valley	0	3-S189i-S-0	A99-28-R-4	Gwydir Valley	2	4-S189i-S-2
A99-28-R-5	Gwydir Valley	0	5-666Line XXXi-S-0	A99-28-R-6	Gwydir Valley	2	6-666Line XXXi-S-2
A99-28-R-7	Gwydir Valley	0	7-CS50i-S-0	A99-28-R-8	Gwydir Valley	2	8-CS50i-S-2
A99-28-R-9	Gwydir Valley	0	9-V2i-S-0	A99-28-R-10	Gwydir Valley	2	10-V2i-S-2
A99-28-R-11	Gwydir Valley	0	11-V15i-S-0	A99-28-R-12	Gwydir Valley	2	12-V15i-S-2
A99-28-R-13	Gwydir Valley	0	13-S189i (ct)-S-0	A99-28-R-14	Gwydir Valley	2	14-S189i (ct)-S-2
A99-28-R-15	Gwydir Valley	0	15-NuC37-S-0	A99-28-R-16	Gwydir Valley	2	16-NuC37-S-2
A99-28-R-17	Gwydir Valley	0	17-L23i-S-0	A99-28-R-18	Gwydir Valley	2	18-L23i-S-2
A99-28-R-19	Gwydir Valley	0	19-V2-S-0	A99-28-R-20	Gwydir Valley	2	20-V2-S-2
A99-28-R-21	Gwydir Valley	0	21-S189-S-0	A99-28-R-22	Gwydir Valley	2	22-S189-S-2
A99-28-R-23	Gwydir Valley	0	23-Opal-S-0	A99-28-R-24	Gwydir Valley	2	24-Opal-S-2
A99-28-R-25	Gwydir Valley	0	25-V16-S-0	A99-28-R-26	Gwydir Valley	2	26-V16-S-2
A99-28-R-27	Gwydir Valley	0	27-V2-G-0	A99-28-R-28	Gwydir Valley	2	28-V2-G-2
A99-28-R-29	Gwydir Valley	0	29-V15i-G-0	A99-28-R-30	Gwydir Valley	2	30-V15i-G-2
A99-28-R-31	Gwydir Valley	0	31-S189-H-0	A99-28-R-32	Gwydir Valley	2	32-S189-H-2
A99-28-R-33	Gwydir Valley	0	33-S189-M-0	A99-28-R-34	Gwydir Valley	2	34-S189-M-2
A99-28-R-35	Gwydir Valley	0	35-V16-M-0	A99-28-R-36	Gwydir Valley	2	36-V16-M-2
A99-28-R-37	Gwydir Valley	0	37-V2i-M-0	A99-28-R-38	Gwydir Valley	2	38-V2i-M-2
A99-28-R-39	Gwydir Valley	0	39-S189i-M-0	A99-28-R-40	Gwydir Valley	2	40-S189i-M-2
A99-28-R-41	Gwydir Valley	0	41-V2-M-0	A99-28-R-42	Gwydir Valley	2	42-V2-M-2
A99-28-R-43	Gwydir Valley	0	43-S40-M-0	A99-28-R-44	Gwydir Valley	2	44-S40-M-2
A99-28-R-45	Gwydir Valley	0	45-V2-M-0	A99-28-R-46	Gwydir Valley	2	46-V2-M-2
A99-28-R-47	Gwydir Valley	0	47-S189-J-0	A99-28-R-48	Gwydir Valley	2	48-S189-J-2
A99-28-R-49	Gwydir Valley	0	49-S40-J-0	A99-28-R-50	Gwydir Valley	2	50-S40-J-2
A99-28-R-51	Gwydir Valley	0	51-V16-W-0	A99-28-R-52	Gwydir Valley	2	52-V16-W-2
A99-28-R-53	Gwydir Valley	0	53-V2i-W-0	A99-28-R-54	Gwydir Valley	2	54-V2i-W-2
A99-28-R-55	Gwydir Valley	0	55-V15i-W-0	A99-28-R-56	Gwydir Valley	2	56-V15i-W-2
A99-28-R-57	Gwydir Valley	0	57-S189-W-0	A99-28-R-58	Gwydir Valley	2	58-S189-W-2
A99-28-R-59	Gwydir Valley	0	59-V2-W-0	A99-28-R-60	Gwydir Valley	2	60-V2-W-2
A99-28-R-61	Gwydir Valley	0	61-S40-Hu-0	A99-28-R-62	Gwydir Valley	2	62-S40-Hu-2
A99-28-R-63	Gwydir Valley	0	63-S40-C-0	A99-28-R-64	Gwydir Valley	2	64-S40-C-2
A99-28-R-65	Gwydir Valley	0	65-S189i-C-0	A99-28-R-66	Gwydir Valley	2	66-S189i-C-2
A99-28-R-67	Gwydir Valley	0	67-NuC37-C-0	A99-28-R-68	Gwydir Valley	2	68-NuC37-C-2
A99-28-R-69	Gwydir Valley	0	69-Emerald-C-0	A99-28-R-70	Gwydir Valley	2	70-Emerald-C-2
A99-28-R-71	Gwydir Valley	0	71-S189-C-0	A99-28-R-72	Gwydir Valley	2	72-S189-C-2

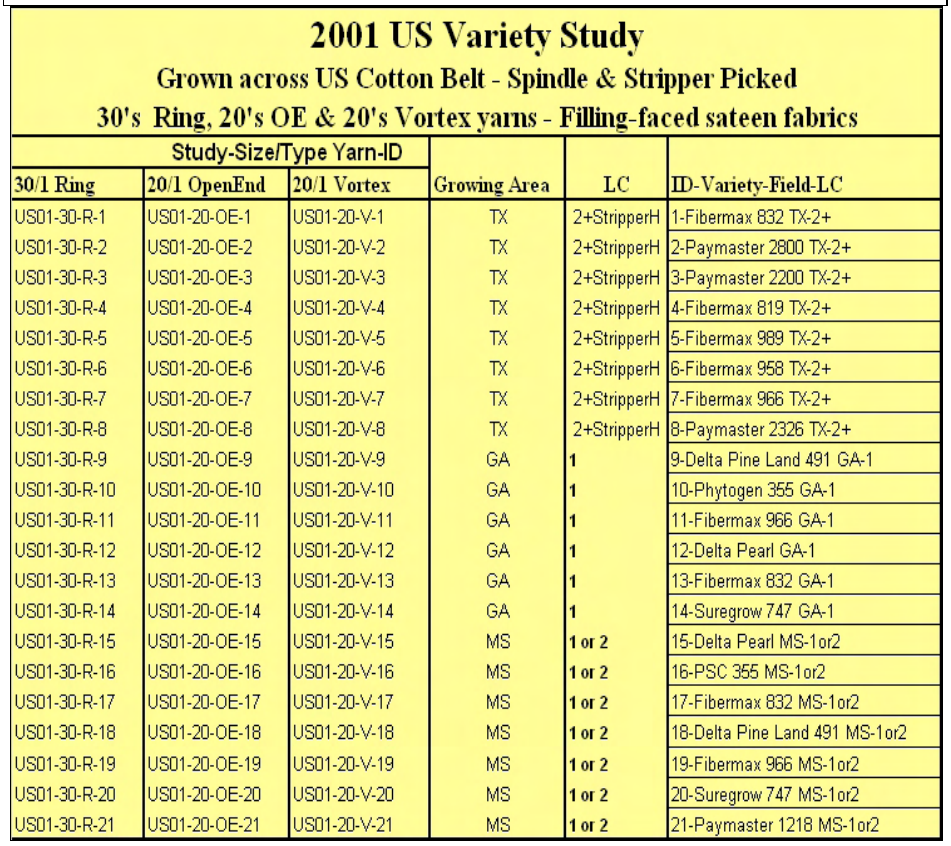
5.2.4 US 2001 Variety Study (U.S. 2001)

The cottons for the U.S. Cotton Variety Textile Processing Trials were grown in Georgia, Mississippi and Texas during the 2001 season. The Georgia cottons were grown in the same field, spindle picked and ginned with one lint cleaner. The Texas cottons were grown in one field, stripper picked and ginned using two lint cleaners. The Mississippi cottons were grown in the same area and obtained commercially without ginning information. Eight bales of cotton were collected for each variety and location for a total of 168 bales. Each bale for each variety was sampled and blended for processing. Yarns were made by CQRS from one blended bale per variety per location (21 Blocks). Blended bales were processed using the same protocol as the LVS (detailed below) study except for carding speeds. Ring, OE and Vortex yarns were spun. See flow chart in Appendix A - Figure A1-5. The processing protocol is in Table 5.5.

Table 5.5: Mill processing protocol for the US 2001 cottons

Opening & Carding: blended bales carded at 150 pounds per hour similar to industry speeds.
Drawing 1st: The card sliver was split into 4 equal groups for further processing:
For Open End Spinning - 55 gr. sliver for spinning.
For Ring Spinning - 60 gr. sliver for 2nd drawing.
For Vortex Spinning - 55 gr. sliver for 2nd drawing.
Drawing 2nd:
For Ring Spinning - 61 gr. sliver for roving.
For Vortex Spinning - 45 gr. sliver for 3rd drawing.
Drawing 3rd:
For Vortex Spinning - 24 cans for spinning 40 gr. sliver.
Roving For Ring Spinning: 0.75 HR (Hank Roving) 1.30 TM (Twist Multiplier)
Spinning:
OES: Spin 20/1’s with a 4.6 TM.
Ring: Spin 20/1’s with a 4.3 TM.
Vortex: Spin 20/1’s.
Weaving: The yarns were woven as a filling faced sateen in a combed common warp as detailed in Figure 5.13.

Table 5.6: Identification of the US 2001 cottons.



2001 US Variety Study

Grown across US Cotton Belt - Spindle & Stripper Picked

30's Ring, 20's OE & 20's Vortex yarns - Filling-faced sateen fabrics

Study-Size/Type Yarn-ID					
30/1 Ring	20/1 OpenEnd	20/1 Vortex	Growing Area	LC	ID-Variety-Field-LC
US01-30-R-1	US01-20-OE-1	US01-20-V-1	TX	2+StripperH	1-Fibermax 832 TX-2+
US01-30-R-2	US01-20-OE-2	US01-20-V-2	TX	2+StripperH	2-Paymaster 2800 TX-2+
US01-30-R-3	US01-20-OE-3	US01-20-V-3	TX	2+StripperH	3-Paymaster 2200 TX-2+
US01-30-R-4	US01-20-OE-4	US01-20-V-4	TX	2+StripperH	4-Fibermax 819 TX-2+
US01-30-R-5	US01-20-OE-5	US01-20-V-5	TX	2+StripperH	5-Fibermax 989 TX-2+
US01-30-R-6	US01-20-OE-6	US01-20-V-6	TX	2+StripperH	6-Fibermax 958 TX-2+
US01-30-R-7	US01-20-OE-7	US01-20-V-7	TX	2+StripperH	7-Fibermax 966 TX-2+
US01-30-R-8	US01-20-OE-8	US01-20-V-8	TX	2+StripperH	8-Paymaster 2326 TX-2+
US01-30-R-9	US01-20-OE-9	US01-20-V-9	GA	1	9-Delta Pine Land 491 GA-1
US01-30-R-10	US01-20-OE-10	US01-20-V-10	GA	1	10-Phytogen 355 GA-1
US01-30-R-11	US01-20-OE-11	US01-20-V-11	GA	1	11-Fibermax 966 GA-1
US01-30-R-12	US01-20-OE-12	US01-20-V-12	GA	1	12-Delta Pearl GA-1
US01-30-R-13	US01-20-OE-13	US01-20-V-13	GA	1	13-Fibermax 832 GA-1
US01-30-R-14	US01-20-OE-14	US01-20-V-14	GA	1	14-Suregrow 747 GA-1
US01-30-R-15	US01-20-OE-15	US01-20-V-15	MS	1 or 2	15-Delta Pearl MS-1or2
US01-30-R-16	US01-20-OE-16	US01-20-V-16	MS	1 or 2	16-PSC 355 MS-1or2
US01-30-R-17	US01-20-OE-17	US01-20-V-17	MS	1 or 2	17-Fibermax 832 MS-1or2
US01-30-R-18	US01-20-OE-18	US01-20-V-18	MS	1 or 2	18-Delta Pine Land 491 MS-1or2
US01-30-R-19	US01-20-OE-19	US01-20-V-19	MS	1 or 2	19-Fibermax 966 MS-1or2
US01-30-R-20	US01-20-OE-20	US01-20-V-20	MS	1 or 2	20-Suregrow 747 MS-1or2
US01-30-R-21	US01-20-OE-21	US01-20-V-21	MS	1 or 2	21-Paymaster 1218 MS-1or2

6. RESULTS OF FIELD STUDIES

Data obtained in the previous chapter were analysed for variety, environment and machinery interactions. The most important fibre data for each of the measurement systems and the white speck fabric data for the four large-scale studies are contained in Appendix B.

6.1 Results - LVS

This study was an extension of the candidate's research with the Agriculture Marketing Services (AMS, USDA) on the leading 26 Varieties in the USA. The U.S. study included varieties exhibiting a wide range in levels of white specks in the finished fabrics. It must be recalled that seedcotton contains very few neps. Thus, neps are largely a result of mechanical processing actions, such as harvesting, ginning, and cleaning. The varieties were collected from different gins and demonstrated that true varietal differences were not readily discernable because of the processing interactions, as can be seen in Figure 6.1.

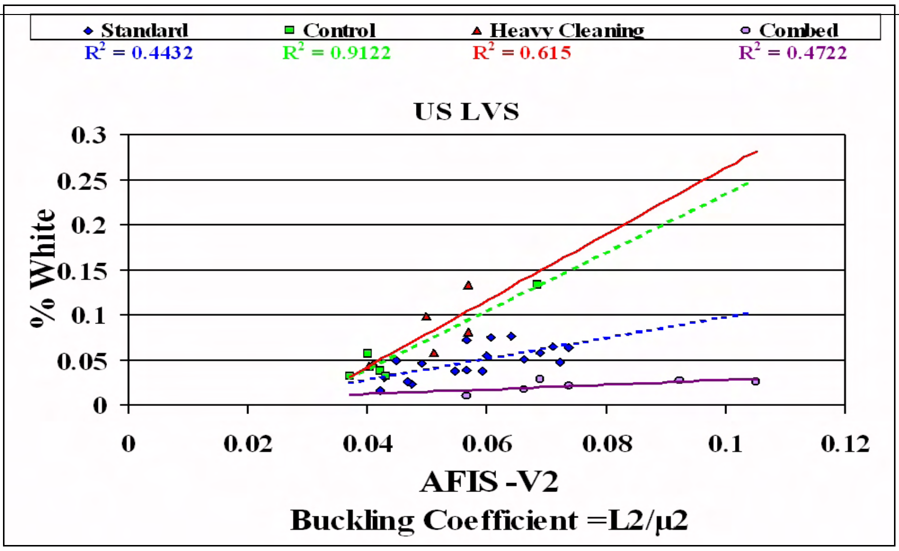


Figure 6.1: AFIS Bale Data vs. White Speck for the US 26 Leading Varieties and the 5 Controls

The different levels of processing break into distinct groups on the graph, signifying that processing definitely has an effect on the level of white specks. The control group has the highest r^2 of 0.92. Even though the other groups have lower R^2 values, the relationships of the Buckling Coefficients (AFIS Version 2) to white specks show that harsher ginning actions will lead to higher levels of white specks, given similar buckling coefficients. Combing removes neps, mainly immature fibre clusters that are the ultimate cause of white specks, and short fibres. Since most neps are white specks, it is not surprising that the combed yarns make fabrics having much lower levels of white specks than the carded yarns, as seen in Figure 6.2. The standard cottons have the next highest level of white specks on Figure 6.1. These fibres were ginned using one or two lint cleaners, but in view of the significant difference between the standard cottons and the controls, which used two lint cleaners, it is probable that most of the standard cottons were processed with only one lint cleaner. The highest level of white specks appears in the heavily cleaned cottons.

Comment [MP1]: We usually use the lower case r for r squared values

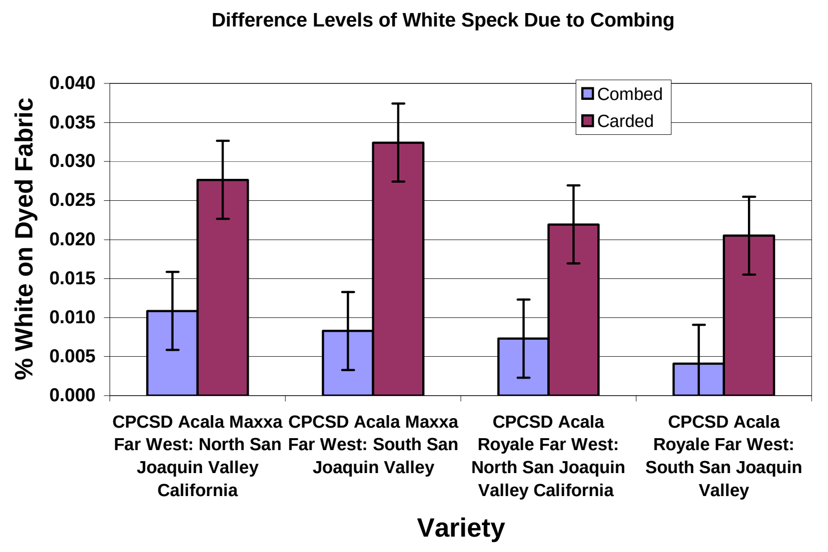


Figure 6.2: Combing significantly reduces white specks (these fabrics are from the LVS).

It is concluded from the analysis that combing results in a major reduction in the level of white specks (Figure 6.2). . Combing is one of the tools that mills can use to improve the quality of cottons with high levels of immature fibres.

It is also concluded that for true varietal differences to be readily discernable, cottons should be grown across a wide region with duplication for varieties, and then ginned at a single gin with yarns produced on the same spinning system. This approach eliminates processing variability in the data. True bale cotton fibre properties could then be related to yarn and fabric strengths and white specks in the finished fabric. The Australian field studies were undertaken to meet this objective.

6.2 Results AU98 & AU99 White Speck Studies

6.2.1 Yarn Spinning System

Open-End (OE) spinning had a significantly lower level of white specks than ring spinning when the Australian fibres were evaluated (Figure 6.3). Essentially, the opening system combs out the clusters of immature fibres and discards them as trash. The opening system was designed to remove trash from the fibre before feeding the individualized fibres to the rotor, to improve uniformity and increase efficiency. Very small differences are seen in fabrics produced from a large range of fibre qualities when OE spinning is employed; however, the fabric quality is much more variable when the fibres are ring spun.

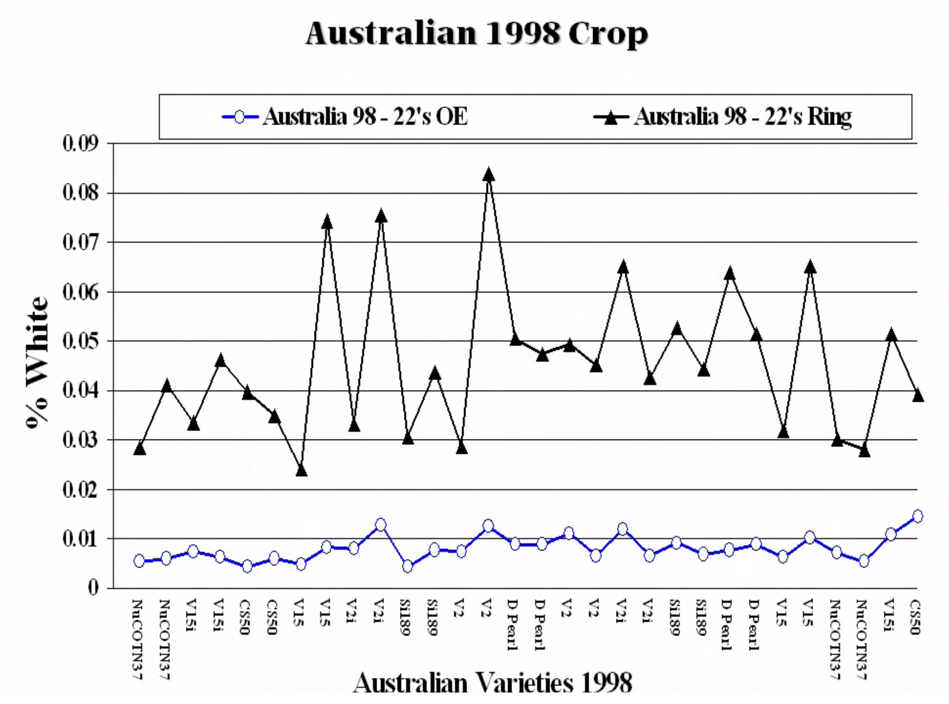


Figure 6.3: OE spinning has minimal levels of white specks as compared to ring spinning.

6.2.2 Yarn Size

OE spinning had such low levels of white specks that no significant differences were seen in the data. Figure 6.3 shows the yarn size effect. However, a significant difference was found in white speck levels for ring spinning. This is easily explainable when it is considered that a smaller yarn (30’s) has less weight for the same length than a heavier yarn (20’s). Essentially, since there is no means of removing the white speck in ring spinning, like the opening system in OE spinning, the number of specks per gram remains the same after spinning. The number of neps should remain the same for a given weight, but when that same weight of fibres is drafted down (stretched) to a smaller yarn size, the same number of neps is spread out over a longer length. This results in lower nep/white speck counts per length of yarn and the fabrics made from smaller yarns, This is characterized in Figure 6.4

with the 36’s having a significantly lower level of white specks than the 22’s. Once the data were adjusted for yarn size, there was no significant difference in white speck levels. It is concluded that comparisons of different studies require the white speck counts to be adjusted by weight to a common basis equivalent to 30’s yarns.

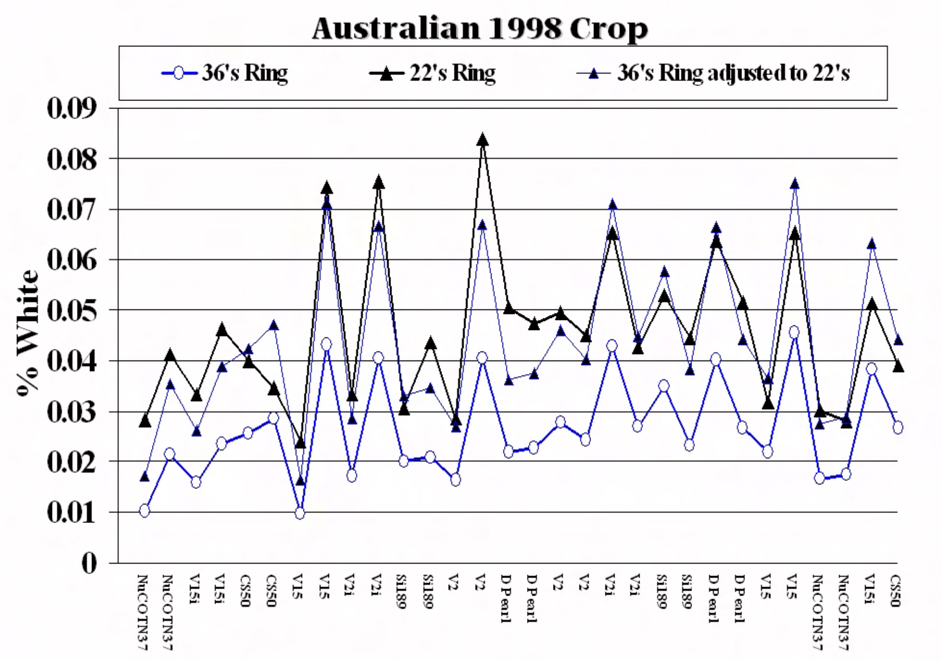


Figure 6.4: Yarn size effect on % white and data adjusted on basis of weight.

6.2.3 Lint Cleaner Treatments

When the 1999 cotton was being ginned, the zero lint cleaner treatment cotton was visibly trashier than the two lint cleaner cotton. In fact, it caused concern among the ginning staff that it would be a problem. While the cotton was being baled, the comment was made that "ginners have lost their jobs for producing lint with less trash than this.” The zero lint cleaner treatment had 160% more trash, but 15% less short fibre content. Short fibre content is a good indicator of severity of gin processing and fibre damage; low short fibre indicates gentle ginning. It was also 2.5% longer (by HVI), which corresponded to 1/32nd of an inch. The only grading attributes where the zero lint cleaner treatment scored worse were the trash and colour attributes. These strongly determine the bale value under the current classing scheme (hence the comment reported above). This is what might be called the *ginner's paradox* **-** he can gin for bale value, or he can gin for best quality of the cotton, but he cannot do both at present. The zero (Au99) and one lint cleaner (Au98) treatments are superior to the two lint cleaner treatment in all attributes that determine the realized quality of the cotton, except for trash content.

Figure 6.5 shows the effect of lint cleaner treatments on fabric quality (% White for the 1998 and 1999 field trials). The quality as seen in the final product, i.e., the dyed fabrics, shows no statistically significant differences between the two gin treatments (one and two lint cleaners for 1998 or between zero and two lint cleaners for 1999) for the % white (percent area of fabric occupied by white speck neps). One might expect from earlier published work by the candidate (Figure 5.8) that there would be a difference in the levels of fabric white specks due to different levels of lint cleaning. However there was no significant difference, indicating that the cards used in these studies were in excellent condition with sharp wires, so that the ginning effects were masked. A card with worn wires would probably have shown lint cleaner effects. This emphasizes how important it is for mills to keep their cards in top condition.

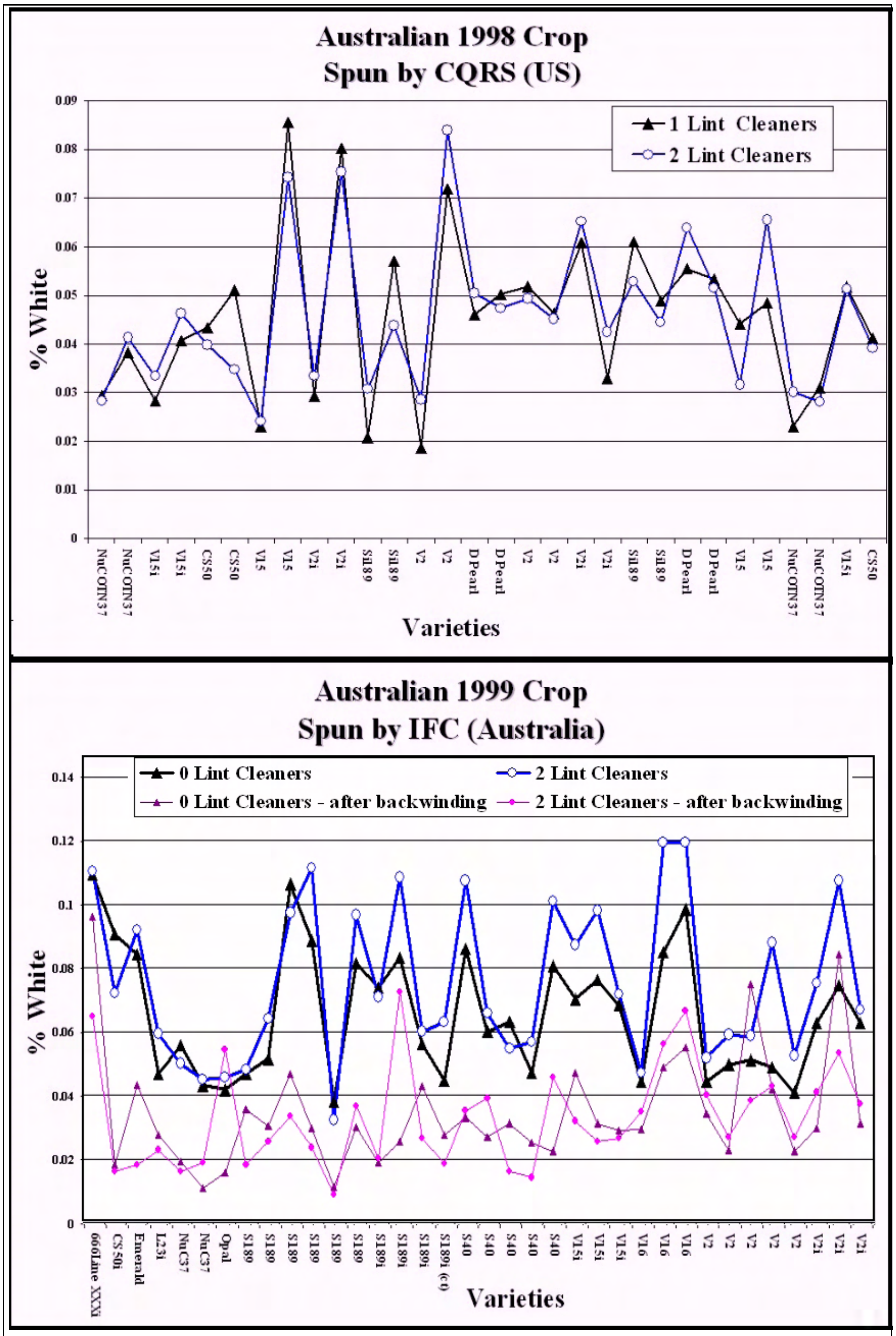


Figure 6.5: Lint cleaner effects on white specks for 1998 and 1999 field studies.

6.2.4 Winding

The Au99 study samples were originally sent to ITC for weaving and dyeing. The subsequent analyses gave very weak fibre to fabric (% white) relationships and the fabrics appeared to have lower levels of white specks than were expected considering the maturity of the fibres. When the weaver was questioned, the reason for these low white speck levels was discovered. The yarns had to be rewound (backwound) to smaller packages when received from Australia. A large amount of “fly,” i.e., loose fibre, was noticed in the air during the winding process. The yarns were shipped to SRRC and the winder was checked for any sharp edges or high tension on trial samples. The Au98 samples were backwound with minimum weights on the tensioners to minimize any fly. New fabrics were woven, dyed, and analysed and a significant difference was seen between the two sets of fabrics; but not between the levels of lint cleaning for either set of fabrics. The % white for the fabrics from ITC (after backwinding) and SRRC are shown in Figure 6.5, bottom graph).

This same phenomenon occurred in a mill in Australia. The mill manager complained that his knitted yarns were all fine, but he had high returns on the same ring yarns due to white specks when the fabrics were woven and dyed. The yarns were sourced from the same process but only half were waxed for knitting. In the waxing application, the yarns are backwound as the wax is applied. A considerable amount of fly, which must have been immature white speck fibres, was stripped off the yarns as they went past the tensioners. Having noted this effect twice (once in the Australian mill and in this study), I conclude that it is an area that warrants future research, but at the moment does not provide a consistent method of white speck removal.

6.3 Results U.S. 2001

6.3.1 Harvesting Method

The U.S. 2001 variety study focussed on two varieties that were grown at three different locations (Georgia, Mississippi and Texas) during the 2001 season. The Georgia cottons were grown in the same field, spindle-picked and ginned with one lint cleaner. The Texas cottons were grown in one field; stripper picked and ginned using two lint cleaners. The Mississippi cottons were grown in the same area and obtained commercially without ginning information. CQRS processed the cottons in the same manner as the other studies, except that they carded at 150 lbs/hour, typical of current mill processing.

The proportion of white area on the fabrics was significantly higher for the stripper-picked cottons in Texas. Drought and the stripper picking process contributed to this effect. . The stripper-picked seedcottons generally have so much more trash that they need extra precleaning and two lint cleaners in the gin to bring the cotton up to grade. The level of white specks in the Texas stripper-picked cottons in this study was almost double that from the other regions, due to the combination of higher levels of immature cotton and harsh processing. These results are illustrated in Figure 6.6 below.

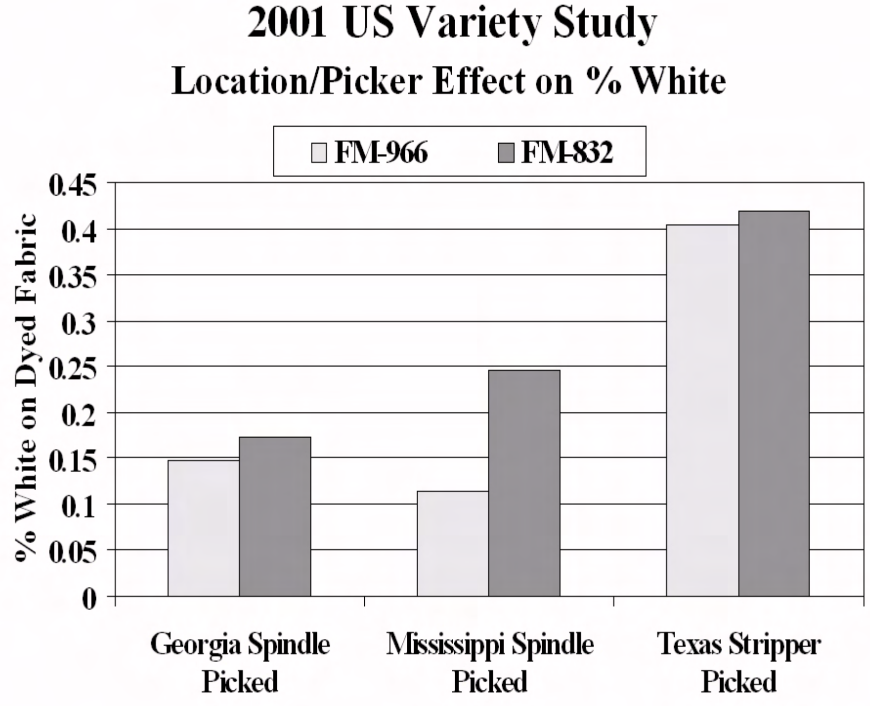


Figure 6.6: Stripper and spindle picking effects on white speck levels.

6.3.2 Spinning Systems

This study also compared three spinning systems. The Open End (OE) and vortex systems both have opening systems that comb the fibres before spinning, removing trash, short fibre, and clusters of immature fibres. This results in a significantly lower level of white specks than occurs with the ring spun yarns across all locations. The Texas cottons, which had extremely high levels of white specks, were dramatically affected (Figure 6.7).

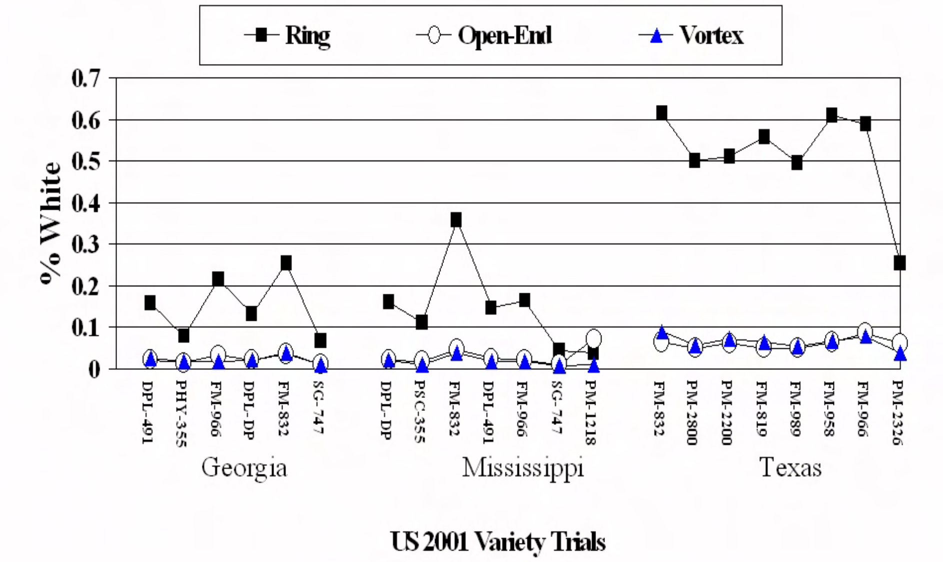


Figure 6.7: OE and Vortex spinning remove white specks. The resultant fabrics are significantly lower in white specks levels than fabrics made from ring spun yarns

6.4 Field Studies' Conclusions

To put all of the studies in perspective and so enable direct comparisons, the data were adjusted for each study to allow for fabric structure and yarn size as if all yarns were 30/1 and the fabrics were 100% experimental yarns. Visually the fabrics can be broken into several groups, based on my judgment from the hundreds of fabrics I analysed in this project.

Excellent fabrics < 0.03 %W
Acceptable fabrics < 0.07 %W
Poor fabrics > 0.09 %W

Figure 6.8 shows the results from the five different white speck studies described in this thesis.

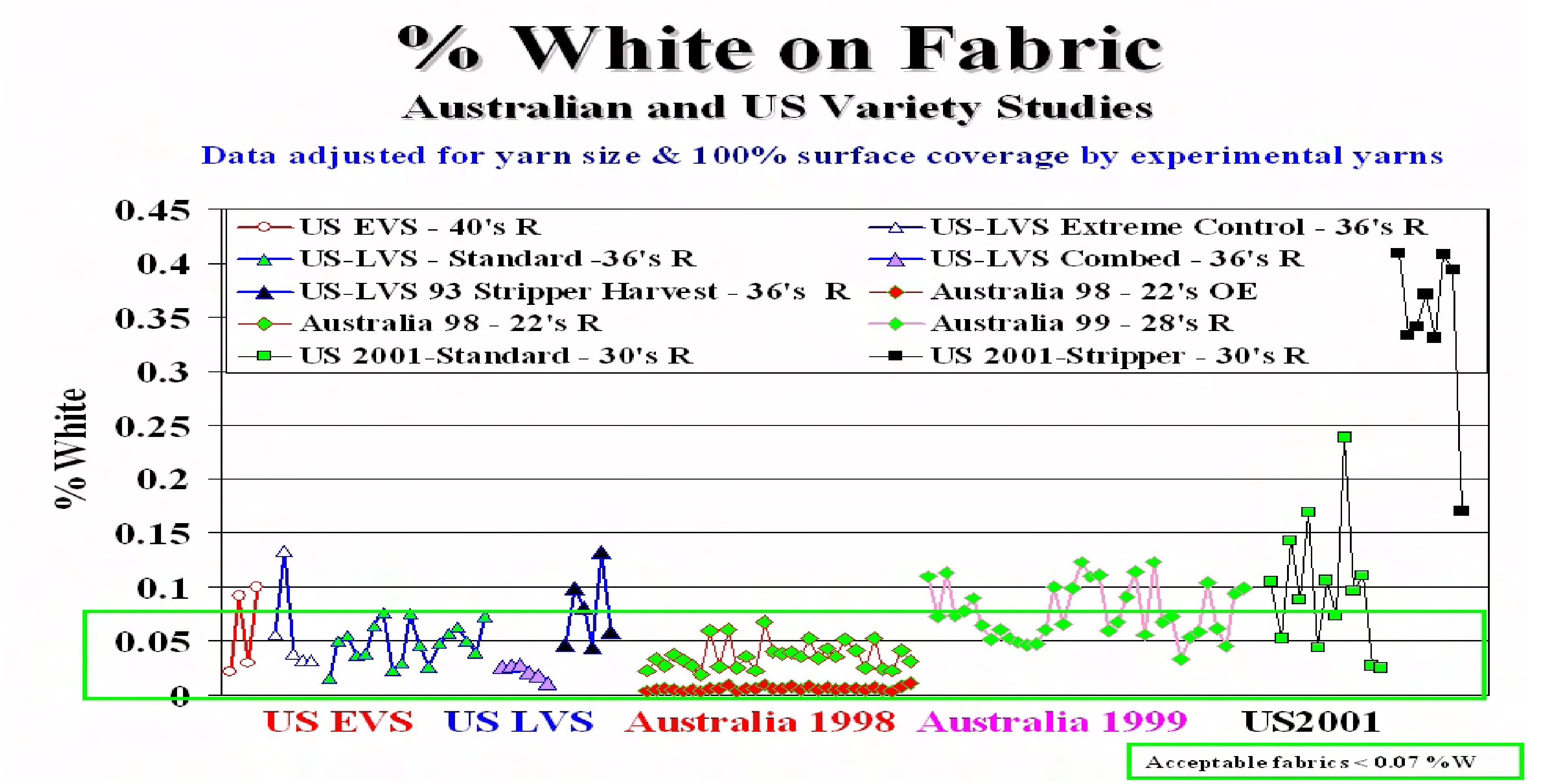


Figure 6.8: % White on fabrics for five studies. Data has been adjusted to account for yarn size, fabric construction and extrapolated to 100% Surface coverage by experimental yarns.

The initial study (U.S. EVS) is the only one that used a full warp and filling for each fabric from the experimental fibres. The remaining studies have a common combed warp (to remove the white specks) and the experimental filling yarns are used to weave a filling faced sateen fabric that has approximately 85% surface coverage from the experimental yarns. The white speck data have been adjusted for yarn size and fabric construction as if all fabrics were 100% surface coverage with 30’s filling yarns, so the results can be evaluated on the same basis. The coloured lines are to help identify the individual studies. The first study, U.S. EVS, is simply the first four data points indicated by the white circles (red lines). DP90 and EAC-30 both yielded excellent fabrics, while the STV825 and EAC-32 were visibly poor fabrics due to the high level of white specks. The results were as expected, with the level of white specks being extremely low and extremely high for the two Acala varieties (see Chapter 4).

The next study, U.S. LVS (triangles and blue lines), also included a control with varieties that were expected to range from extremely low to extremely high levels of white specks. All of the cottons were processed identically in the mill by CQRS. The five white triangles indicate the extreme control varieties in the study for that year. The extreme control group was also grown in the same field and processed identically to those in the previous extreme study. The green triangles indicate the varieties with one and two lint cleaners. The purple triangles indicate the varieties that were combed and have very low levels of white specks. Finally, the black triangles are for the varieties that were heavily cleaned (stripper harvested with 2 or 3 lint cleaners).

The LVS data show significant differences in levels of white specks due to processing. Most of the cottons in the LVS fall within a range that is visibly acceptable. The green box indicates the range (% White < 0.07%) representing acceptable levels of white speck. Any value greater than this is likely to be problematic. The combed cottons are nice and clean, below the 0.05 percent level.

In the third study, Australia 1998 (diamonds) cotton was considered one of the best crop years in Australian history. The cotton had excellent fibre properties and as shown in Fig 5.24, produced excellent fabrics, many of which were as good as combed cottons. The seedcottons were brought to the same gin and both 1 and 2 lint cleaners were used. This particular crop year produced very mature fibres and no significant difference was seen due to lint cleaning. This study showed there was a difference due to yarn sizes and type of spinning system. OE spinning combined with one of Australia's best crop years produced fabrics that had the lowest white speck levels of all the studies.

The fourth study, Australia's 1999 crop (green diamonds, pink lines), had maturity problems due to drought and the levels of white specks were significantly higher than for the 1998 crop. The Australian 1999 crop yield was less than anticipated due to late planting, high insect pressure and harvest rains, all of which contributed to a smaller, lower quality crop. There were unusually wet conditions before planting, and a summer that was not exceptionally hot; in addition, aphid numbers were much higher than usual. In addition to these problems, some areas of the Australian cotton crop suffered from an unidentified disease or virus, which seemed to be associated with the presence of aphids early in the season. The disease resulted in low numbers of bolls, and small bolls containing only 5-6 seeds (usually 9 or 10) [159](Southern Hemisphere Crop report 4/26/1999). The report states, “Fortunately, the quality of this cotton has not been affected, only yields. All parameters have been more than adequate, with all merchants extremely satisfied with the quality outruns[160](Southern Hemisphere Crop report 4/26/1999).” This illustrates that what appears to be a good crop by HVI standards may in fact be a poor quality crop when the final product (dyed fabric) is judged. The 1999 crop resulted in white speck problems in the mills in 2000.

The Australia 1999 crop’s higher white speck levels are more similar to the standard cottons in the final study, i.e., the U.S. 2001 study (shown as black lines, with green squares for the standard cottons and black squares for the stripper-harvested cottons), which also experienced weather problems that affected maturity. The higher white speck level is also due to higher carding rates (150 lbs per hour as compared to 70 lbs per hour). High cylinder speeds are known to increase nep levels. The stripper-harvested crops are black squares for the US 2001 crop and black triangles for the U.S. LVS crop; in both cases, the excess cleaning significantly increased the level of white specks compared to the varieties with standard cleaning for those years. The higher carding rates make the U.S.2001 stripper samples the most extreme (highest % White) in the study. When all of this information is analysed, the measurements of immaturity can be evaluated to predict levels of the white speck phenomenon. Many measurement systems are attempting to characterize maturity. Results obtained from several of these systems will be presented in the next chapter.

7. WHITE SPECK MODEL DEVELOPMENT

PREDICTING WHITE SPECKS FROM HIGH-SPEED FIBRE MEASUREMENT SYSTEMS

This chapter combines and analyses the results and knowledge presented in the previous chapters to develop prediction equations of white speck from fibre data measured by several high-speed fibre measurement systems.

7.1 Introduction

The studies undertaken in this project provide an enormous amount of insight into mechanical processing effects on white specks, but only the last study was processed at the higher speeds used by industry. The US 2001 cottons are therefore considered to provide the best set of data to develop prediction equations of white specks in fabrics from fibre properties. Not only did the US 2001 study have higher carding rates, it also had the widest range in white speck levels of all of the studies. Some white speck levels were as low as those found in some of the combed cottons in the LVS study. The stripper-harvested cottons from regions with drought problems had the highest white speck levels in all of the studies.

Ring, Open End and Vortex yarns were spun for this study, but the OE and Vortex spinning removed the bulk of the white specks, so the prediction equations are based on data from the fabrics made with ring spun filling. Cross-sections, FMT, HVI, AFIS, and Lintronics provided measured fibre properties from the bale.

The present cotton marketing system is based on average values of fibre length, strength, micronaire, colour and trash. The commercial price only reflects fibre value on a broad basis. With increased processing speeds, more cleaning of fibre, new varieties, field treatments and other improvements such as genetically engineered cotton, the bale fibre properties provided by the current system can not accurately predict yarn and fabric quality, nor the processability of cotton. In general, cottons with low micronaire, long fibres, low fibre weight per length, and a high percentage of large motes tend to develop more neps during processing [161](Hughs, 1988). The fundamental importance of fibre maturity is not adequately reflected in these values. Micronaire is the most valuable of the HVI parameters currently available for indicating the level of fibre maturity, because it correlates with average maturity and indicates thin walled fibres. Micronaire is correlated to a combination of maturity and fineness and is more useful if the variety is known. Given two varieties with the same micronaire, but different fully mature perimeters, the smaller perimeter fibre will be more mature than the larger perimeter fibre. Unless extreme, the fibre values currently provided to mills on a bale of cotton do not fully indicate a white speck problem.

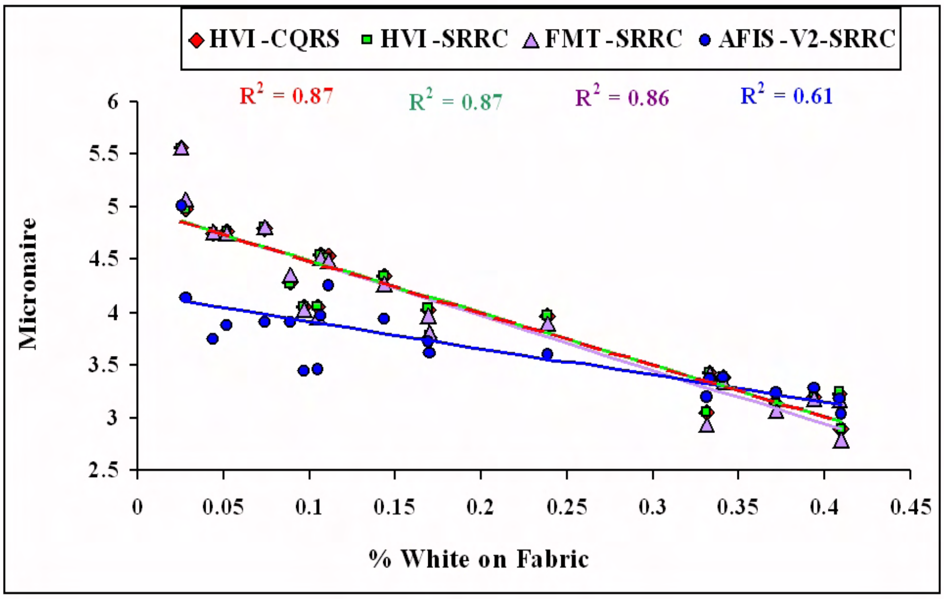


Figure 7.1: Micronaire predicts 87% of white specks for the US 2001 study. Micronafis by AFIS Version 2 only predicts 61% of the white specks.

Immature fibres are the ultimate cause of white specks and micronaire is the measurement that has been classically used to judge maturity. Graph 7.1 shows that micronaire as measured by HVI and FMT predicts approximately 87% of the white specks seen on the dyed fabric. Micronafis is the Micronaire measurement provided by AFIS Version 2 but it tends to be lower (only 61%) than the classical measurements.

7.2 Methodology

This study was designed from the standpoint that cotton is ultimately valued at the consumer product level, so the best way to gauge the effects of a particular factor in cotton processing is to analyse its effect on realised quality, that is, quality seen at the fabric stage. However, since quality of cotton is based on fibre quality, fibre measurements from different testing systems must be correlated with levels of white specks on the fabrics. Multiple regressions were used to investigate the relationship between several independent or predictor variables and the dependent or criterion variable, % white, by using the "least squares" method to fit a line through a set of observations. Multiple linear regressions are used to analyse how a single dependent variable is affected by the values of one or more independent variables.

Multiple regression designs contain the separate simple regression designs for two or more continuous predictor variables. The regression equation for a multiple regression design for the first-order effects of three continuous predictor variables P, Q, and R would be

$$\mathbf{Y = b_0 + b_1P + b_2Q + b_3R.}$$

The regression line expresses the best prediction of the dependent variable (Y) in this case % White, given the independent variables (*X*), fibre properties. However, nature is rarely (if ever) perfectly predictable, and usually there is substantial variation of the observed points around the fitted regression line. The deviation of a particular point from the regression line (its predicted value) is called the *residual* value. The difference between unity (1.0) and the ratio of the residual variability of the *Y* variable to the original variance is referred to as *R-square* (R^2) or the *coefficient of determination*. If we have an R^2 of 0.4 then we know that the variability of the *Y* values around the regression line is 1-0.4 times the original variance; in other words, we have explained 40% of the original variability, and are left with 60% residual variability. Ideally, we would like to explain most if not all of the original variability. The R^2 value is an indicator of how well the model fits the data (e.g., an R^2 close to 1.0 indicates that we have accounted for almost all of the variability with the variables specified in the model) [162](StatSoft, 2004).

Choice of the Number of Variables. Multiple regression is a seductive technique: "plug in" as many predictor variables as you can think of and usually at least a few of them will come out as being significant. This is because one is capitalizing on chance when simply including as many variables as one can think of as predictors of some other variable of interest. This problem is compounded when the number of observations is relatively low. Intuitively, it is clear that one can hardly draw conclusions from an analysis of 100 questionnaire items based on 10 respondents. Most authors recommend that one should have at least 10 to 20 times as many observations (cases, respondents) as one has variables, otherwise the estimates of the regression line are probably very unstable and unlikely to replicate if one were to do the study over.

For these regressions, all of the fabric data was adjusted to compensate for yarn size, and fabric structure. All % white data was based on 30's ring spun yarns with 100% surface coverage of experimental yarns. Because the sample set (US2001 study) is only 21 fabrics, it was extremely important to minimise the number of variables in the predictions. % White for each of the 21 fabrics were analysed in linear regressions with each variable for each system. The variable with the highest R-square was considered the starting point for the multiple regressions developed for each system. The other variables were systematically added in and regressed against % white. The variable that showed the largest improvement in the adjusted R^2 was then entered as the second variable and this process continued until reductions were seen in the adjusted R^2. If the adjusted R^2 drops from .89 to .85 even though the R^2 may have improved from .90 to .95, it indicates that the improvement in R^2 isn't valid and the variable should be dropped as part of the final regression. Knowledge of the subject is also important in ensuring that the result is meaningful. In AFIS, perhaps both average length by number and average length by weight may improve the R^2, but only one would be needed and the one which raises the adjusted R^2 the most would be the preferred choice. Between statistical and logical evaluation, the final fibre properties that had the best regressions for each test were used to make the final predictions. SAS/STAT® Analysis software, (Version 8.02 of the SAS System for Windows TS Level 02M0 Copyright, SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.) was also used to evaluate stepwise regressions and forward regression selections. Once the final predictions were developed, they were compared to regressions of the same fibre properties across all studies to validate their legitimacy.

7.3 Model Results

The fibre and white speck data for the following relationships can be found in Appendix B. Forward selection model and stepwise regressions were run on fibre and white speck data for all studies in SAS to verify the adjusted R-square method.

7.3.1 FMT

Maturity ratio and fineness were the best predictors of white speck for FMT. Maturity ratio alone had an R-square of 0.58 and fineness increased the R-square to 0.62 and an adjusted R-square of 0.61. The FMT (maturity ratio and fineness) data in Figure 7.2 show a strong relation to white specks for the 2001 study, but when evaluating all of the studies together, the R-square drops down from 0.86 (adjusted R^2 = 0.85) to 0.62, which may be explained by the variations between studies such as card condition and speeds. The % white prediction for the 2001 fabrics is slightly higher than the predicted % white based on all studies. This is due to the increase in carding rates for the 2001 study. As cylinder speeds increase, nep levels increase making this 2001 study more accurate for current mill processing rates. It also has a much higher R-square explaining approximately 86 % of the variability of white specks. FMT only measures maturity. Although maturity is the predominant factor for white specks, it doesn’t tell the whole story as can be seen in analysis of some of the other fibre measurement systems, which indicates that the FMT is not sufficient as a basis for predicting white specks.

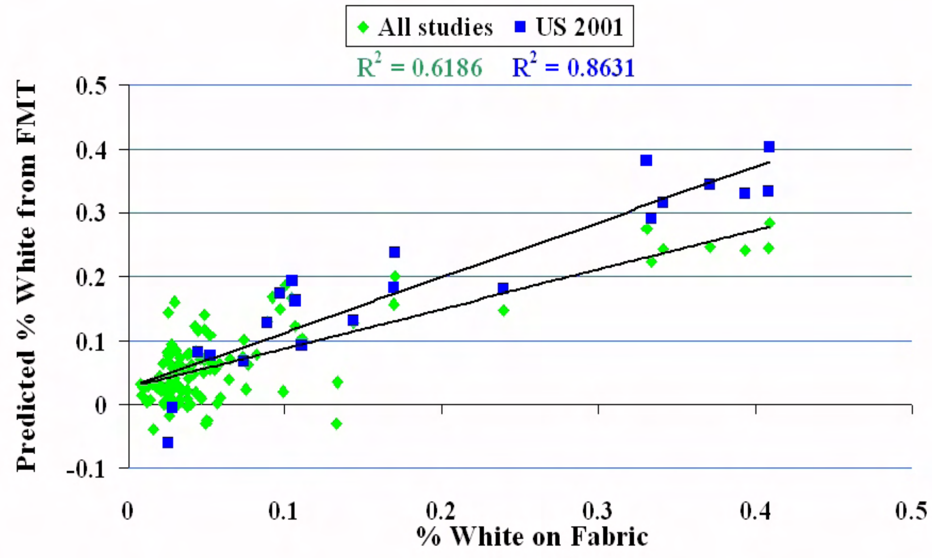


Figure 7.2: % White predicted from FMT (maturity ratio and fineness) data.

7.3.2 HVI

A forward selection model was used across the data for all studies to verify that the buckling coefficient, uniformity index and reflectance (Rd) are the best predictors of white speck. Buckling coefficient alone had an R-square of 0.41 and uniformity index increased the R-square to 0.44, Rd increased the R-square to 0.46 and an adjusted R-square of 0.45. Buckling coefficient and its components, UQL (Upper Quartile length) and micronaire, were considered separately to eliminate false results due to colinearity.

Mechanical entanglements develop when cotton is exposed to processing (harvesting, ginning and mill). As Alon and Alexander [163](1978) pointed out, the fibre tangles on itself during processing and the longer and more immature the fibre is, the more it is prone to nepping. The fibre is stretched and whips back on itself, entangling other fibres in the process. In Figure 7.3, the buckling coefficient (from HVI data as defined below) is graphed against white speck. In this case, we see little change as compared to the regressions in Figure 7.1.

Buckling Coefficient [164](Alon, 1978) **= L^2/μ^2**

μ = Micronaire Value

L = 2.5% Span Length

The HVI micronaire predicts about 87% (Figure 7.1) of the white specks for the 2001 study, but for all the studies together the prediction drops down to only 52%; similarly, buckling coefficient drops from 89% to 67%. This shows how difficult it is for the mills to use micronaire or even the buckling coefficient, which is slightly better than micronaire alone, as a way to predict white specks. The information is getting lost because of near multi-colinearity when there is a large mixture of different cottons with different conditions. When examining the US 2001 study, an initial R-square of 0.87 (Figure 7.1), was only slightly improved to 0.89 by using the buckling coefficient. With lower carding rates the buckling coefficient was too clustered to adequately predict white specks, but with higher carding speeds, and extreme differences in maturity for the 2001 study, the buckling coefficient does have a strong relationship accounting for 89% of the variability in white specks.

Uniformity ratio is an indicator of processing severity in the gin (the more processing the higher the level of short fibres, which results in lower uniformity). Colour, Rd - degree of reflectance, is often an indicator of immaturity due to the reflective quality of the flat immature fibres Buckling coefficient, an indicator of neps, with the addition of the uniformity ratio, and colour, Rd increased the R-square to 0.93 for the 2001 study and to 0.88 for the combined US studies.

The HVI data in Figure 7.3 show a strong relation to white specks for the 2001 study when using buckling coefficient, uniformity ratio and Rd, from the adjusted R-square studies. When evaluating all of the studies together, the R-square drops down from 0.93 (adjusted R-square = 0.91) to 0.46 (adjusted R-square = 0.45), which may be explained by the variations between studies such as mill processing differences.

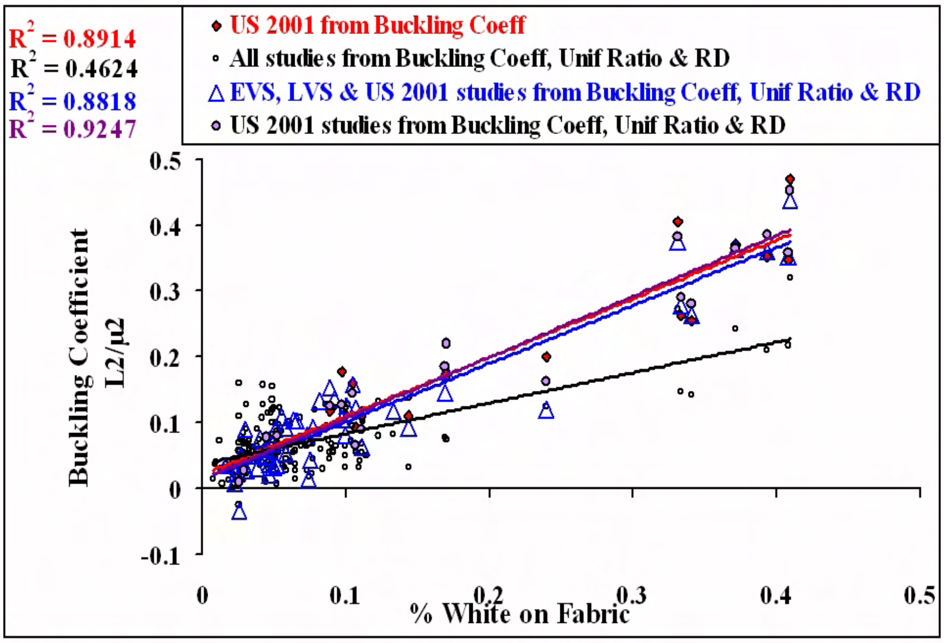


Figure 7.3: % White predicted from HVI Buckling Coefficient, Uniformity Ratio and RD.

The Au98 crop, was one of the best cotton crops in Australia's history and the resulting fabrics were uniformly low in white specks, many as low as combed cottons, which adds a cluster effect to the left bottom corner of Figure 7.3. By leaving the Au 98 data out, the R-square went up from 0.46 to 0.64. By removing the Au99 data (because those fibres were processed on different mill equipment than the other studies), leaves only the US studies for the third regression in Figure 7.3: the R-square improved to 0.88. This emphasizes the importance for large-scale studies with identical mill processing from year to year to obtain a solid database.

7.3.3 AFIS

Three different versions of AFIS (Advanced Fiber Information System by Zellweger Uster) were used during this study and they provided a variety of fibre maturity measurements that related to white specks (Appendix B). The AFIS rapidly measures fibre properties such as length, diameter, maturity, fineness, and neps. Figures 7.4, 7.5 and 7.6 show the best predictions of white specks from the fibre properties for each version.

7.3.3.1 Version 2

The most significant AFIS fibre properties relating to white speck are Neps per gram, Theta CV and SFC(n) (Short Fibre Content (by number)). Theta CV is an indicator of maturity. Theta, the circularity of a fibre is a good indicator of maturity in general for each variety, although some varieties can be mature and not as circular as other mature varieties, but the variability of maturity is an indication of the level of mature fibres for that particular sample. Neps/gram obviously provides a good indicator of neps, and when Theta CV (an indicator of maturity) and SCF(n) (an indicator of harshness of processing) are added the predictions are improved from an R-square of 0.73 to 0.82 for the combined AFIS factors for the US Studies (Figure 7.4). The R-square for the US 2001 study is 0.864. An obvious theme has started to emerge, as the regressions improve in this analysis. Neps, maturity and processing levels are all very influential factors in the level of white specks in a bale of cotton.

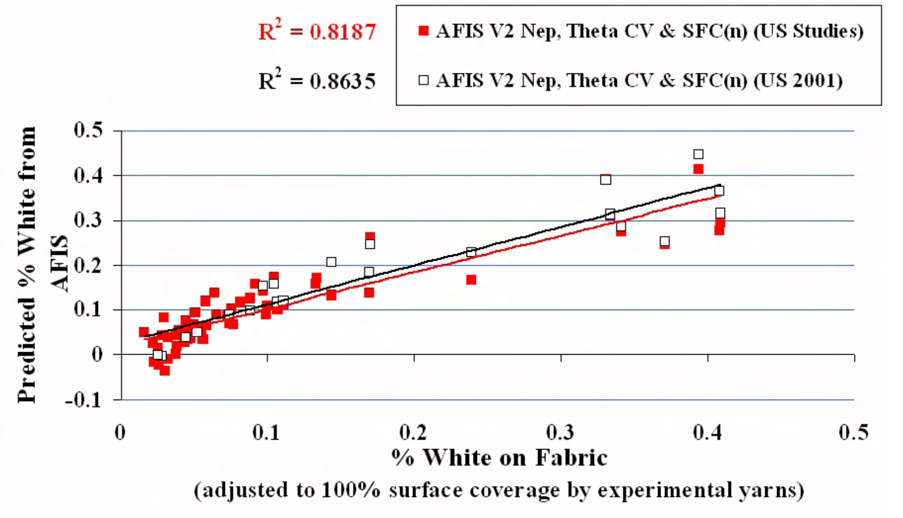


Figure 7.4: White speck predicted from AFIS version 2 using Neps/gram, SFC(n) and Theta CV.

The regression with buckling coefficient instead of Neps/gram was practically identical to the former parameter's results, further indicating the importance of neps or some predictor of neps. IFF (Immature Fibre Fraction- the percentage of fibre with values of theta less than 0.25) slightly, but not significantly increases the R-square (Figure 7.5). For a small sample set three variables are enough for the prediction equation, although it will be interesting to keep an eye on the combination of the four factors in future research, especially since IFC (Version 4's version of IFF) is a major factor in Version 4's predictions.

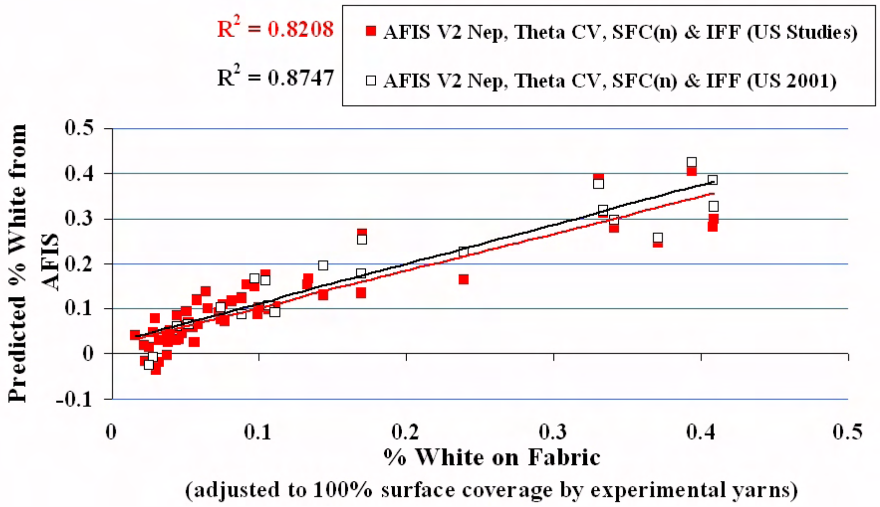


Figure 7.5: White speck predicted from AFIS version 2 using IFF, Neps/gram, SFC(n) and Theta CV.

7.3.3.2 Version 4

The most significant AFIS Version 4 fibre properties relating to white speck are Neps per gram, SFC(n) and IFC (Figure 7.6). IFC (Immature Fibre Content %) measures the percentage of fibre with values of theta less than 0.25. If there was a larger data set, fineness and maturity might be added as indicated by the SAS Forward Selection procedure, but with a small sample set of 21 this could not be done. Knowing that nep, maturity and processing factors are all represented, and given the high R^2 value of 0.95 for the US2001 studies, I concluded that it was best to stay with only three variables.

Figure 7.6 also shows the regression results for “All Studies” (The US and Australian studies combined) as the first regression line. The US Studies results are presented as the second regression and the US 2001 study as the final regression. The same pattern occurs as was found in the analysis of the HVI data. Again this emphasizes the importance for large-scale studies with identical mill processing from year to year to obtain a large, solid database with minium mill interactions and enough variation in bale fibre properties to provide accurate predictions for % White on fabrics.

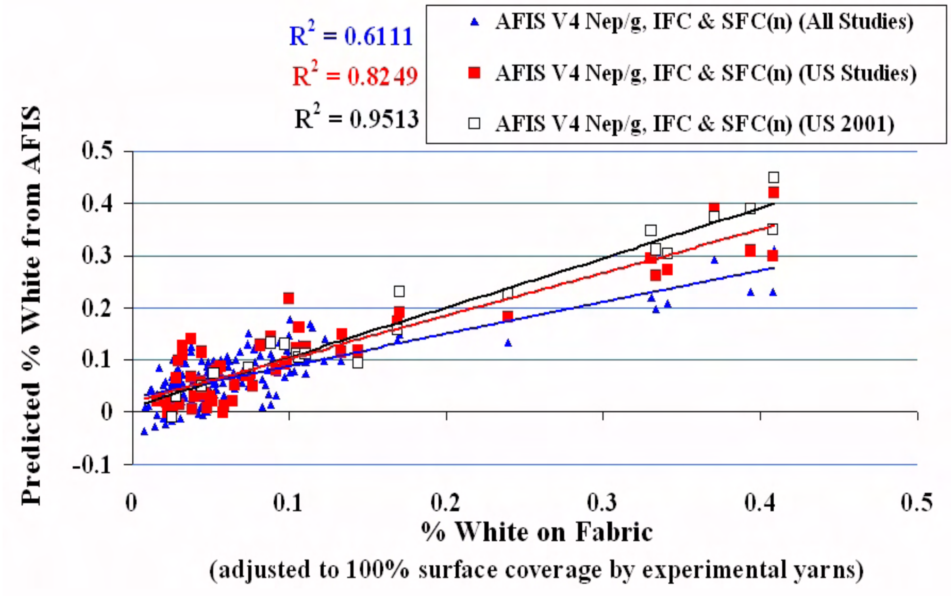


Figure 7.6: White speck predicted from AFIS version 4 using IFC, Neps/gram, and SFC(n).

7.3.3.3 Version 5

The SAS Forward selection model indicated that Neps/gram, Nep Size, Seed coat Fragment size (SC Size) and SCF(w) (by weight) were the best predictors of % White for AFIS Version 5 data as shown in Figure 7.7. Using the adjusted R-square procedures and the knowledge that was gained from the other studies (Neps, maturity and processing levels are import factors in predicting % white), another set of variables fitting these criteria was chosen and presented in figure 7.8. Neps/gram, Fineness, Neps/gram, Seed coats/gram and SFC(n) also provided an excellent basis for predicting white specks using Version 5 data. Fibres for the LVS samples were not tested on Version 5, but the regressions for all studies except LVS, have much higher regressions for % White when the Australian studies were included than any of the other measurements studied at this point.

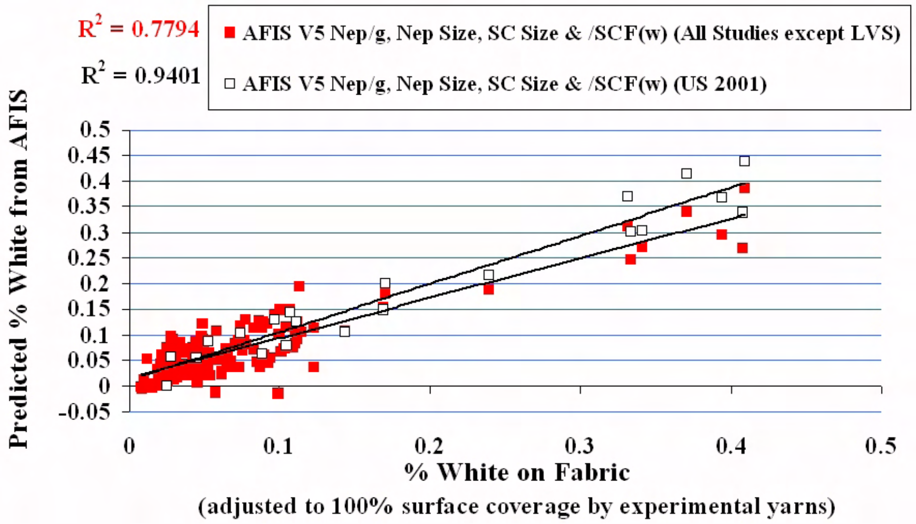


Figure 7.7: White speck predicted from AFIS version 5 using Neps/gram, Nep Size, Seed coats Size and SFC(w).

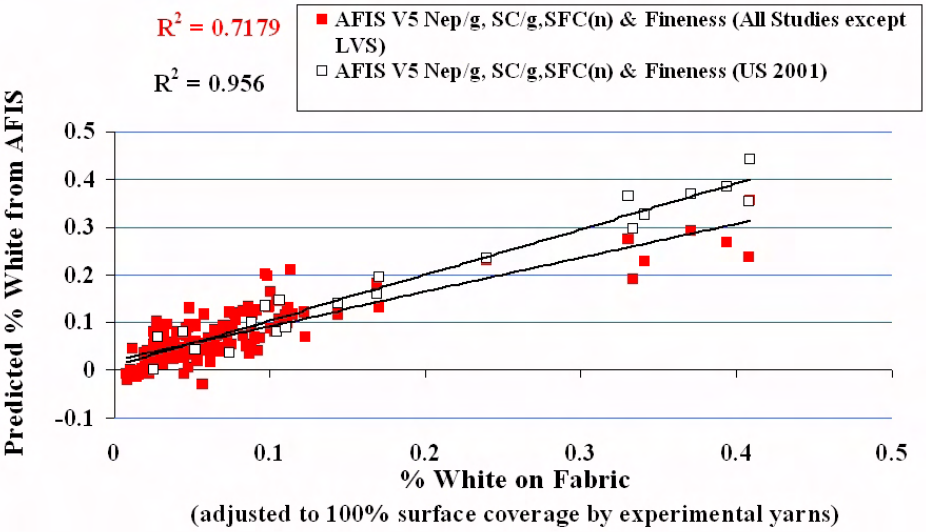


Figure 7.8: White speck predicted from AFIS version 5 using Fineness, Neps/gram, Seed Coats/gram and SFC(n).

7.3.4 Lintronics

The SAS Forward selection model indicated that Neps/gram, Nep Area per gram, Seed Coat Fragment size (SC Size) and Maturity were the best predictors of % White for Lintronic’s FiberLab system as shown in Figure 7.9. Excessive lint cleaning at the gin tends to increase the number and reduce the size of seed coats fragments in processing, so SC Size may be an indicator of processing severity. The analysis also includes maturity and neps, so it seems to follow the logical trends seen in the other systems’ results.

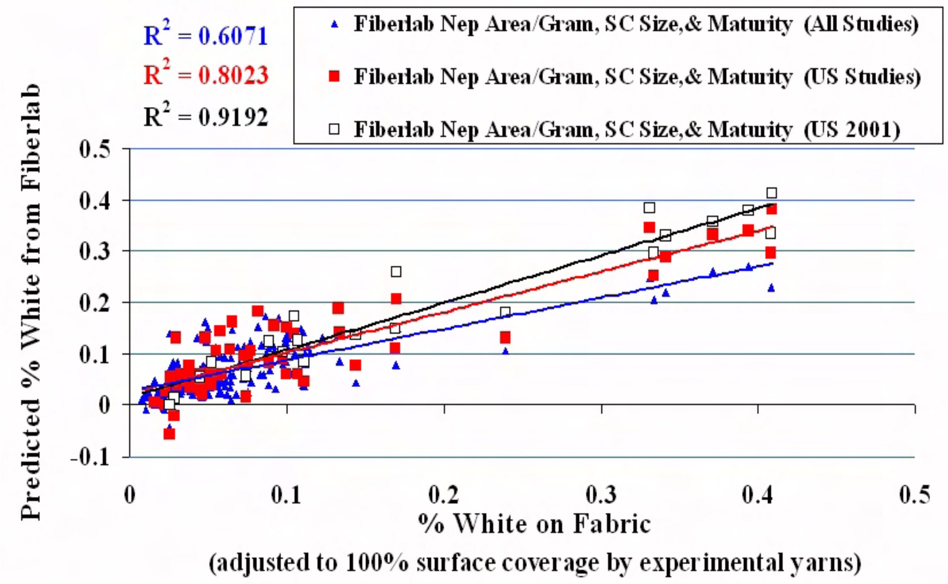


Figure 7.9: White speck predicted from Lintronic’s FiberLab using Neps (area/gram), Seed Coats Neps Size, and Maturity

8. CONCLUSIONS

A bale of cotton's white speck potential (WSP) can be determined by using the prediction equations presented in this thesis. White specks can be predicted from bale fibre properties as measured by the range of high-speed instruments studied herein. The US 2001 study has a much broader range of fibre and fabric (% White) data and since this study was run at speeds similar to industry, the White Speck Potential (WSP) prediction equations were based on this study. The common theme that runs true for all of these measurement systems is that the number of neps, fibre maturity and severity of processing influence white speck levels. The HVI WSP prediction equations below are both based on the Buckling Coefficient (UQL^2/mic^2). The equation with the highest R-Square (0.9247) includes Uniformity Index (an indication of the level of processing), but the equation indicates that as the Uniformity index increases, white specks increase. This is contrary to my experience (as processing increases, white specks increase and as processing increases the Uniformity Index decreases), which indicates that the second HVI prediction equation (R-Square = 0.8914) without the Uniformity Index would be the more reliable prediction equation until a larger database is available. The remaining equations for AFIS and Lintronics all have fiber to fabric relationships that I have found typical in other studies.

HVI R-Square = 0.9247

%W = 3.3682 *(UQL^2/mic^2) + 0.02169 * Uniformity Index + 0.00848 * Rd- 2.51531

HVI R-Square = 0.8914

%W = 3.516205 *(UQL2/mic2) - 0.11382

AFIS-V2 R-Square = 0.8635

%W = 0.0000936 * Nep/g - 0.02054 * SCF(n) + 0.04053 * Theta CV – 1.27841

AFIS-V4 R-Square = 0.9514

$$\%W = 0.000484 * \text{Neps/g} + 0.07983 * \text{IFC} - 0.01006 * \text{SFC(n)} - 0.13291$$

AFIS-V5 R-Square = 0.9401

$$\%W = 0.000904 * \text{Nep Size} + 0.00047 * \text{Nep/g} + 0.00059 * \text{SC Size} + 0.2283 * \text{SFC(w)} - 1.0662$$

Lintronic's FiberLab R-Square = 0.9192

$$\%W = - 0.97314 * \text{Maturity} + 0.000353 * \text{Nep Area/g} - 0.51652 * \text{SC Size} + 1.367854$$

These equations should be seen as providing preliminary predictions of white specks from fibre measurements. They are based on mechanically harvested cottons and are only the beginning of a larger scale research project. It's clear that more studies are required to provide a large enough database of collected fibre and fabric measurements to improve the prediction equations. The database should have an international fibre set including hand picked cottons, considering the world market today, and the confusion as to the meaningfulness of high-speed fibre measurements. The most important factor for the success of these future studies is that testing and mill processing must be standardised from year to year. The mill equipment must have proper settings, and consistent card wires.

This thesis has successfully provided an initial basis for the cotton industry to quantify white speck potential from high-speed fibre data. It has also successfully provided a foundation for continuing long-term studies to refine this basis. The US 2001 fibres and fabric have already been adopted as the first year of a continuing follow-on study to this project. When the long-term study that is being undertaken by SRRC and CQRS is completed, the White Speck Potential (WSP) can be confidently expected to provide the required nep management tool for mills and breeders. The breeders will be able to eliminate varieties that have a propensity to white speck early on. In addition, when there is a drought situation that will result in white specks, the affected bales can be identified. If these high WSP cottons are used in the right product line, where dyeability is not a problem (such as whites), both the producers and the mills will have solved a major economic problem. Shirting, undergarments, and sheets and towelling are big markets that consume large quantities of cotton, which could handle white speck cottons, without any losses due to defects. There is a place for these cottons, where they will not cause a problem; it just needs to be identified. Alternatively, if a mill does find it has a white speck problem they can minimize it. First, the mill may want to check their card settings and wire condition, if the cards are in good running order, the mills may comb it or using open-end or vortex spinning to minimize the problem.

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APPENDIX A

Processing Flow Charts

EVS Flow Chart

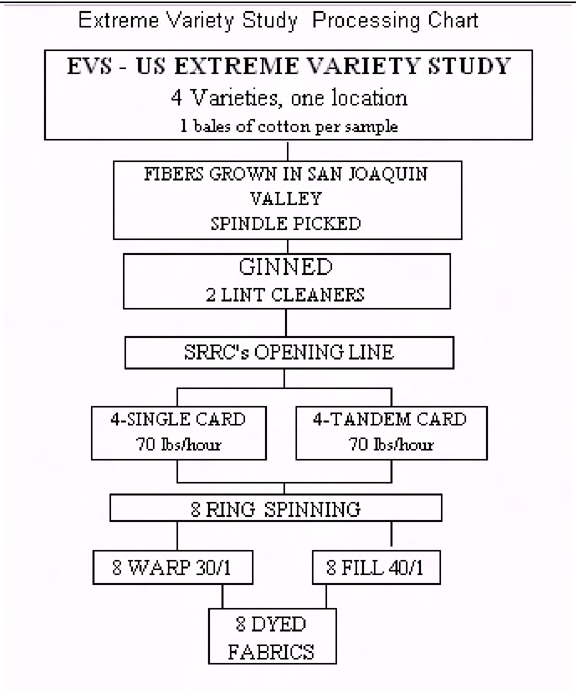


Figure A-1: Extreme Variety Study Processing Chart

LVS Flow Chart

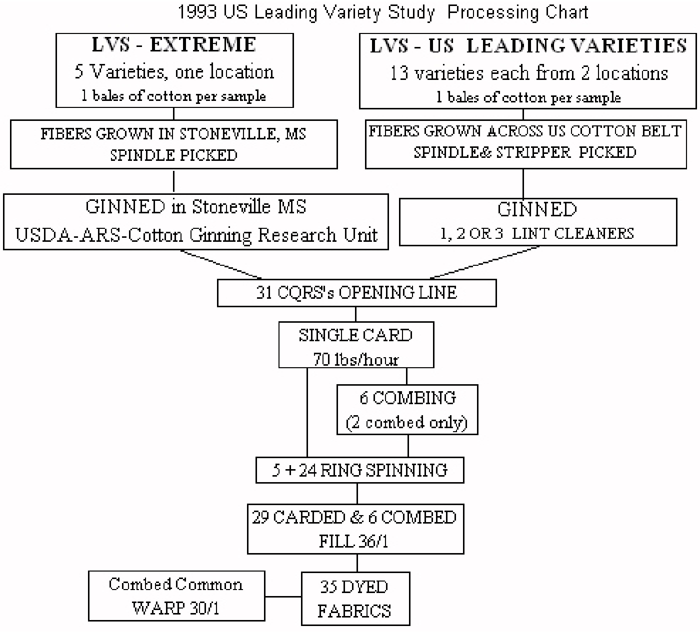


Figure A-2: US 1987 Leading Variety Study Processing Chart

Au98 Flow Chart

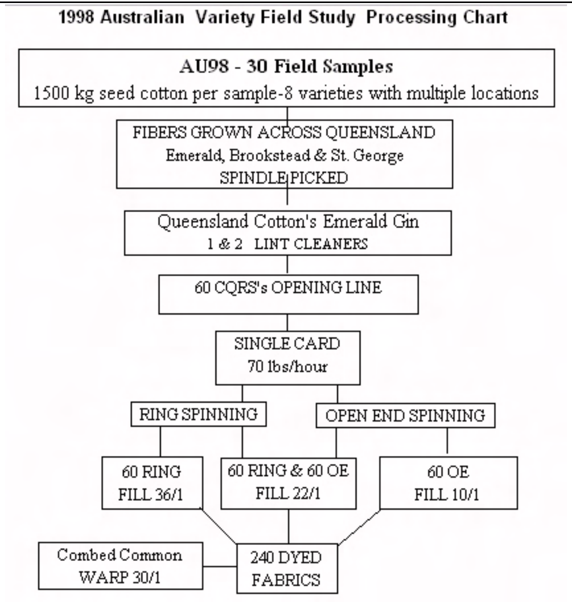


Figure A-3: Australia’s 1998 Field Study Processing Chart

Au99 Flow Chart

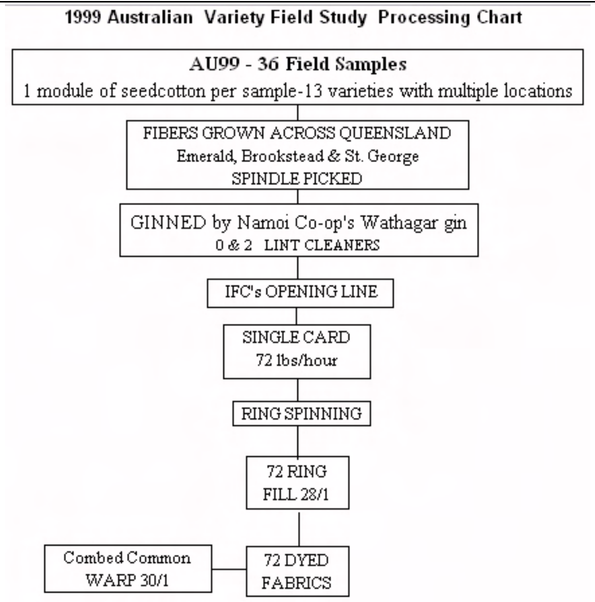


Figure A-4: Australia's 1999 Field Study Processing Chart

US 2001 Flow Chart

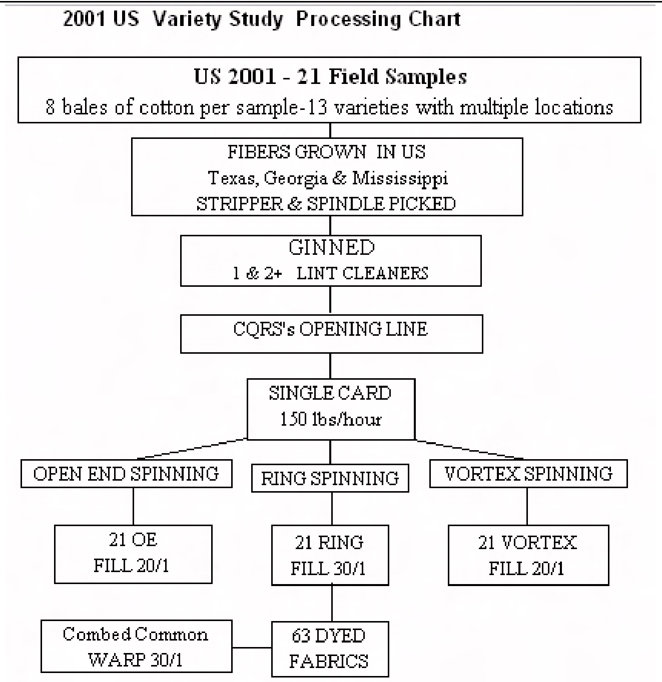


Figure A-5: US 2001 Variety Study Processing Chart

Opening & Carding: 2 **-** 300 pound blended bales were carded at 150 pounds per hour similar to industry speeds.

Drawing 1st: The card sliver was split into 4 equal groups for further processing:

1. **For Open End Spinning -** Used RSB 51 **-** Made 55 gr. sliver for spinning.
2. **For Ring Spinning -** Used RSB 951 **-** Made 60 gr. sliver for 2nd drawing.
3. **For Vortex Spinning -** Used RSB 951 **-** Made 55 gr. sliver for 2nd drawing.

Drawing 2nd:

1. **For Ring Spinning -** Used RSB51 -Made 61 gr. sliver for roving.
2. **For Vortex Spinning -** Used RSB 951 -Made 45 gr. sliver for 3rd drawing.

Drawing 3rd:

1. **For Vortex Spinning** - Used RSB 51 -Made 24 cans for spinning 40 gr. sliver.

Roving For Ring Spinning: Made 0.75 HR (Hank Roving) with a 1.30 TM (Twist Multiplier) for spinning.

Spinning:

1. **OES:** Spin 20/1's with a 4.6 TM.
2. **Ring:** Spin 20/1's with a 4.3 TM.
3. **Vortex:** Spin 20/1's.

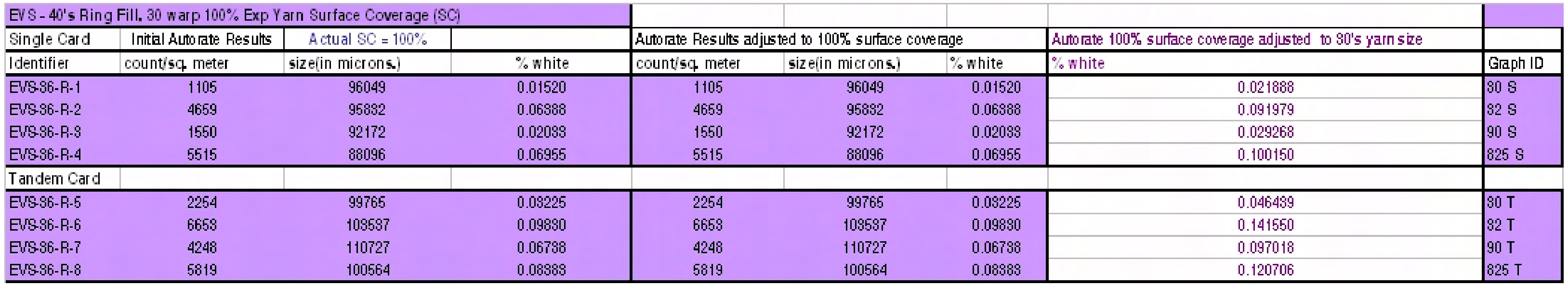
Weaving: The yarns were woven at 90 picks per inch as a 4/1 filling faced sateen (a 5 harness sateen with a 2 move sateen pattern) in a combed common warp (30/1 ring yarns, 72 ends/inch).

APPENDIX B

Fabric White Speck Data & Fibre Data

Fabric White Speck AutoRate (AR-02-03) Data

EVS 40’s Ring

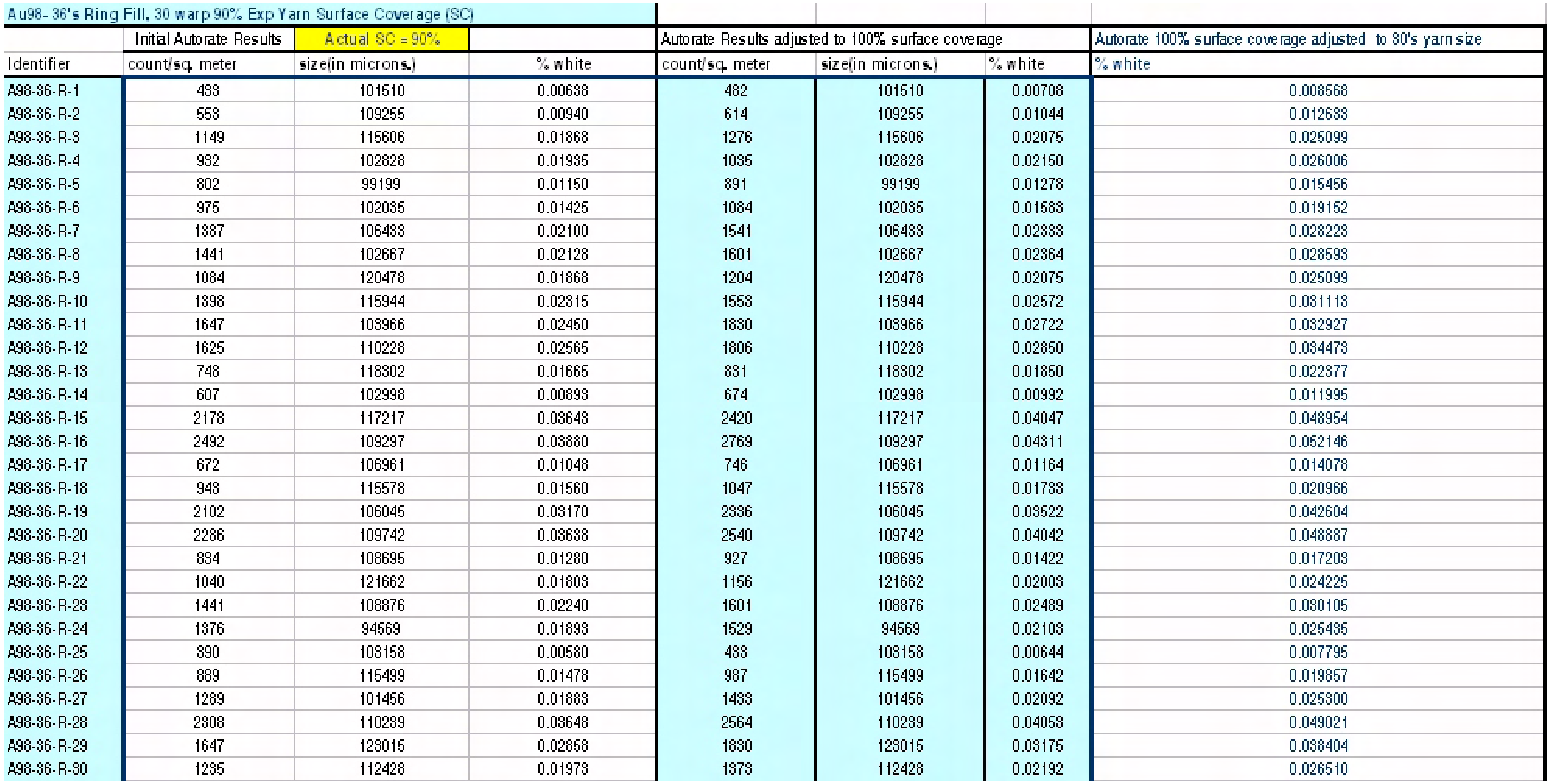


EVS - 40's Ring Fill, 30 warp 100% Exp Yarn Surface Coverage (SC)								
Single Card	Initial Autorate Results	Actual SC = 100%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size	
Identifier	count/sq. meter	size(in microns.)	% white	count/sq. meter	size(in microns.)	% white	% white	Graph ID
EVS-36-R-1	1105	96049	0.01520	1105	96049	0.01520	0.021888	30 S
EVS-36-R-2	4659	95832	0.06388	4659	95832	0.06388	0.091979	32 S
EVS-36-R-3	1550	92172	0.02033	1550	92172	0.02033	0.029268	90 S
EVS-36-R-4	5515	88096	0.06955	5515	88096	0.06955	0.100150	825 S
Tandem Card								
EVS-36-R-5	2254	99765	0.03225	2254	99765	0.03225	0.046439	30 T
EVS-36-R-6	6653	103537	0.09830	6653	103537	0.09830	0.141550	32 T
EVS-36-R-7	4248	110727	0.06738	4248	110727	0.06738	0.097018	90 T
EVS-36-R-8	5819	100564	0.08383	5819	100564	0.08383	0.120706	825 T

LVS 36's Ring

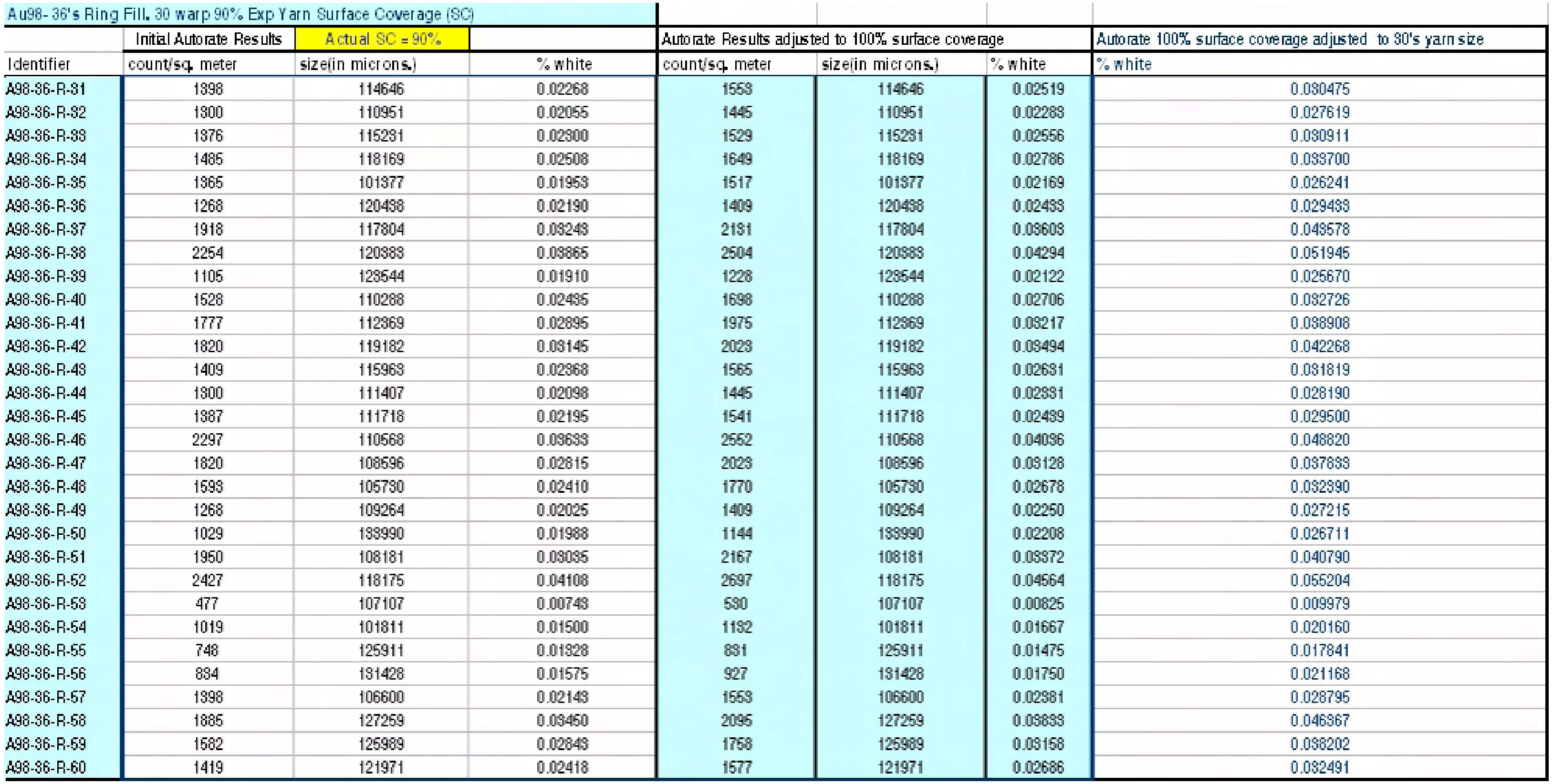
LVS - 36's Ring Fill, 30 warp 89% Exp Yarn Surface Coverage (SC)							
	Initial Autorate Results	Actual SC = 89%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size
Identifier	count/sq. meter	size(in microns)	% white	count/sq. meter	size(in microns)	% white	% white
LVS-36-R-1	769	104250	0.01183	835	104250	0.01284	0.015849
LVS-36-R-2	2601	100267	0.03718	2824	100267	0.04037	0.049824
LVS-36-R-3	2774	102884	0.04068	3012	102884	0.04417	0.054515
LVS-36-R-4	2308	103611	0.03433	2506	103611	0.03727	0.046004
LVS-36-R-5	1745	113307	0.02803	1894	113307	0.03043	0.037561
LVS-36-R-6	1712	117116	0.02848	1859	117116	0.03092	0.038164
LVS-36-R-7	2698	126112	0.04843	2930	126112	0.05258	0.064902
LVS-36-R-8	3197	125357	0.05715	3471	125357	0.06206	0.076596
LVS-36-R-9	1138	104893	0.01703	1235	104893	0.01849	0.022818
LVS-36-R-10	1203	132010	0.02250	1306	132010	0.02443	0.030156
LVS-36-R-11	2882	136300	0.05610	3130	136300	0.06092	0.075189
LVS-36-R-12	2243	109796	0.03495	2436	109796	0.03795	0.046842
LVS-36-R-13	3749	113590	0.06085	4071	113590	0.06608	0.081555
LVS-36-R-14	1896	119753	0.03258	2059	119753	0.03537	0.043659
LVS-36-R-15	5678	121948	0.09903	6166	121948	0.10753	0.132719
LVS-36-R-16	2308	131715	0.04365	2506	131715	0.04740	0.058502
LVS-36-R-17	1257	111716	0.01943	1365	111716	0.02109	0.026035
LVS-36-R-18	2211	113348	0.03588	2400	113348	0.03896	0.048082
LVS-36-R-19	2666	113754	0.04310	2895	113754	0.04680	0.057765
LVS-36-R-20	2514	131545	0.04753	2730	131545	0.05161	0.063696
LVS-36-R-21	1885	140385	0.03763	2047	140385	0.04086	0.050427
LVS-36-R-22	1669	123955	0.02970	1812	123955	0.03225	0.039806
LVS-36-R-23	4443	116774	0.07390	4824	116774	0.08025	0.099045
LVS-36-R-24	2752	137615	0.05443	2989	137615	0.05910	0.072944
LVS-36-R-25	1214	114738	0.01960	1318	114738	0.02128	0.026269
LVS-36-R-26	1203	119721	0.02048	1306	119721	0.02223	0.027442
LVS-36-R-27	1203	124216	0.02130	1306	124216	0.02313	0.028548
LVS-36-R-28	997	114484	0.01623	1083	114484	0.01762	0.021746
LVS-36-R-29	726	122698	0.01315	788	122698	0.01428	0.017624
LVS-36-R-30	553	99272	0.00793	600	99272	0.00861	0.010622
LVS-36-R-31	2265	129783	0.04183	2459	129783	0.04542	0.056056
LVS-36-R-32	5310	131052	0.09970	5766	131052	0.10826	0.133624
LVS-36-R-33	1571	123318	0.02808	1706	123318	0.03049	0.037628
LVS-36-R-34	1398	116817	0.02388	1518	116817	0.02593	0.031999
LVS-36-R-35	1604	105673	0.02398	1741	105673	0.02603	0.032133

Au98 36’s Ring



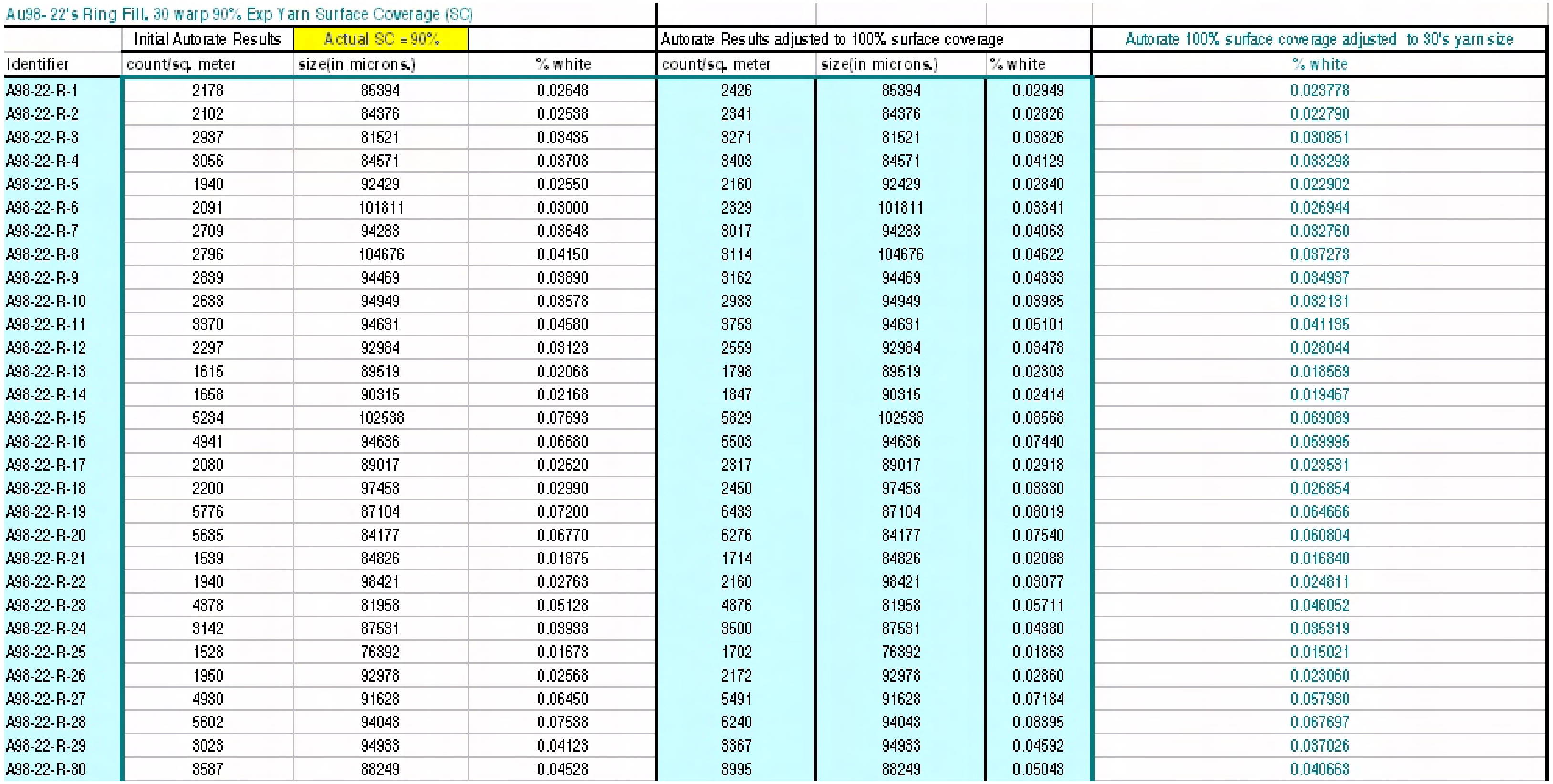
Au98- 36's Ring Fill, 30 warp 90% Exp Yarn Surface Coverage (SC)							
	Initial Autorate Results	Actual SC = 90%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size
Identifier	count/sq. meter	size(in microns.)	% white	count/sq. meter	size(in microns.)	% white	% white
A98-36-R-1	433	101510	0.00638	482	101510	0.00708	0.008568
A98-36-R-2	553	109255	0.00940	614	109255	0.01044	0.012633
A98-36-R-3	1149	115606	0.01868	1276	115606	0.02075	0.025099
A98-36-R-4	932	102828	0.01935	1035	102828	0.02150	0.026006
A98-36-R-5	802	99199	0.01150	891	99199	0.01278	0.015456
A98-36-R-6	975	102035	0.01425	1084	102035	0.01583	0.019152
A98-36-R-7	1387	106433	0.02100	1541	106433	0.02333	0.028223
A98-36-R-8	1441	102667	0.02128	1601	102667	0.02364	0.028593
A98-36-R-9	1084	120478	0.01868	1204	120478	0.02075	0.025099
A98-36-R-10	1398	115944	0.02315	1553	115944	0.02572	0.031113
A98-36-R-11	1647	103966	0.02450	1830	103966	0.02722	0.032927
A98-36-R-12	1625	110228	0.02565	1806	110228	0.02850	0.034473
A98-36-R-13	748	118302	0.01665	831	118302	0.01850	0.022377
A98-36-R-14	607	102998	0.00893	674	102998	0.00992	0.011995
A98-36-R-15	2178	117217	0.03643	2420	117217	0.04047	0.048954
A98-36-R-16	2492	109297	0.03880	2769	109297	0.04311	0.052146
A98-36-R-17	672	106961	0.01048	746	106961	0.01164	0.014078
A98-36-R-18	943	115578	0.01560	1047	115578	0.01733	0.020966
A98-36-R-19	2102	106045	0.03170	2336	106045	0.03522	0.042604
A98-36-R-20	2286	109742	0.03638	2540	109742	0.04042	0.048887
A98-36-R-21	834	108695	0.01280	927	108695	0.01422	0.017203
A98-36-R-22	1040	121662	0.01803	1156	121662	0.02003	0.024225
A98-36-R-23	1441	108876	0.02240	1601	108876	0.02489	0.030105
A98-36-R-24	1376	94569	0.01893	1529	94569	0.02103	0.025435
A98-36-R-25	390	103158	0.00580	433	103158	0.00644	0.007795
A98-36-R-26	889	115499	0.01478	987	115499	0.01642	0.019857
A98-36-R-27	1289	101456	0.01883	1433	101456	0.02092	0.025300
A98-36-R-28	2308	110239	0.03648	2564	110239	0.04053	0.049021
A98-36-R-29	1647	123015	0.02858	1830	123015	0.03175	0.038404
A98-36-R-30	1236	112428	0.01973	1373	112428	0.02192	0.026510

Au98 36’s Ring (continued)



Au98- 36's Ring Fill. 30 warp 90% Exp Yarn Surface Coverage (SC)							
	Initial Autorate Results	Actual SC = 90%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size
Identifier	count/sq. meter	size(in microns.)	% white	count/sq. meter	size(in microns.)	% white	% white
A98-36-R-31	1398	114646	0.02268	1553	114646	0.02519	0.030475
A98-36-R-32	1300	110951	0.02055	1445	110951	0.02283	0.027619
A98-36-R-33	1376	115231	0.02300	1529	115231	0.02556	0.030911
A98-36-R-34	1485	118169	0.02508	1649	118169	0.02786	0.033700
A98-36-R-35	1365	101377	0.01953	1517	101377	0.02169	0.026241
A98-36-R-36	1268	120438	0.02190	1409	120438	0.02433	0.029433
A98-36-R-37	1918	117804	0.03243	2131	117804	0.03603	0.043578
A98-36-R-38	2254	120383	0.03865	2504	120383	0.04294	0.051945
A98-36-R-39	1105	123544	0.01910	1228	123544	0.02122	0.025670
A98-36-R-40	1528	110288	0.02435	1698	110288	0.02706	0.032726
A98-36-R-41	1777	112369	0.02895	1975	112369	0.03217	0.038908
A98-36-R-42	1820	119182	0.03145	2023	119182	0.03494	0.042268
A98-36-R-43	1409	115963	0.02368	1565	115963	0.02631	0.031819
A98-36-R-44	1300	111407	0.02098	1445	111407	0.02331	0.028190
A98-36-R-45	1387	111718	0.02195	1541	111718	0.02439	0.029500
A98-36-R-46	2297	110568	0.03633	2552	110568	0.04036	0.048820
A98-36-R-47	1820	108596	0.02815	2023	108596	0.03128	0.037833
A98-36-R-48	1593	105730	0.02410	1770	105730	0.02678	0.032390
A98-36-R-49	1268	109264	0.02025	1409	109264	0.02250	0.027215
A98-36-R-50	1029	133990	0.01988	1144	133990	0.02208	0.026711
A98-36-R-51	1950	108181	0.03035	2167	108181	0.03372	0.040790
A98-36-R-52	2427	118175	0.04108	2697	118175	0.04564	0.055204
A98-36-R-53	477	107107	0.00743	530	107107	0.00825	0.009979
A98-36-R-54	1019	101811	0.01500	1132	101811	0.01667	0.020160
A98-36-R-55	748	125911	0.01328	831	125911	0.01475	0.017841
A98-36-R-56	834	131428	0.01575	927	131428	0.01750	0.021168
A98-36-R-57	1398	106600	0.02143	1553	106600	0.02381	0.028795
A98-36-R-58	1885	127259	0.03450	2095	127259	0.03833	0.046367
A98-36-R-59	1582	125989	0.02843	1758	125989	0.03158	0.038202
A98-36-R-60	1419	121971	0.02418	1577	121971	0.02686	0.032491

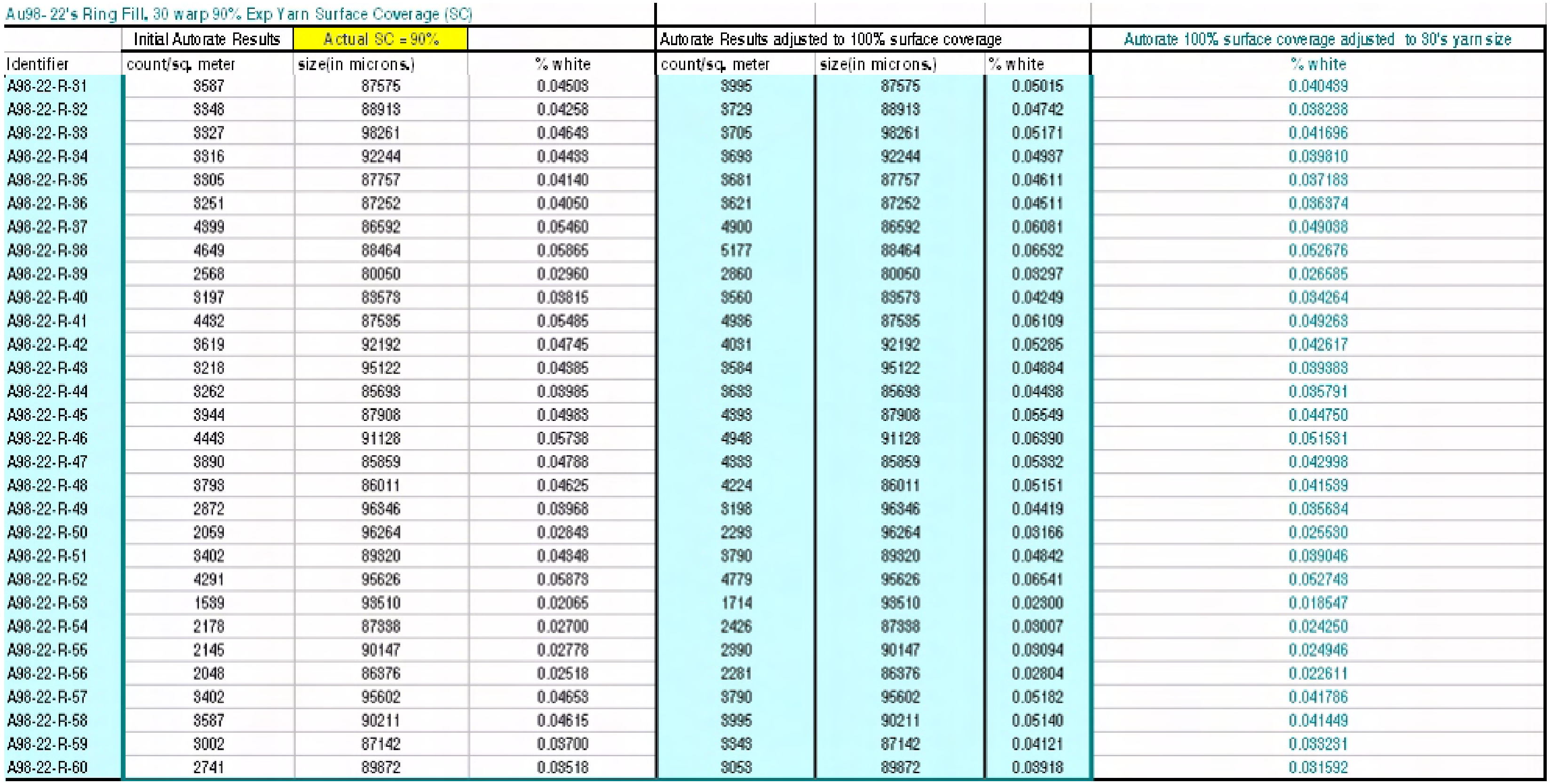
Au98 22’s Ring



Au98- 22's Ring Fill, 30 warp 90% Exp Yarn Surface Coverage (SC)

	Initial Autorate Results	Actual SC = 90%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size
Identifier	count/sq. meter	size(in microns)	% white	count/sq. meter	size(in microns)	% white	% white
A98-22-R-1	2178	85394	0.02648	2426	85394	0.02949	0.023778
A98-22-R-2	2102	84376	0.02538	2341	84376	0.02826	0.022790
A98-22-R-3	2937	81521	0.03435	3271	81521	0.03826	0.030851
A98-22-R-4	3056	84571	0.03708	3403	84571	0.04129	0.033298
A98-22-R-5	1940	92429	0.02550	2160	92429	0.02840	0.022902
A98-22-R-6	2091	101811	0.03000	2329	101811	0.03341	0.026944
A98-22-R-7	2709	94283	0.03648	3017	94283	0.04063	0.032760
A98-22-R-8	2796	104676	0.04150	3114	104676	0.04622	0.037273
A98-22-R-9	2839	94469	0.03890	3162	94469	0.04333	0.034937
A98-22-R-10	2633	94949	0.03578	2933	94949	0.03985	0.032131
A98-22-R-11	3370	94631	0.04580	3753	94631	0.05101	0.041135
A98-22-R-12	2297	92984	0.03123	2559	92984	0.03478	0.028044
A98-22-R-13	1615	89519	0.02068	1798	89519	0.02303	0.018569
A98-22-R-14	1658	90315	0.02168	1847	90315	0.02414	0.019467
A98-22-R-15	5234	102538	0.07693	5829	102538	0.08568	0.069089
A98-22-R-16	4941	94636	0.06680	5503	94636	0.07440	0.059995
A98-22-R-17	2080	89017	0.02620	2317	89017	0.02918	0.023531
A98-22-R-18	2200	97453	0.02990	2450	97453	0.03330	0.026854
A98-22-R-19	5776	87104	0.07200	6433	87104	0.08019	0.064666
A98-22-R-20	5635	84177	0.06770	6276	84177	0.07540	0.060804
A98-22-R-21	1539	84826	0.01875	1714	84826	0.02088	0.016840
A98-22-R-22	1940	98421	0.02763	2160	98421	0.03077	0.024811
A98-22-R-23	4378	81958	0.05128	4876	81958	0.05711	0.046052
A98-22-R-24	3142	87531	0.03933	3500	87531	0.04380	0.035319
A98-22-R-25	1528	76392	0.01673	1702	76392	0.01863	0.015021
A98-22-R-26	1950	92978	0.02568	2172	92978	0.02860	0.023060
A98-22-R-27	4930	91628	0.06450	5491	91628	0.07184	0.057930
A98-22-R-28	5602	94043	0.07538	6240	94043	0.08395	0.067697
A98-22-R-29	3023	94933	0.04123	3367	94933	0.04592	0.037026
A98-22-R-30	3587	88249	0.04528	3995	88249	0.05043	0.040663

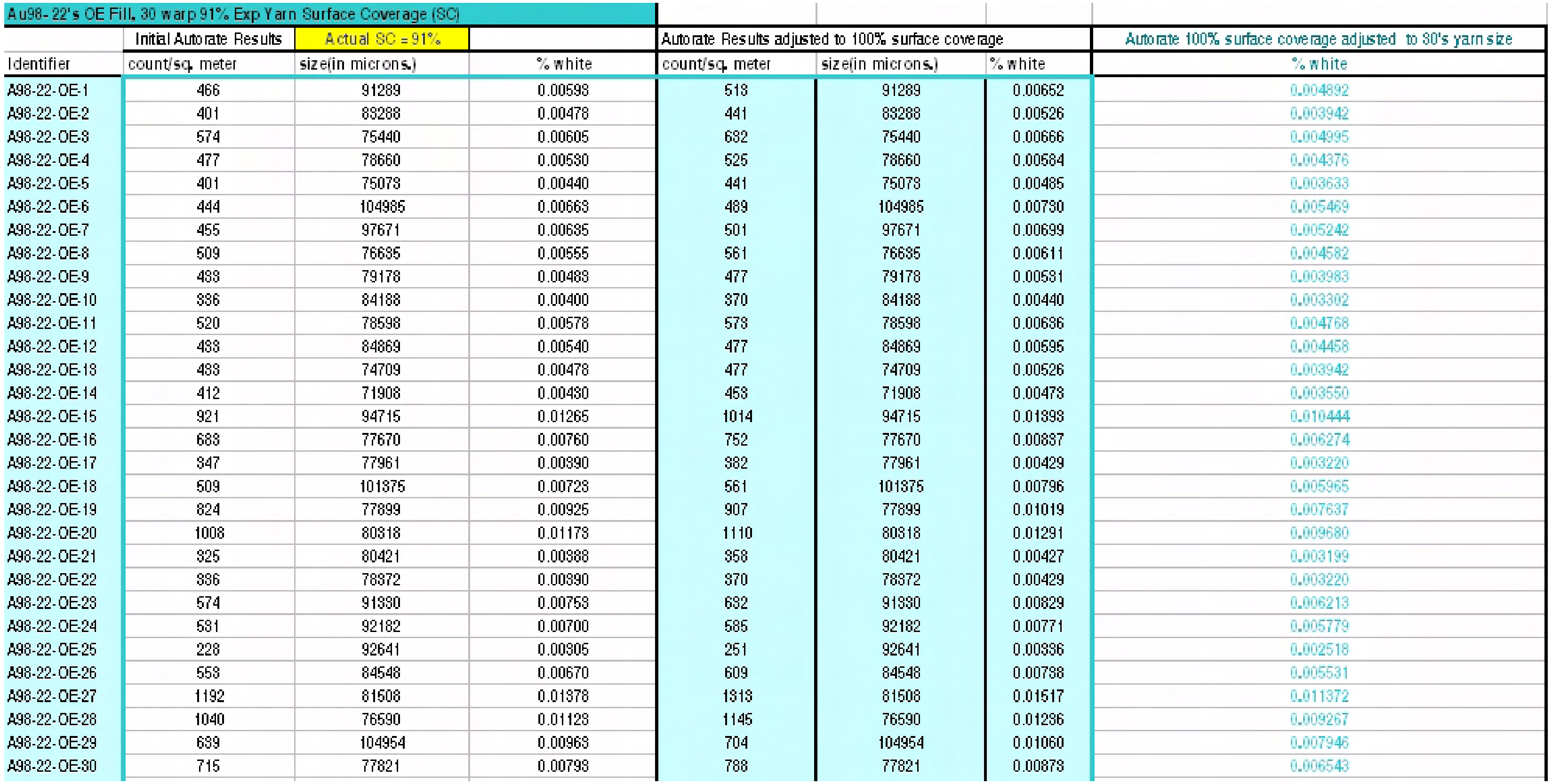
Au98 22’s Ring (continued)



Au98- 22's Ring Fill. 30 warp 90% Exp Yarn Surface Coverage (SC)

	Initial Autorate Results	Actual SC = 90%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size
Identifier	count/sq. meter	size(in microns.)	% white	count/sq. meter	size(in microns.)	% white	% white
A98-22-R-31	3587	87575	0.04503	3995	87575	0.05015	0.040439
A98-22-R-32	3348	88913	0.04258	3729	88913	0.04742	0.038238
A98-22-R-33	3327	98261	0.04643	3705	98261	0.05171	0.041696
A98-22-R-34	3316	92244	0.04433	3693	92244	0.04937	0.039810
A98-22-R-35	3305	87757	0.04140	3681	87757	0.04611	0.037183
A98-22-R-36	3251	87252	0.04050	3621	87252	0.04511	0.036374
A98-22-R-37	4399	86592	0.05460	4900	86592	0.06081	0.049038
A98-22-R-38	4649	88464	0.05865	5177	88464	0.06532	0.052676
A98-22-R-39	2568	80050	0.02960	2860	80050	0.03297	0.026585
A98-22-R-40	3197	89573	0.03815	3560	89573	0.04249	0.034264
A98-22-R-41	4432	87535	0.05485	4936	87535	0.06109	0.049263
A98-22-R-42	3619	92192	0.04745	4031	92192	0.05285	0.042617
A98-22-R-43	3218	95122	0.04385	3584	95122	0.04884	0.039383
A98-22-R-44	3262	85693	0.03985	3633	85693	0.04438	0.035791
A98-22-R-45	3944	87908	0.04983	4393	87908	0.05549	0.044750
A98-22-R-46	4443	91128	0.05738	4948	91128	0.06390	0.051531
A98-22-R-47	3890	85859	0.04788	4333	85859	0.05332	0.042998
A98-22-R-48	3793	86011	0.04625	4224	86011	0.05151	0.041539
A98-22-R-49	2872	96346	0.03968	3198	96346	0.04419	0.035634
A98-22-R-50	2059	96264	0.02843	2293	96264	0.03166	0.025530
A98-22-R-51	3402	89320	0.04348	3790	89320	0.04842	0.039046
A98-22-R-52	4291	95626	0.05873	4779	95626	0.06541	0.052743
A98-22-R-53	1539	93510	0.02065	1714	93510	0.02300	0.018547
A98-22-R-54	2178	87338	0.02700	2426	87338	0.03007	0.024250
A98-22-R-55	2145	90147	0.02778	2390	90147	0.03094	0.024946
A98-22-R-56	2048	86376	0.02518	2281	86376	0.02804	0.022611
A98-22-R-57	3402	95602	0.04653	3790	95602	0.05182	0.041786
A98-22-R-58	3587	90211	0.04615	3995	90211	0.05140	0.041449
A98-22-R-59	3002	87142	0.03700	3343	87142	0.04121	0.033231
A98-22-R-60	2741	89872	0.03518	3053	89872	0.03918	0.031592

Au98 22’s OE



Au98- 22's OE Fill, 30 warp 91% Exp Yarn Surface Coverage (SC)							
	Initial Autorate Results	Actual SC = 91%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size
Identifier	count/sq. meter	size(in microns.)	% white	count/sq. meter	size(in microns.)	% white	% white
A98-22-OE-1	466	91289	0.00593	518	91289	0.00652	0.004892
A98-22-OE-2	401	83288	0.00478	441	83288	0.00526	0.003942
A98-22-OE-3	574	75440	0.00605	632	75440	0.00666	0.004995
A98-22-OE-4	477	78660	0.00530	525	78660	0.00584	0.004376
A98-22-OE-5	401	75073	0.00440	441	75073	0.00485	0.003633
A98-22-OE-6	444	104985	0.00663	489	104985	0.00730	0.005469
A98-22-OE-7	455	97671	0.00635	501	97671	0.00699	0.005242
A98-22-OE-8	509	76635	0.00555	561	76635	0.00611	0.004582
A98-22-OE-9	433	79178	0.00483	477	79178	0.00531	0.003983
A98-22-OE-10	336	84188	0.00400	370	84188	0.00440	0.003302
A98-22-OE-11	520	78598	0.00578	573	78598	0.00636	0.004768
A98-22-OE-12	433	84869	0.00540	477	84869	0.00595	0.004458
A98-22-OE-13	433	74709	0.00478	477	74709	0.00526	0.003942
A98-22-OE-14	412	71908	0.00430	453	71908	0.00473	0.003550
A98-22-OE-15	921	94715	0.01265	1014	94715	0.01393	0.010444
A98-22-OE-16	683	77670	0.00760	752	77670	0.00837	0.006274
A98-22-OE-17	347	77961	0.00390	382	77961	0.00429	0.003220
A98-22-OE-18	509	101375	0.00723	561	101375	0.00796	0.005965
A98-22-OE-19	824	77899	0.00925	907	77899	0.01019	0.007637
A98-22-OE-20	1008	80318	0.01173	1110	80318	0.01291	0.009680
A98-22-OE-21	325	80421	0.00388	358	80421	0.00427	0.003199
A98-22-OE-22	336	78372	0.00390	370	78372	0.00429	0.003220
A98-22-OE-23	574	91330	0.00753	632	91330	0.00829	0.006213
A98-22-OE-24	531	92182	0.00700	585	92182	0.00771	0.005779
A98-22-OE-25	228	92641	0.00305	251	92641	0.00336	0.002518
A98-22-OE-26	553	84548	0.00670	609	84548	0.00738	0.005531
A98-22-OE-27	1192	81508	0.01378	1313	81508	0.01517	0.011372
A98-22-OE-28	1040	76590	0.01123	1145	76590	0.01236	0.009267
A98-22-OE-29	639	104954	0.00963	704	104954	0.01060	0.007946
A98-22-OE-30	715	77821	0.00793	788	77821	0.00873	0.006543

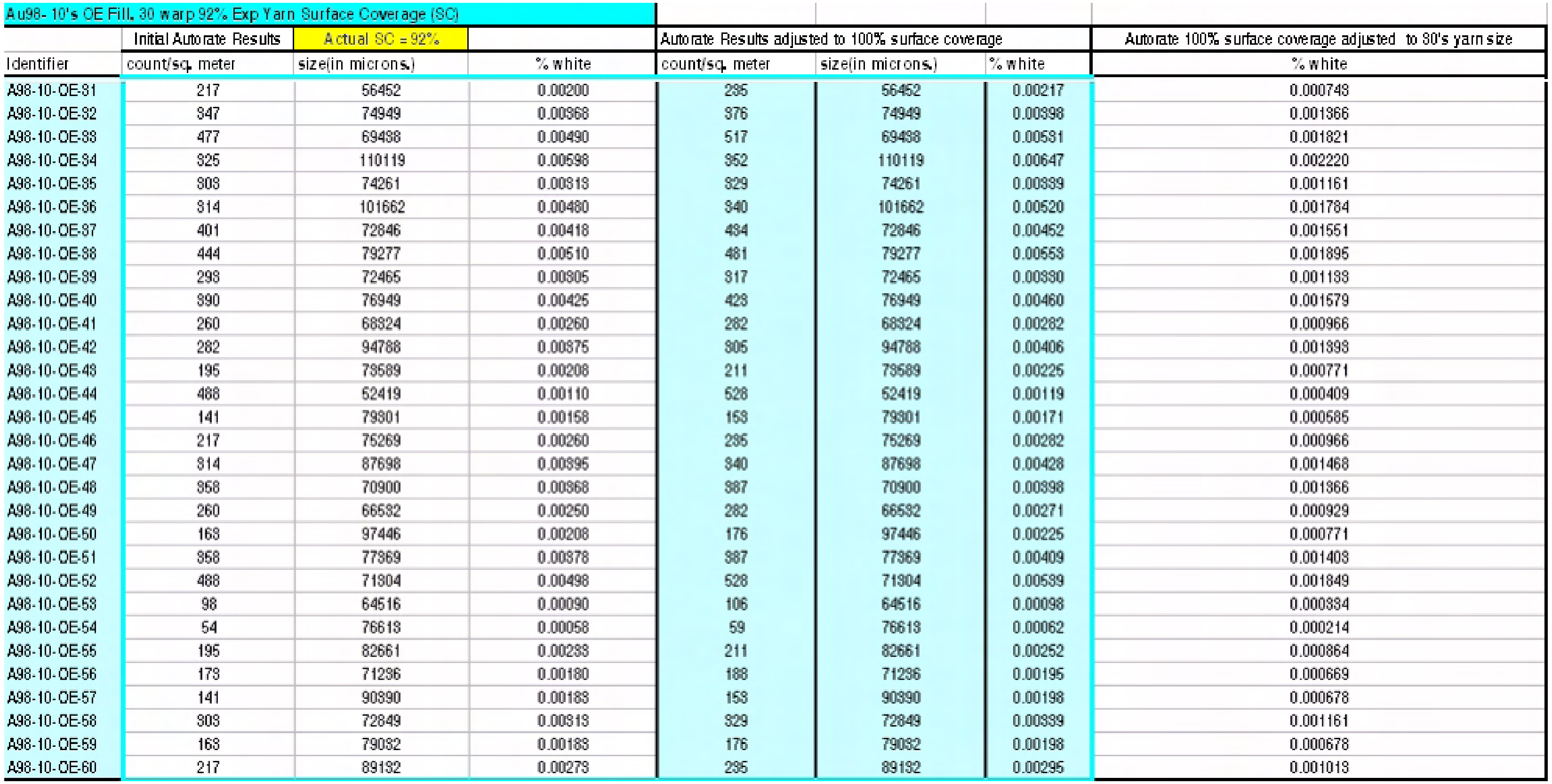
Au98 22’s OE (continued)

Au98- 22's OE Fill, 30 warp 91% Exp Yarn Surface Coverage (SC)							
	Initial Autorate Results	Actual SC = 91%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size
Identifier	count/sq. meter	size(in microns.)	% white	count/sq. meter	size(in microns.)	% white	% white
A98-22-OE-31	542	74462	0.00558	597	74462	0.00614	0.004603
A98-22-OE-32	704	79775	0.00795	776	79775	0.00875	0.006563
A98-22-OE-33	488	76633	0.00540	537	76633	0.00595	0.004458
A98-22-OE-34	813	88819	0.01015	895	88819	0.01118	0.008380
A98-22-OE-35	596	79751	0.00665	656	79751	0.00732	0.005490
A98-22-OE-36	498	79756	0.00583	549	79756	0.00641	0.004809
A98-22-OE-37	899	83809	0.01130	990	83809	0.01244	0.009329
A98-22-OE-38	889	83058	0.01075	978	83058	0.01184	0.008875
A98-22-OE-39	433	93476	0.00565	477	93476	0.00622	0.004665
A98-22-OE-40	498	84821	0.00595	549	84821	0.00655	0.004912
A98-22-OE-41	455	82796	0.00545	501	82796	0.00600	0.004499
A98-22-OE-42	661	90149	0.00835	728	90149	0.00919	0.006894
A98-22-OE-43	585	79215	0.00683	644	79215	0.00752	0.005635
A98-22-OE-44	509	80998	0.00628	561	80998	0.00691	0.005181
A98-22-OE-45	596	96811	0.00775	656	96811	0.00853	0.006398
A98-22-OE-46	563	86972	0.00695	620	86972	0.00765	0.005738
A98-22-OE-47	748	86313	0.00920	823	86313	0.01013	0.007595
A98-22-OE-48	683	81311	0.00795	752	81311	0.00875	0.006563
A98-22-OE-49	303	70564	0.00310	334	70564	0.00341	0.002559
A98-22-OE-50	412	95718	0.00558	453	95718	0.00614	0.004603
A98-22-OE-51	802	82111	0.00968	883	82111	0.01065	0.007988
A98-22-OE-52	704	94909	0.00938	776	94909	0.01032	0.007740
A98-22-OE-53	130	117943	0.00205	143	117943	0.00226	0.001692
A98-22-OE-54	509	88412	0.00650	561	88412	0.00716	0.005366
A98-22-OE-55	325	85154	0.00415	358	85154	0.00457	0.003426
A98-22-OE-56	358	98092	0.00483	394	98092	0.00531	0.003983
A98-22-OE-57	780	90516	0.01000	859	90516	0.01101	0.008256
A98-22-OE-58	726	96636	0.00990	799	96636	0.01090	0.008173
A98-22-OE-59	737	84273	0.00900	811	84273	0.00991	0.007430
A98-22-OE-60	1051	88202	0.01323	1157	88202	0.01456	0.010918

Au98 10’s OE

Au98- 10's OE Fill, 30 warp 92% Exp Yarn Surface Coverage (SC)							
	Initial Autorate Results	Actual SC = 92%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size
Identifier	count/sq. meter	size(in microns.)	% white	count/sq. meter	size(in microns.)	% white	% white
A98-10-OE-1	163	67742	0.00160	176	67742	0.00173	0.000595
A98-10-OE-2	553	71816	0.00550	599	71816	0.00596	0.002044
A98-10-OE-3	206	72350	0.00220	223	72350	0.00238	0.000817
A98-10-OE-4	238	75590	0.00268	258	75590	0.00290	0.000994
A98-10-OE-5	314	71068	0.00323	340	71068	0.00349	0.001198
A98-10-OE-6	130	80981	0.00155	141	80981	0.00168	0.000576
A98-10-OE-7	238	64516	0.00220	258	64516	0.00238	0.000817
A98-10-OE-8	152	64516	0.00140	164	64516	0.00152	0.000520
A98-10-OE-9	184	111175	0.00373	200	111175	0.00404	0.001384
A98-10-OE-10	195	97043	0.00268	211	97043	0.00290	0.000994
A98-10-OE-11	173	76901	0.00185	188	76901	0.00200	0.000687
A98-10-OE-12	184	75000	0.00200	200	75000	0.00217	0.000743
A98-10-OE-13	108	64516	0.00100	117	64516	0.00108	0.000372
A98-10-OE-14	141	86357	0.00175	153	86357	0.00190	0.000650
A98-10-OE-15	336	81125	0.00363	364	81125	0.00393	0.001347
A98-10-OE-16	303	72760	0.00310	329	72760	0.00336	0.001152
A98-10-OE-17	130	69892	0.00130	141	69892	0.00141	0.000483
A98-10-OE-18	130	69220	0.00138	141	69220	0.00149	0.000511
A98-10-OE-19	379	73502	0.00395	411	73502	0.00428	0.001468
A98-10-OE-20	704	67939	0.00680	763	67939	0.00737	0.002527
A98-10-OE-21	98	103494	0.00163	106	103494	0.00176	0.000604
A98-10-OE-22	163	73589	0.00195	176	73589	0.00211	0.000725
A98-10-OE-23	282	69508	0.00280	305	69508	0.00303	0.001040
A98-10-OE-24	390	82738	0.00440	423	82738	0.00477	0.001635
A98-10-OE-25	206	79749	0.00225	223	79749	0.00244	0.000836
A98-10-OE-26	98	76613	0.00110	106	76613	0.00119	0.000409
A98-10-OE-27	704	69714	0.00710	763	69714	0.00769	0.002638
A98-10-OE-28	954	68320	0.00930	1033	68320	0.01008	0.003456
A98-10-OE-29	217	100302	0.00305	235	100302	0.00330	0.001133
A98-10-OE-30	282	73835	0.00295	305	73835	0.00320	0.001096

Au98 10's OE (continued)



Au98- 10's OE Fill, 30 warp 92% Exp Yarn Surface Coverage (SC)							
	Initial Autorate Results	Actual SC = 92%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 80's yarn size
Identifier	count/sq. meter	size(in microns)	% white	count/sq. meter	size(in microns)	% white	% white
A98-10-OE-31	217	56452	0.00200	235	56452	0.00217	0.000743
A98-10-OE-32	347	74949	0.00368	376	74949	0.00398	0.001366
A98-10-OE-33	477	69438	0.00490	517	69438	0.00531	0.001821
A98-10-OE-34	325	110119	0.00598	352	110119	0.00647	0.002220
A98-10-OE-35	303	74261	0.00313	329	74261	0.00339	0.001161
A98-10-OE-36	314	101662	0.00480	340	101662	0.00520	0.001784
A98-10-OE-37	401	72846	0.00418	434	72846	0.00452	0.001551
A98-10-OE-38	444	79277	0.00510	481	79277	0.00553	0.001895
A98-10-OE-39	293	72465	0.00305	317	72465	0.00330	0.001133
A98-10-OE-40	390	76949	0.00425	423	76949	0.00460	0.001579
A98-10-OE-41	260	68324	0.00260	282	68324	0.00282	0.000966
A98-10-OE-42	282	94788	0.00375	305	94788	0.00406	0.001393
A98-10-OE-43	195	73589	0.00208	211	73589	0.00225	0.000771
A98-10-OE-44	488	52419	0.00110	528	52419	0.00119	0.000409
A98-10-OE-45	141	79301	0.00158	153	79301	0.00171	0.000585
A98-10-OE-46	217	75269	0.00260	235	75269	0.00282	0.000966
A98-10-OE-47	314	87698	0.00395	340	87698	0.00428	0.001468
A98-10-OE-48	358	70900	0.00368	387	70900	0.00398	0.001366
A98-10-OE-49	260	66532	0.00250	282	66532	0.00271	0.000929
A98-10-OE-50	163	97446	0.00208	176	97446	0.00225	0.000771
A98-10-OE-51	358	77369	0.00378	387	77369	0.00409	0.001403
A98-10-OE-52	488	71304	0.00498	528	71304	0.00539	0.001849
A98-10-OE-53	98	64516	0.00090	106	64516	0.00098	0.000334
A98-10-OE-54	54	76613	0.00058	59	76613	0.00062	0.000214
A98-10-OE-55	195	82661	0.00233	211	82661	0.00252	0.000864
A98-10-OE-56	173	71236	0.00180	188	71236	0.00195	0.000669
A98-10-OE-57	141	90390	0.00183	153	90390	0.00198	0.000678
A98-10-OE-58	303	72849	0.00313	329	72849	0.00339	0.001161
A98-10-OE-59	163	79032	0.00183	176	79032	0.00198	0.000678
A98-10-OE-60	217	89132	0.00273	235	89132	0.00295	0.001013

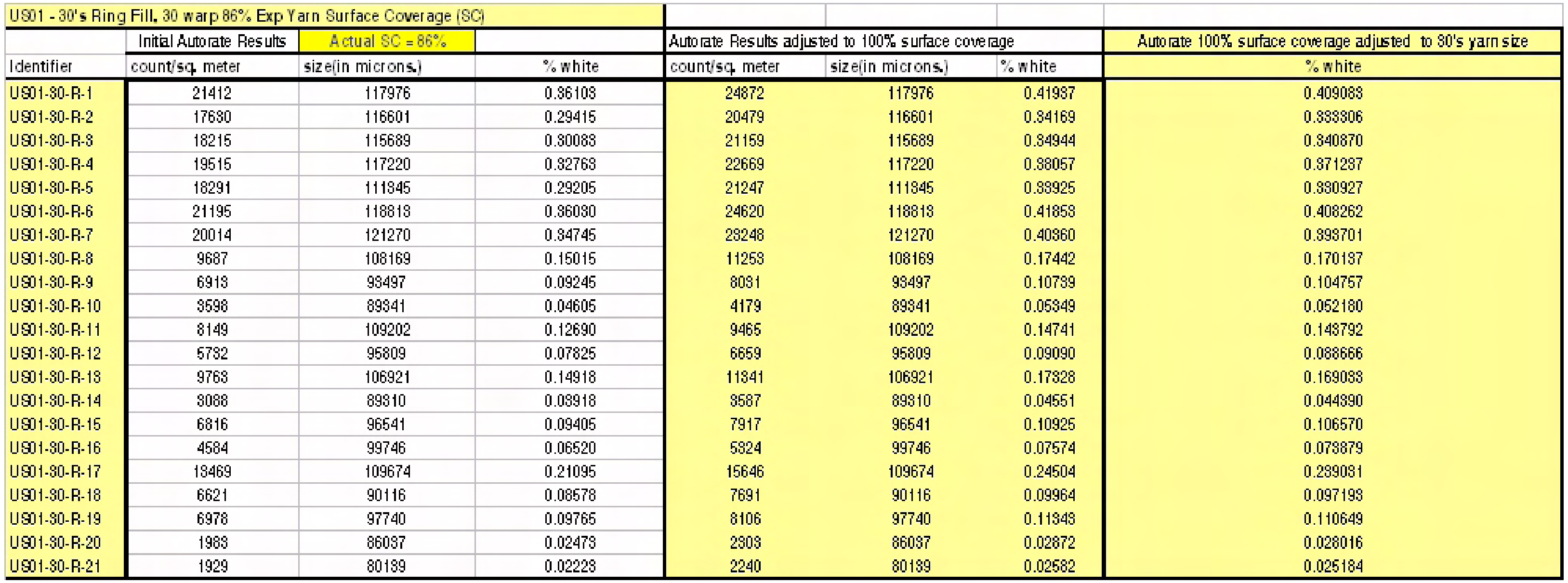
Au99 28’s Ring

Au 99- 28's Ring Fill, 30 warp 84% Exp Yarn Surface Coverage (SC)							
	Initial Autorate Results	Actual SC = 84%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size
Identifier	count/sq. meter	size(in microns.)	% white	count/sq. meter	size(in microns.)	% white	% white
A99-28-R-1	3955	128120	0.07252	4698	128120	0.08614	0.088300
A99-28-R-2	5170	122776	0.09053	6140	122776	0.10753	0.110229
A99-28-R-3	3581	122016	0.06199	4253	122016	0.07363	0.075475
A99-28-R-4	3272	128557	0.05980	3887	128557	0.07103	0.072810
A99-28-R-5	5559	115987	0.09188	6603	115987	0.10913	0.111864
A99-28-R-6	5645	115157	0.09283	6706	115157	0.11026	0.113020
A99-28-R-7	4280	126232	0.07608	5084	126232	0.09036	0.092626
A99-28-R-8	3392	124815	0.06068	4029	124815	0.07207	0.073876
A99-28-R-9	2752	132849	0.05255	3269	132849	0.06242	0.063983
A99-28-R-10	3608	122712	0.06340	4286	122712	0.07531	0.077194
A99-28-R-11	3478	119518	0.05918	4131	119518	0.07029	0.072049
A99-28-R-12	4042	126355	0.07338	4801	126355	0.08715	0.089339
A99-28-R-13	2102	125616	0.03740	2497	125616	0.04442	0.045537
A99-28-R-14	3002	123532	0.05290	3565	123532	0.06283	0.064409
A99-28-R-15	2373	139386	0.04690	2819	139386	0.05571	0.057104
A99-28-R-16	2048	144358	0.04213	2433	144358	0.05004	0.051290
A99-28-R-17	2395	114376	0.03918	2844	114376	0.04653	0.047698
A99-28-R-18	2806	125193	0.04995	3334	125193	0.05933	0.060817
A99-28-R-19	2308	111471	0.03703	2741	111471	0.04398	0.045080
A99-28-R-20	2427	125145	0.04355	2883	125145	0.05173	0.053025
A99-28-R-21	2059	130773	0.03918	2445	130773	0.04653	0.047698
A99-28-R-22	2211	126998	0.04040	2626	126998	0.04799	0.049190
A99-28-R-23	1950	125517	0.03510	2317	125517	0.04169	0.042736
A99-28-R-24	2048	129830	0.03843	2433	129830	0.04564	0.046785
A99-28-R-25	1929	134042	0.03728	2291	134042	0.04427	0.045385
A99-28-R-26	2276	122257	0.03958	2703	122257	0.04701	0.048185
A99-28-R-27	2330	125515	0.04173	2767	125515	0.04956	0.050803
A99-28-R-28	3012	114346	0.04975	3578	114346	0.05909	0.060574
A99-28-R-29	3966	113388	0.06420	4711	113388	0.07626	0.078168
A99-28-R-30	5050	114726	0.08263	5998	114726	0.09814	0.100601
A99-28-R-31	2492	120237	0.04310	2960	120237	0.05119	0.052477
A99-28-R-32	3272	114185	0.05385	3887	114185	0.06396	0.065566
A99-28-R-33	4844	129151	0.08963	5753	129151	0.10646	0.109124
A99-28-R-34	6556	87306	0.08183	7787	87306	0.09719	0.099627
A99-28-R-35	4031	124511	0.07150	4788	124511	0.08493	0.087056
A99-28-R-36	5570	126668	0.10055	6616	126668	0.11943	0.122426

Au99 28’s Ring

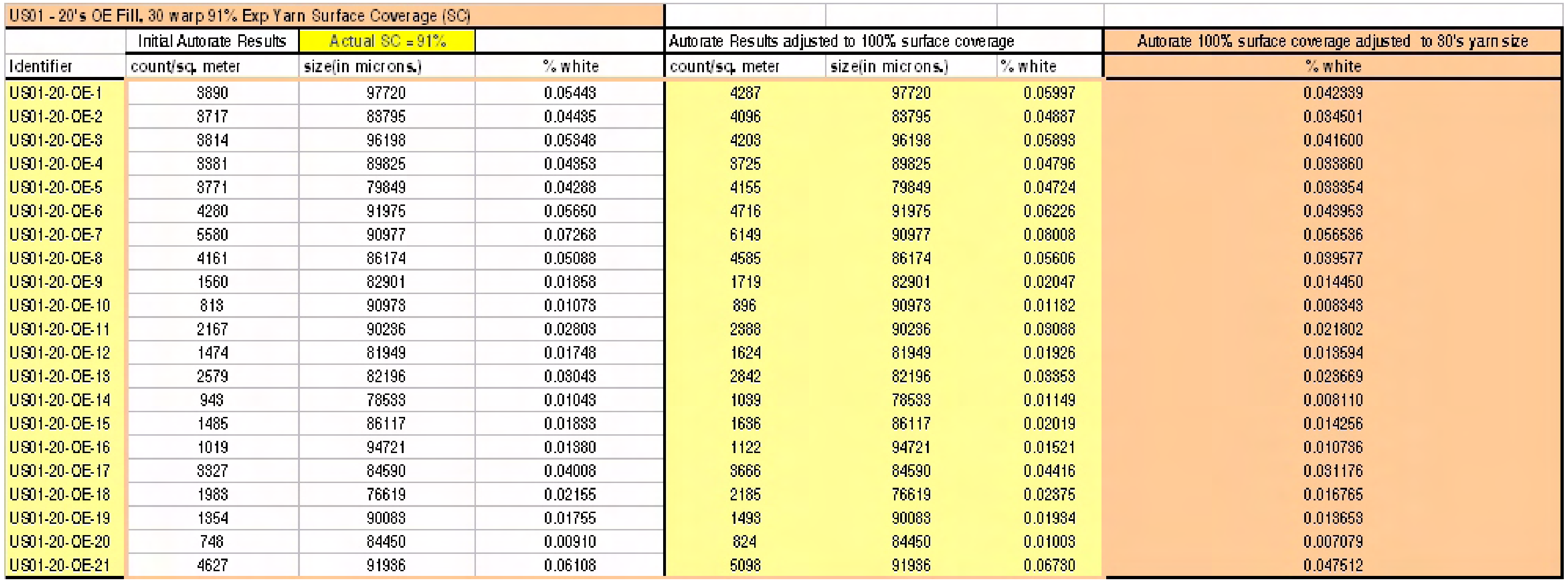
Au 99- 28's Ring Fill. 30 warp 84% Exp Yarn Surface Coverage (SC)							
	Initial Autorate Results	Actual SC = 84%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 80's yarn size
Identifier	count/sq. meter	size(in microns)	% white	count/sq. meter	size(in microns)	% white	% white
A99-28-R-37	3760	116259	0.06275	4466	116259	0.07453	0.076402
A99-28-R-38	5255	120061	0.09055	6242	120061	0.10755	0.110250
A99-28-R-39	3717	131516	0.06993	4415	131516	0.08306	0.085138
A99-28-R-40	4833	131592	0.09143	5740	131592	0.10859	0.111316
A99-28-R-41	2406	124580	0.04308	2857	124580	0.05116	0.052447
A99-28-R-42	3056	110877	0.04938	3630	110877	0.05865	0.060117
A99-28-R-43	2839	124340	0.05050	3372	124340	0.05998	0.061487
A99-28-R-44	3413	114562	0.05553	4054	114562	0.06595	0.067605
A99-28-R-45	2536	113105	0.04108	3012	113105	0.04879	0.050011
A99-28-R-46	4150	125106	0.07410	4929	125106	0.08802	0.090221
A99-28-R-47	4334	120758	0.07455	5148	120758	0.08855	0.090769
A99-28-R-48	5580	117146	0.09383	6628	117146	0.11144	0.114238
A99-28-R-49	3002	123142	0.05308	3565	123142	0.06304	0.064622
A99-28-R-50	3121	103142	0.04600	3707	103142	0.05464	0.056008
A99-28-R-51	4703	122261	0.08285	5586	122261	0.09841	0.100875
A99-28-R-52	5656	124378	0.10060	6719	124378	0.11949	0.122487
A99-28-R-53	2937	126930	0.05273	3488	126930	0.06263	0.064196
A99-28-R-54	3316	117640	0.05630	3938	117640	0.06687	0.068549
A99-28-R-55	3402	118393	0.05763	4041	118393	0.06845	0.070162
A99-28-R-56	3522	120168	0.06018	4183	120168	0.07148	0.073267
A99-28-R-57	1734	124510	0.03213	2059	124510	0.03816	0.039114
A99-28-R-58	1560	122248	0.02698	1853	122248	0.03204	0.032844
A99-28-R-59	1961	122260	0.03428	2330	122260	0.04071	0.041732
A99-28-R-60	2611	118765	0.04408	3102	118765	0.05235	0.053664
A99-28-R-61	2091	132099	0.03948	2484	132099	0.04689	0.048063
A99-28-R-62	2763	120295	0.04790	3282	120295	0.05690	0.058321
A99-28-R-63	3706	128120	0.06795	4402	128120	0.08071	0.082738
A99-28-R-64	4844	122776	0.08483	5753	122776	0.10076	0.103280
A99-28-R-65	2698	122588	0.04733	3205	122588	0.05621	0.057621
A99-28-R-66	2785	127269	0.05063	3308	127269	0.06013	0.061639
A99-28-R-67	2211	115052	0.03633	2626	115052	0.04315	0.044228
A99-28-R-68	2200	120763	0.03765	2613	120763	0.04472	0.045841
A99-28-R-69	4031	122755	0.07088	4788	122755	0.08418	0.086295
A99-28-R-70	4486	121032	0.07738	5328	121032	0.09191	0.094209
A99-28-R-71	3858	124098	0.06840	4582	124098	0.08124	0.083281
A99-28-R-72	4594	123557	0.08130	5457	123557	0.09657	0.098988

US01 30’s Ring



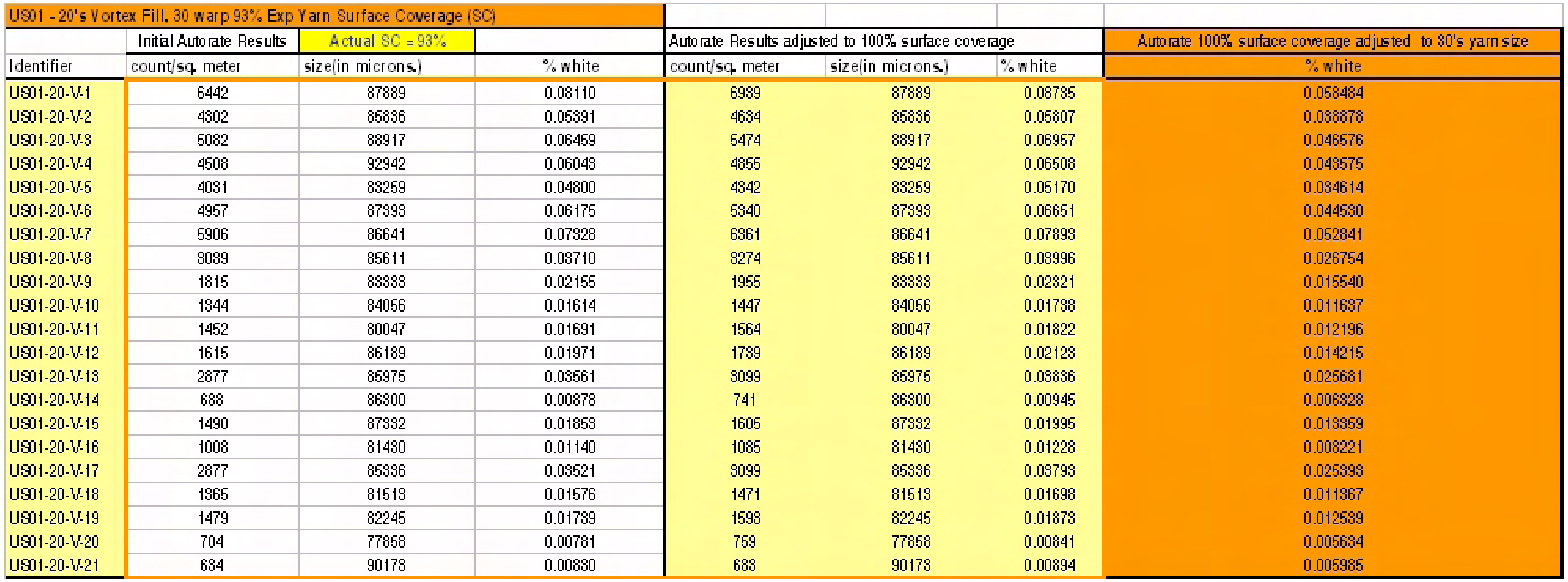
US01 - 30's Ring Fill, 30 warp 86% Exp Yarn Surface Coverage (SC)							
	Initial Autorate Results	Actual SC = 86%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size
Identifier	count/sq. meter	size(in microns.)	% white	count/sq. meter	size(in microns.)	% white	% white
US01-30-R-1	21412	117976	0.36103	24872	117976	0.41937	0.409083
US01-30-R-2	17630	116601	0.29415	20479	116601	0.34169	0.333306
US01-30-R-3	18215	115689	0.30083	21159	115689	0.34944	0.340870
US01-30-R-4	19515	117220	0.32768	22669	117220	0.38057	0.371237
US01-30-R-5	18291	111345	0.29205	21247	111345	0.33925	0.330927
US01-30-R-6	21195	118813	0.36030	24620	118813	0.41853	0.408262
US01-30-R-7	20014	121270	0.34745	23248	121270	0.40360	0.393701
US01-30-R-8	9687	108169	0.15015	11253	108169	0.17442	0.170137
US01-30-R-9	6913	93497	0.09245	8031	93497	0.10739	0.104757
US01-30-R-10	3598	89341	0.04605	4179	89341	0.05349	0.052180
US01-30-R-11	8149	109202	0.12690	9465	109202	0.14741	0.143792
US01-30-R-12	5732	95809	0.07825	6659	95809	0.09090	0.088666
US01-30-R-13	9763	106921	0.14918	11341	106921	0.17328	0.169033
US01-30-R-14	3088	89310	0.03918	3587	89310	0.04551	0.044390
US01-30-R-15	6816	96541	0.09405	7917	96541	0.10925	0.106570
US01-30-R-16	4584	99746	0.06520	5324	99746	0.07574	0.073879
US01-30-R-17	13469	109674	0.21095	15646	109674	0.24504	0.239031
US01-30-R-18	6621	90116	0.08578	7691	90116	0.09964	0.097193
US01-30-R-19	6978	97740	0.09765	8106	97740	0.11343	0.110649
US01-30-R-20	1983	86037	0.02473	2303	86037	0.02872	0.028016
US01-30-R-21	1929	80139	0.02223	2240	80139	0.02582	0.025184

US01 20’s OE



US01 - 20's OE Fill, 30 warp 91% Exp Yarn Surface Coverage (SC)							
	Initial Autorate Results	Actual SC = 91%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size
Identifier	count/sq. meter	size(in microns.)	% white	count/sq. meter	size(in microns.)	% white	% white
US01-20-OE-1	3890	97720	0.05443	4287	97720	0.05997	0.042339
US01-20-OE-2	3717	83795	0.04435	4096	83795	0.04887	0.034501
US01-20-OE-3	3814	96198	0.05348	4203	96198	0.05893	0.041600
US01-20-OE-4	3381	89825	0.04353	3725	89825	0.04796	0.033860
US01-20-OE-5	3771	79849	0.04288	4155	79849	0.04724	0.033354
US01-20-OE-6	4280	91975	0.05650	4716	91975	0.06226	0.043953
US01-20-OE-7	5580	90977	0.07268	6149	90977	0.08008	0.056536
US01-20-OE-8	4161	86174	0.05088	4585	86174	0.05606	0.039577
US01-20-OE-9	1560	82901	0.01858	1719	82901	0.02047	0.014450
US01-20-OE-10	813	90973	0.01073	896	90973	0.01182	0.008343
US01-20-OE-11	2167	90236	0.02803	2388	90236	0.03088	0.021802
US01-20-OE-12	1474	81949	0.01748	1624	81949	0.01926	0.013594
US01-20-OE-13	2579	82196	0.03043	2842	82196	0.03353	0.023669
US01-20-OE-14	943	78533	0.01043	1039	78533	0.01149	0.008110
US01-20-OE-15	1485	86117	0.01833	1636	86117	0.02019	0.014256
US01-20-OE-16	1019	94721	0.01380	1122	94721	0.01521	0.010736
US01-20-OE-17	3327	84590	0.04008	3666	84590	0.04416	0.031176
US01-20-OE-18	1983	76619	0.02155	2185	76619	0.02375	0.016765
US01-20-OE-19	1354	90083	0.01755	1493	90083	0.01934	0.013653
US01-20-OE-20	748	84450	0.00910	824	84450	0.01003	0.007079
US01-20-OE-21	4627	91936	0.06108	5098	91936	0.06730	0.047512

US01 20’s Vortex



US01 - 20's Vortex Fill. 30 warp 93% Exp Yarn Surface Coverage (SC)							
	Initial Autorate Results	Actual SC = 93%		Autorate Results adjusted to 100% surface coverage			Autorate 100% surface coverage adjusted to 30's yarn size
Identifier	count/sq. meter	size(in microns.)	% white	count/sq. meter	size(in microns.)	% white	% white
US01-20-V-1	6442	87889	0.08110	6939	87889	0.08735	0.058484
US01-20-V-2	4302	85836	0.05391	4634	85836	0.05807	0.038878
US01-20-V-3	5082	88917	0.06459	5474	88917	0.06957	0.046576
US01-20-V-4	4508	92942	0.06043	4855	92942	0.06508	0.043575
US01-20-V-5	4031	83259	0.04800	4342	83259	0.05170	0.034614
US01-20-V-6	4957	87393	0.06175	5340	87393	0.06651	0.044530
US01-20-V-7	5906	86641	0.07328	6361	86641	0.07893	0.052841
US01-20-V-8	3039	85611	0.03710	3274	85611	0.03996	0.026754
US01-20-V-9	1815	83333	0.02155	1955	83333	0.02321	0.015540
US01-20-V-10	1344	84056	0.01614	1447	84056	0.01738	0.011637
US01-20-V-11	1452	80047	0.01691	1564	80047	0.01822	0.012196
US01-20-V-12	1615	86189	0.01971	1739	86189	0.02123	0.014215
US01-20-V-13	2877	85975	0.03561	3099	85975	0.03836	0.025681
US01-20-V-14	688	86300	0.00878	741	86300	0.00945	0.006328
US01-20-V-15	1490	87332	0.01853	1605	87332	0.01995	0.013359
US01-20-V-16	1008	81430	0.01140	1085	81430	0.01228	0.008221
US01-20-V-17	2877	85336	0.03521	3099	85336	0.03793	0.025393
US01-20-V-18	1365	81513	0.01576	1471	81513	0.01698	0.011367
US01-20-V-19	1479	82245	0.01739	1593	82245	0.01873	0.012539
US01-20-V-20	704	77858	0.00781	759	77858	0.00841	0.005634
US01-20-V-21	634	90173	0.00830	683	90173	0.00894	0.005985

Fibre Data

HVI (US 2001 & EVS)

ID	% White (30's)*	HVI	HVI	HVI
Study-original yarn size -Ring-ID #	US01 - % White (30's)*	Buckling Coeff L2/µ2	Uniformity Index	Rd
US01-30-R-1	0.40908	0.16638	80.28	78.38
US01-30-R-2	0.33331	0.10693	81.06	81.10
US01-30-R-3	0.34087	0.10494	81.19	80.41
US01-30-R-4	0.37124	0.13784	80.31	79.38
US01-30-R-5	0.33093	0.14731	80.19	78.00
US01-30-R-6	0.40826	0.13093	80.56	80.56
US01-30-R-7	0.39370	0.13256	81.19	81.63
US01-30-R-8	0.17014	0.08244	81.93	80.11
US01-30-R-9	0.10476	0.07803	80.25	77.34
US01-30-R-10	0.05218	0.05143	81.94	76.16
US01-30-R-11	0.14379	0.06362	82.03	77.94
US01-30-R-12	0.08867	0.06562	80.25	79.94
US01-30-R-13	0.16903	0.07967	81.72	77.81
US01-30-R-14	0.04439	0.05075	81.38	77.47
US01-30-R-15	0.10657	0.05898	79.34	77.97
US01-30-R-16	0.07388	0.05341	82.00	74.00
US01-30-R-17	0.23903	0.08929	81.19	72.72
US01-30-R-18	0.09719	0.08319	80.69	72.31
US01-30-R-19	0.11065	0.06368	81.22	74.31
US01-30-R-20	0.02802	0.04611	80.54	75.57
US01-30-R-21	0.02518	0.03586	81.88	74.19

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

ID	% White (30's)*	HVI	HVI	HVI
Study-original yarn size -Ring-ID #	EVS- % White (30's)*	Buckling Coeff L2/µ2	Uniformity Index	Rd
EVS-36-R-1	0.02189	0.06342	84.67	74.43
EVS-36-R-2	0.09198	0.10073	83.33	73.90
EVS-36-R-3	0.02927	0.07547	82.20	74.97
EVS-36-R-4	0.10015	0.08715	80.93	73.37

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

HVI (LVS)

ID	% White (30's)*	HVI	HVI	HVI
Study-original yarn size -Ring-ID #	LVS- % White (30's)*	Buckling Coeff L2/µ2	Uniformity Index	Rd
LVS-36-R-1	0.01585	0.05867	81.90	74.20
LVS-36-R-2	0.04982	0.05928	82.10	74.20
LVS-36-R-3	0.05452	0.07596	81.00	74.72
LVS-36-R-4	0.04600	0.05578	81.50	74.72
LVS-36-R-5	0.03756	0.06479	81.40	73.35
LVS-36-R-6	0.03816	0.06418	82.60	73.35
LVS-36-R-7	0.06490	0.07669	81.90	75.35
LVS-36-R-8	0.07660	0.07462	82.20	75.35
LVS-36-R-9	0.02282	0.05823	82.80	74.55
LVS-36-R-10	0.03016	0.05780	82.50	74.55
LVS-36-R-11	0.07519	0.06735	81.30	72.05
LVS-36-R-12	0.04684	0.06418	82.20	72.05
LVS-36-R-13	0.08155	0.07490	80.60	76.50
LVS-36-R-14	0.04366	0.04938	81.10	76.50
LVS-36-R-15	0.13272	0.07669	81.30	75.70
LVS-36-R-16	0.05850	0.06364	82.90	75.70
LVS-36-R-17	0.02603	0.06479	81.50	73.35
LVS-36-R-18	0.04808	0.07596	82.40	73.35
LVS-36-R-19	0.05777	0.07153	82.90	77.00
LVS-36-R-20	0.06370	0.07628	83.10	77.00
LVS-36-R-21	0.05043	0.07111	82.60	76.65
LVS-36-R-22	0.03981	0.07029	83.50	76.65
LVS-36-R-23	0.09905	0.07153	81.90	74.72
LVS-36-R-24	0.07294	0.07153	81.80	74.72
LVS-36-R-31	0.05606	0.05914	81.80	
LVS-36-R-32	0.13362	0.08843	83.10	
LVS-36-R-33	0.03763	0.06137	81.40	
LVS-36-R-34	0.03200	0.05867	81.40	
LVS-36-R-35	0.03213	0.05549	81.60	

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

HVI (Au 1998Continued)

ID	% White (30's)*	HVI	HVI	HVI
Study-original yarn size -Ring-ID #	Au98- % White (30's)*	Buckling Coeff L2/μ2	Uniformity Index	Rd
A98-36-R-1	0.00857	0.05935	81.00	77.00
A98-36-R-2	0.01263	0.05729	81.00	78.00
A98-36-R-3	0.02510	0.07406	80.30	82.00
A98-36-R-4	0.02601	0.07663	80.30	82.00
A98-36-R-5	0.01546	0.07153	82.00	83.00
A98-36-R-6	0.01915	0.07128	81.80	84.00
A98-36-R-7	0.02822	0.07806	81.00	83.00
A98-36-R-8	0.02859	0.07249	80.80	83.00
A98-36-R-9	0.02510	0.07384	81.00	83.00
A98-36-R-10	0.03111	0.07128	81.00	82.00
A98-36-R-11	0.03293	0.07813	81.50	82.00
A98-36-R-12	0.03447	0.07694	81.30	82.00
A98-36-R-13	0.02238	0.06143	81.80	73.00
A98-36-R-14	0.01199	0.06971	81.30	73.00
A98-36-R-15	0.04895	0.09959	82.80	83.00
A98-36-R-16	0.05215	0.09706	83.00	84.00
A98-36-R-17	0.01408	0.06310	82.70	83.00
A98-36-R-18	0.02097	0.06277	82.80	84.00
A98-36-R-19	0.04260	0.10373	81.30	74.00
A98-36-R-20	0.04889	0.09377	81.00	74.00
A98-36-R-21	0.01720	0.06739	82.00	82.00
A98-36-R-22	0.02423	0.06588	82.50	82.00
A98-36-R-23	0.03011	0.09296	81.30	75.00
A98-36-R-24	0.02543	0.08568	80.80	76.00
A98-36-R-25	0.00780	0.06195	82.00	82.00
A98-36-R-26	0.01986	0.06358	81.70	82.00
A98-36-R-27	0.02530	0.11898	82.00	83.00
A98-36-R-28	0.04902	0.11752	82.00	83.00
A98-36-R-29	0.03840	0.07467	81.50	85.00
A98-36-R-30	0.02651	0.07277	81.30	84.00

HVI (Au 1998Continued)

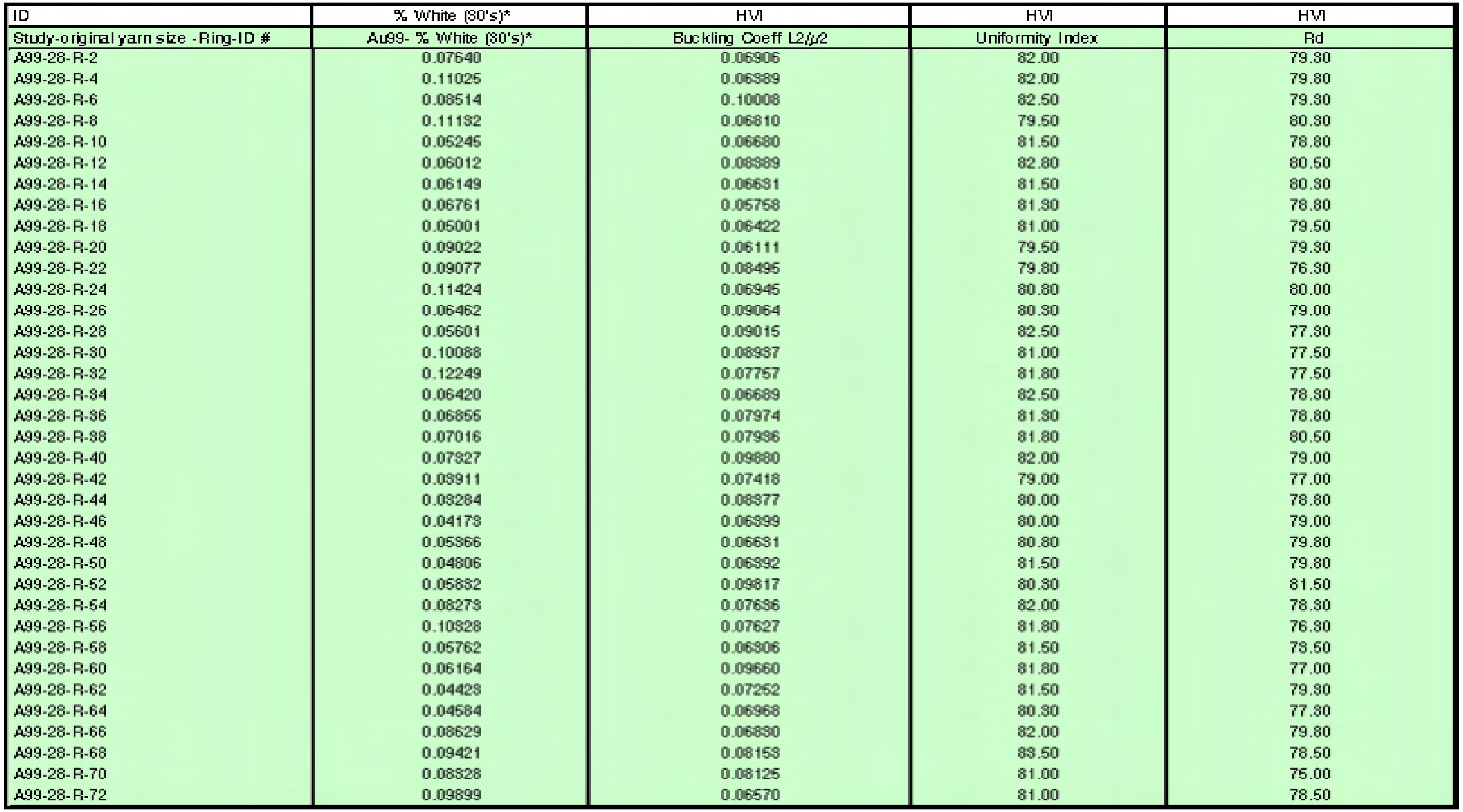
ID	% White (80's)*	HVI	HVI	HVI
Study-original yarn size -Ring-ID #	Au98- % White (80's)*	Buckling Coeff L2/µ2	Uniformity Index	Rd
A98-36-R-31	0.03047	0.08776	81.00	84.00
A98-36-R-32	0.02762	0.08465	81.30	85.00
A98-36-R-33	0.03091	0.08085	83.00	82.00
A98-36-R-34	0.03370	0.08213	82.50	82.00
A98-36-R-35	0.02624	0.07767	82.70	82.00
A98-36-R-36	0.02943	0.07531	83.00	83.00
A98-36-R-37	0.04358	0.07701	83.00	81.00
A98-36-R-38	0.05194	0.07867	82.30	81.00
A98-36-R-39	0.02567	0.07609	83.00	82.00
A98-36-R-40	0.03273	0.07794	82.00	82.00
A98-36-R-41	0.03891	0.08779	82.00	84.00
A98-36-R-42	0.04227	0.08039	81.80	84.00
A98-36-R-43	0.03182	0.07969	81.80	81.00
A98-36-R-44	0.02819	0.07651	81.00	81.00
A98-36-R-45	0.02960	0.07366	80.50	81.00
A98-36-R-46	0.04882	0.07460	79.80	80.00
A98-36-R-47	0.03783	0.08072	80.30	81.00
A98-36-R-48	0.03289	0.07282	80.00	81.00
A98-36-R-49	0.02722	0.06629	82.50	82.00
A98-36-R-50	0.02671	0.06700	82.00	82.00
A98-36-R-51	0.04079	0.09060	82.50	74.00
A98-36-R-52	0.05520	0.09467	83.00	73.00
A98-36-R-53	0.00998	0.06475	81.00	81.00
A98-36-R-54	0.02016	0.06340	80.80	81.00
A98-36-R-55	0.01784	0.05937	81.50	83.00
A98-36-R-56	0.02117	0.06222	81.30	83.00
A98-36-R-57	0.02879	0.08747	83.00	77.00
A98-36-R-58	0.04637	0.08612	83.00	78.00
A98-36-R-59	0.03820	0.08025	81.30	84.00
A98-36-R-60	0.03249	0.07559	81.50	84.00

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

HVI (Au 1999)

ID	% White (30's)*	HVI	HVI	HVI
Study-original yarn size -Ring-ID #	Au99- % White (30's)*	Buckling Coeff L2/μ2	Uniformity Index	Rd
A99-28-R-1	0.08830	0.07546	83.30	78.00
A99-28-R-3	0.11023	0.06018	82.30	77.00
A99-28-R-5	0.07548	0.09715	83.80	75.50
A99-28-R-7	0.07281	0.07252	81.30	78.00
A99-28-R-9	0.11186	0.06972	84.00	76.50
A99-28-R-11	0.11302	0.07934	82.80	77.00
A99-28-R-13	0.09263	0.06418	82.00	77.50
A99-28-R-15	0.07388	0.06203	82.00	76.50
A99-28-R-17	0.06398	0.06447	82.00	77.30
A99-28-R-19	0.07719	0.06256	81.30	77.30
A99-28-R-21	0.07205	0.09000	81.50	75.50
A99-28-R-23	0.08934	0.07215	81.50	77.30
A99-28-R-25	0.04554	0.09314	81.80	76.50
A99-28-R-27	0.06441	0.09306	83.30	75.00
A99-28-R-29	0.05710	0.09914	83.00	75.50
A99-28-R-31	0.05129	0.07853	82.80	75.50
A99-28-R-33	0.04770	0.06914	83.50	76.50
A99-28-R-35	0.06082	0.08195	82.80	77.00
A99-28-R-37	0.04508	0.08694	82.30	78.50
A99-28-R-39	0.05302	0.10695	83.80	75.50
A99-28-R-41	0.04770	0.07869	80.80	74.50
A99-28-R-43	0.04919	0.08470	81.50	76.50
A99-28-R-45	0.04274	0.06507	81.50	76.50
A99-28-R-47	0.04678	0.07315	82.30	77.30
A99-28-R-49	0.04538	0.06453	83.50	78.30
A99-28-R-51	0.04819	0.09829	81.30	79.30
A99-28-R-53	0.05080	0.07957	83.50	76.50
A99-28-R-55	0.06057	0.07644	82.50	73.80
A99-28-R-57	0.07817	0.06559	83.00	73.00
A99-28-R-59	0.10060	0.09712	82.30	73.80
A99-28-R-61	0.05248	0.07295	82.80	77.00
A99-28-R-63	0.06557	0.07071	82.30	73.80
A99-28-R-65	0.10912	0.06415	82.80	77.00
A99-28-R-67	0.09963	0.07966	83.80	75.50
A99-28-R-69	0.08706	0.08489	82.30	74.00
A99-28-R-71	0.12243	0.06968	83.80	76.50

HVI (Au 1999 Continued)



ID	% White (30's)*	HVI	HVI	HVI
Study-original yarn size -Ring-ID #	Au99- % White (30's)*	Buckling Coeff L2/μ2	Uniformity Index	Rd
A99-28-R-2	0.07640	0.06906	82.00	79.30
A99-28-R-4	0.11025	0.06389	82.00	79.80
A99-28-R-6	0.08514	0.10008	82.50	79.30
A99-28-R-8	0.11132	0.06810	79.50	80.30
A99-28-R-10	0.05245	0.06680	81.50	78.80
A99-28-R-12	0.06012	0.08389	82.80	80.50
A99-28-R-14	0.06149	0.06631	81.50	80.30
A99-28-R-16	0.06761	0.05758	81.30	78.80
A99-28-R-18	0.05001	0.06422	81.00	79.50
A99-28-R-20	0.09022	0.06111	79.50	79.30
A99-28-R-22	0.09077	0.08495	79.80	76.30
A99-28-R-24	0.11424	0.06945	80.80	80.00
A99-28-R-26	0.06462	0.09064	80.30	79.00
A99-28-R-28	0.05601	0.09015	82.50	77.30
A99-28-R-30	0.10088	0.08937	81.00	77.50
A99-28-R-32	0.12249	0.07757	81.80	77.50
A99-28-R-34	0.06420	0.06689	82.50	78.30
A99-28-R-36	0.06855	0.07974	81.30	78.80
A99-28-R-38	0.07016	0.07936	81.80	80.50
A99-28-R-40	0.07327	0.09880	82.00	79.00
A99-28-R-42	0.03911	0.07418	79.00	77.00
A99-28-R-44	0.03284	0.08377	80.00	78.80
A99-28-R-46	0.04173	0.06399	80.00	79.00
A99-28-R-48	0.05366	0.06631	80.80	79.80
A99-28-R-50	0.04806	0.06392	81.50	79.80
A99-28-R-52	0.05832	0.09817	80.30	81.50
A99-28-R-54	0.08273	0.07636	82.00	78.30
A99-28-R-56	0.10328	0.07627	81.80	76.30
A99-28-R-58	0.05762	0.06306	81.50	73.50
A99-28-R-60	0.06164	0.09660	81.80	77.00
A99-28-R-62	0.04423	0.07252	81.50	79.30
A99-28-R-64	0.04584	0.06968	80.30	77.30
A99-28-R-66	0.08629	0.06830	82.00	79.80
A99-28-R-68	0.09421	0.08153	83.50	78.50
A99-28-R-70	0.08328	0.08125	81.00	75.00
A99-28-R-72	0.09899	0.06570	81.00	78.50

AFIS Versions 2 & 4 (US 2001 & EVS)

ID	% White (30's)*	AFIS V-2	AFIS V-2	AFIS V-2		AFIS V-4	AFIS V-4	AFIS V-4
Study-original yarn size -Ring-ID #	US01 - % White (30's)*	Nep Count/gram	THETA CV	SFC(n)		Nep Count/gram	IFC	SFC(n)
US01-30-R-1	0.40908	614	45.53	15.10		738	6.90	32.50
US01-30-R-2	0.33331	684	44.97	14.40		494	6.40	30.50
US01-30-R-3	0.34087	602	44.88	15.10		491	6.60	32.50
US01-30-R-4	0.37124	525	45.99	18.60		674	6.50	33.80
US01-30-R-5	0.33093	822	47.04	15.40		550	6.50	30.50
US01-30-R-6	0.40826	408	47.62	15.90		522	7.10	33.70
US01-30-R-7	0.39370	770	48.43	15.10		567	7.00	31.00
US01-30-R-8	0.17014	670	42.58	12.90		368	6.20	30.90
US01-30-R-9	0.10476	446	44.64	20.20		272	5.10	29.30
US01-30-R-10	0.05218	280	41.25	18.00		219	4.70	27.20
US01-30-R-11	0.14379	193	44.78	17.00		258	5.00	29.60
US01-30-R-12	0.08867	387	43.80	21.10		305	5.20	29.60
US01-30-R-13	0.16903	261	44.13	17.10		332	5.60	31.70
US01-30-R-14	0.04439	366	40.82	18.10		226	5.00	32.50
US01-30-R-15	0.10657	244	44.72	21.40		307	5.20	32.30
US01-30-R-16	0.07388	222	42.00	17.30		243	4.30	24.10
US01-30-R-17	0.23903	258	45.76	18.10		403	5.40	26.50
US01-30-R-18	0.09719	358	43.43	17.70		270	4.80	24.90
US01-30-R-19	0.11065	323	42.26	16.80		278	5.00	28.80
US01-30-R-20	0.02802	337	40.12	18.70		190	4.40	27.90
US01-30-R-21	0.02518	253	38.14	14.30		177	2.70	17.90
	*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)							

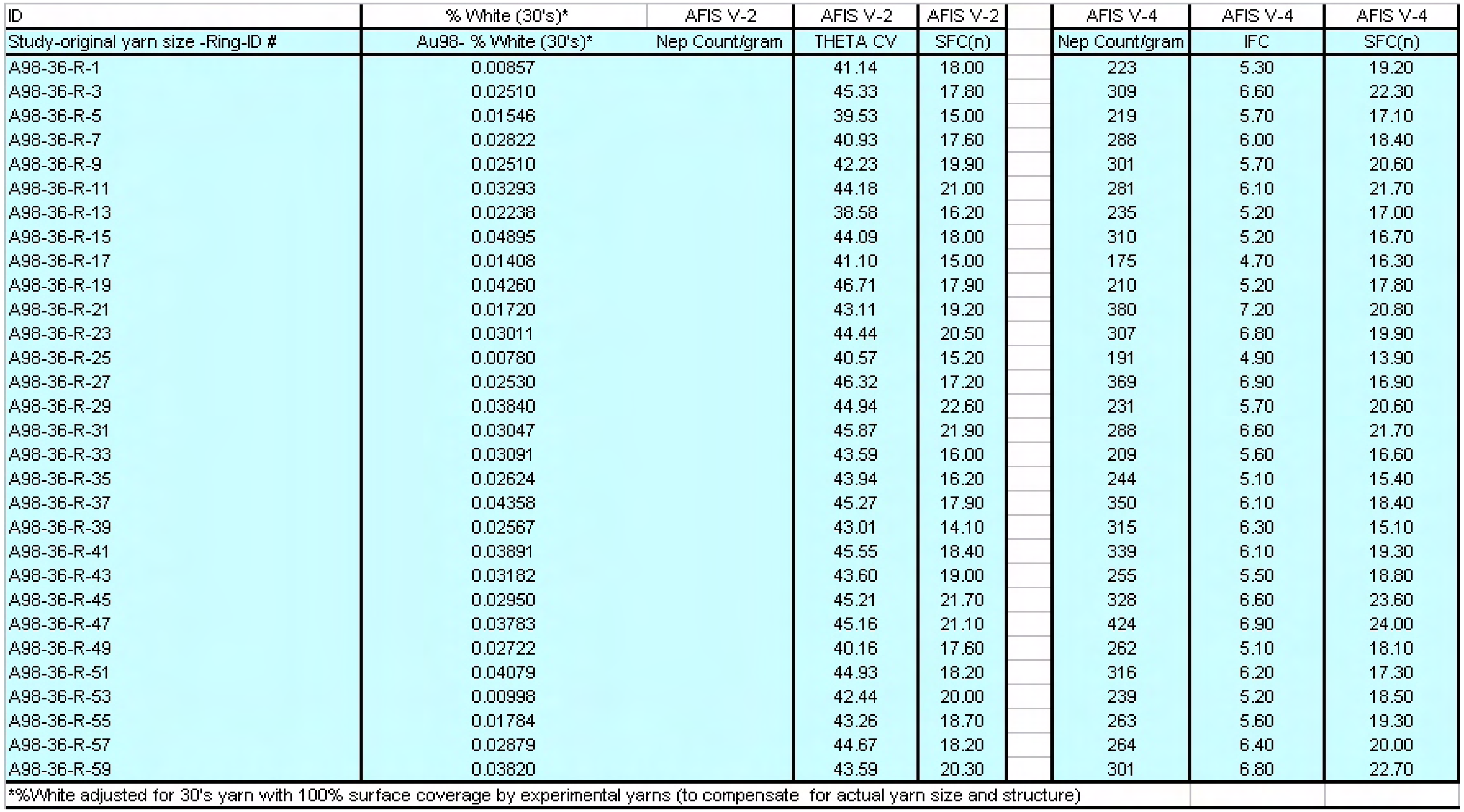
ID	% White (30's)*	AFIS V-2	AFIS V-2	AFIS V-2		AFIS V-4	AFIS V-4	AFIS V-4
Study-original yarn size -Ring-ID #	EVS- % White (30's)*	Nep Count/gram	THETA CV	SFC(n)		Nep Count/gram	IFC	SFC(n)
EVS-36-R-1	0.02189	219	39.40	15.38		291	5.88	11.22
EVS-36-R-2	0.09198	306	43.62	15.08		394	7.72	11.47
EVS-36-R-3	0.02927	276	42.30	18.25		361	6.73	17.37
EVS-36-R-4	0.10015	414	42.48	20.21		525	6.26	20.72
	*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)							

AFIS Versions 2 & 4 (LVS)

ID	% White (30's)*	AFIS V-2	AFIS V-2	AFIS V-2		AFIS V-4	AFIS V-4	AFIS V-4
Study-original yarn size -Ring-ID #	LVS- % White (30's)*	Nep Count/gram	THETA CV	SFC(n)		Nep Count/gram	IFC	SFC(n)
LVS-36-R-1	0.01585	202	44.45	24.75		177	169.77	17.82
LVS-36-R-2	0.04982	227	45.44	25.95		197	166.41	17.48
LVS-36-R-3	0.05452	318	44.04	26.75		279	165.99	17.92
LVS-36-R-4	0.04600	257	43.74	26.08		213	174.65	16.16
LVS-36-R-5	0.03756	304	45.08	29.98		264	171.83	17.22
LVS-36-R-6	0.03816	196	45.02	29.05		188	167.67	14.46
LVS-36-R-7	0.06490	284	45.86	26.47		284	162.47	12.93
LVS-36-R-8	0.07660	297	44.88	26.73		257	165.53	15.27
LVS-36-R-9	0.02282	237	41.83	26.05		207	169.91	11.68
LVS-36-R-10	0.03016	205	42.65	28.95		174	171.08	17.23
LVS-36-R-11	0.07519	325	46.55	28.13		281	166.20	16.80
LVS-36-R-12	0.04684	272	43.75	24.08		230	172.10	15.54
LVS-36-R-13	0.08155	403	42.88	20.25		353	160.25	13.80
LVS-36-R-14	0.04366	274	40.48	19.45		270	171.28	15.37
LVS-36-R-15	0.13272	363	44.17	18.23		344	158.59	17.50
LVS-36-R-16	0.05850	214	43.41	21.07		214	166.67	13.08
LVS-36-R-17	0.02603	226	41.64	25.88		186	170.76	14.65
LVS-36-R-18	0.04808	235	44.67	27.58		198	165.66	13.90
LVS-36-R-19	0.05777	221	46.37	23.05		192	159.68	13.54
LVS-36-R-20	0.06370	242	43.81	27.80		216	159.50	14.57
LVS-36-R-21	0.05043	266	44.61	22.50		228	154.26	13.78
LVS-36-R-22	0.03981	266	42.89	22.30		224	154.60	15.55
LVS-36-R-23	0.09905	310	45.87	27.35		262	170.50	22.04
LVS-36-R-24	0.07294	309	45.56	26.73		265	167.08	17.66
LVS-36-R-31	0.05606	305	43.85	27.70		320	153.12	15.54
LVS-36-R-32	0.13362	382	46.74	23.58		393	168.07	18.04
LVS-36-R-33	0.03763	377	41.75	28.08		385	164.24	17.45
LVS-36-R-34	0.03200	251	42.13	26.48		322	161.95	13.78
LVS-36-R-35	0.03213	328	43.38	26.90		337	167.43	19.48

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

AFIS Versions 2 & 4 (Au 1998)



ID	% White (30's)*	AFIS V-2	AFIS V-2	AFIS V-2		AFIS V-4	AFIS V-4	AFIS V-4
Study-original yarn size -Ring-ID #	Au98- % White (30's)*	Nep Count/gram	THETA CV	SFC(n)		Nep Count/gram	IFC	SFC(n)
A98-36-R-1	0.00857		41.14	18.00		223	5.30	19.20
A98-36-R-3	0.02510		45.33	17.80		309	6.60	22.30
A98-36-R-5	0.01546		39.53	15.00		219	5.70	17.10
A98-36-R-7	0.02822		40.93	17.60		288	6.00	18.40
A98-36-R-9	0.02510		42.23	19.90		301	5.70	20.60
A98-36-R-11	0.03293		44.18	21.00		281	6.10	21.70
A98-36-R-13	0.02238		38.58	16.20		235	5.20	17.00
A98-36-R-15	0.04895		44.09	18.00		310	5.20	16.70
A98-36-R-17	0.01408		41.10	15.00		175	4.70	16.30
A98-36-R-19	0.04260		46.71	17.90		210	5.20	17.80
A98-36-R-21	0.01720		43.11	19.20		380	7.20	20.80
A98-36-R-23	0.03011		44.44	20.50		307	6.80	19.90
A98-36-R-25	0.00780		40.57	15.20		191	4.90	13.90
A98-36-R-27	0.02530		46.32	17.20		369	6.90	16.90
A98-36-R-29	0.03840		44.94	22.60		231	5.70	20.60
A98-36-R-31	0.03047		45.87	21.90		288	6.60	21.70
A98-36-R-33	0.03091		43.59	16.00		209	5.60	16.60
A98-36-R-35	0.02624		43.94	16.20		244	5.10	15.40
A98-36-R-37	0.04358		45.27	17.90		350	6.10	18.40
A98-36-R-39	0.02567		43.01	14.10		315	6.30	15.10
A98-36-R-41	0.03891		45.55	18.40		339	6.10	19.30
A98-36-R-43	0.03182		43.60	19.00		255	5.50	18.80
A98-36-R-45	0.02950		45.21	21.70		328	6.60	23.60
A98-36-R-47	0.03783		45.16	21.10		424	6.90	24.00
A98-36-R-49	0.02722		40.16	17.60		262	5.10	18.10
A98-36-R-51	0.04079		44.93	18.20		316	6.20	17.30
A98-36-R-53	0.00998		42.44	20.00		239	5.20	18.50
A98-36-R-55	0.01784		43.26	18.70		263	5.60	19.30
A98-36-R-57	0.02879		44.67	18.20		264	6.40	20.00
A98-36-R-59	0.03820		43.59	20.30		301	6.80	22.70

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

AFIS Versions 2 & 4 (Au 1998 Continued*)*

ID	% White (30's)*	AFIS V-2	AFIS V-2	AFIS V-2		AFIS V-4	AFIS V-4	AFIS V-4
Study-original yarn size -Ring-ID #	Au98- % White (30's)*	Nep Count/gram	THETA CV	SFC(n)		Nep Count/gram	IFC	SFC(n)
A98-36-R-2	0.01263		42.39	19.10		292	5.50	20.00
A98-36-R-4	0.02601		45.09	18.00		398	6.60	21.90
A98-36-R-6	0.01915		41.93	17.80		286	5.50	18.30
A98-36-R-8	0.02859		41.83	18.50		356	6.30	21.70
A98-36-R-10	0.03111		42.87	22.30		303	5.90	22.00
A98-36-R-12	0.03447		43.49	20.90		395	6.30	21.10
A98-36-R-14	0.01199		39.95	17.20		288	6.40	20.20
A98-36-R-16	0.05215		44.34	18.10		355	6.00	17.60
A98-36-R-18	0.02097		41.90	17.10		211	4.90	14.90
A98-36-R-20	0.04889		47.42	19.10		260	6.70	17.40
A98-36-R-22	0.02423		42.69	18.50		288	4.70	17.20
A98-36-R-24	0.02543		46.00	22.40		311	6.70	20.30
A98-36-R-26	0.01986		42.38	16.80		238	4.90	14.80
A98-36-R-28	0.04902		47.03	18.20		372	7.10	17.70
A98-36-R-30	0.02651		44.15	20.60		310	6.40	21.00
A98-36-R-32	0.02762		45.70	22.30		417	6.80	21.20
A98-36-R-34	0.03370		44.37	16.30		292	5.50	17.30
A98-36-R-36	0.02943		42.86	15.90		309	5.40	17.20
A98-36-R-38	0.05194		43.96	16.20		440	6.40	18.90
A98-36-R-40	0.03273		44.29	15.10		325	5.90	16.50
A98-36-R-42	0.04227		44.38	19.40		373	5.70	19.10
A98-36-R-44	0.02819		45.54	20.60		377	6.00	20.00
A98-36-R-46	0.04882		47.05	23.40		336	6.80	25.20
A98-36-R-48	0.03239		45.78	23.40		374	6.90	24.30
A98-36-R-50	0.02671		40.78	19.00		272	5.20	18.30
A98-36-R-54	0.02016		44.23	21.80		319	6.00	19.60
A98-36-R-56	0.02117		43.96	20.00		293	6.40	22.00
A98-36-R-58	0.04637		45.54	19.60		322	6.60	20.90
A98-36-R-60	0.03249		42.99	20.50		357	5.90	20.20

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

AFIS Versions 2 & 4 (Au 1999)

ID	% White (30's)*	AFIS V-2	AFIS V-2	AFIS V-2		AFIS V-4	AFIS V-4	AFIS V-4
Study-original yarn size -Ring-ID #	Au99- % White (30's)*	Nep Count/gram	THETA CV	SFC(n)		Nep Count/gram	IFC	SFC(n)
A99-28-R-1	0.08830		43.45	17.20		265	6.10	17.00
A99-28-R-5	0.07548		42.42	19.60		297	6.20	22.90
A99-28-R-9	0.11186		44.94	19.40		393	7.30	23.00
A99-28-R-13	0.09263		42.10	22.90		270	6.90	26.20
A99-28-R-17	0.06398		44.96	20.40		285	6.40	23.00
A99-28-R-21	0.07205		44.41	19.90		337	6.50	24.10
A99-28-R-25	0.04554		44.19	20.30		236	6.30	22.10
A99-28-R-29	0.05710		43.70	20.60		138	6.30	23.70
A99-28-R-33	0.04770		44.91	20.60		273	6.90	26.00
A99-28-R-37	0.04508		43.90	20.10		170	5.50	19.90
A99-28-R-41	0.04770		42.55	21.60		206	5.80	22.70
A99-28-R-45	0.04274		42.20	20.10		261	5.50	21.70
A99-28-R-49	0.04538		43.52	18.20		239	5.90	20.90
A99-28-R-53	0.05080		42.83	22.50		263	6.60	28.20
A99-28-R-57	0.07817		45.32	20.40		345	6.80	24.50
A99-28-R-61	0.05248		42.80	21.30		243	6.00	24.80
A99-28-R-65	0.10912		48.11	23.20		327	7.40	28.30
A99-28-R-69	0.08706		45.38	19.40		233	6.80	22.20
A99-28-R-2	0.07640		47.27	19.30		329	6.80	21.10
A99-28-R-6	0.08514		47.27	21.20		268	7.00	22.80
A99-28-R-10	0.05245		45.96	21.40		246	6.30	21.50
A99-28-R-14	0.06149		46.18	22.30		225	6.20	21.40
A99-28-R-18	0.05001		45.19	20.20		260	6.90	21.50
A99-28-R-22	0.09077		44.44	23.40		298	6.80	26.90
A99-28-R-26	0.06462		45.29	20.10		248	6.70	25.70
A99-28-R-30	0.10088		43.51	18.50		318	6.40	23.10
A99-28-R-34	0.06420		42.87	21.60		275	6.10	26.00
A99-28-R-38	0.07016		42.51	20.40		257	6.30	24.10
A99-28-R-42	0.03911		39.92	21.50		268	5.30	24.10
A99-28-R-46	0.04173		43.21	19.90		237	5.30	21.40
A99-28-R-50	0.04806		42.95	20.20		211	5.00	18.40
A99-28-R-54	0.08273		46.78	18.20		254	5.30	17.20
A99-28-R-58	0.05762		45.36	20.50		309	6.20	20.90
A99-28-R-62	0.04423		44.36	22.30		198	5.50	20.80
A99-28-R-66	0.08629		44.08	22.70		336	6.20	22.70
A99-28-R-70	0.08328		45.18	22.20		290	6.50	22.90

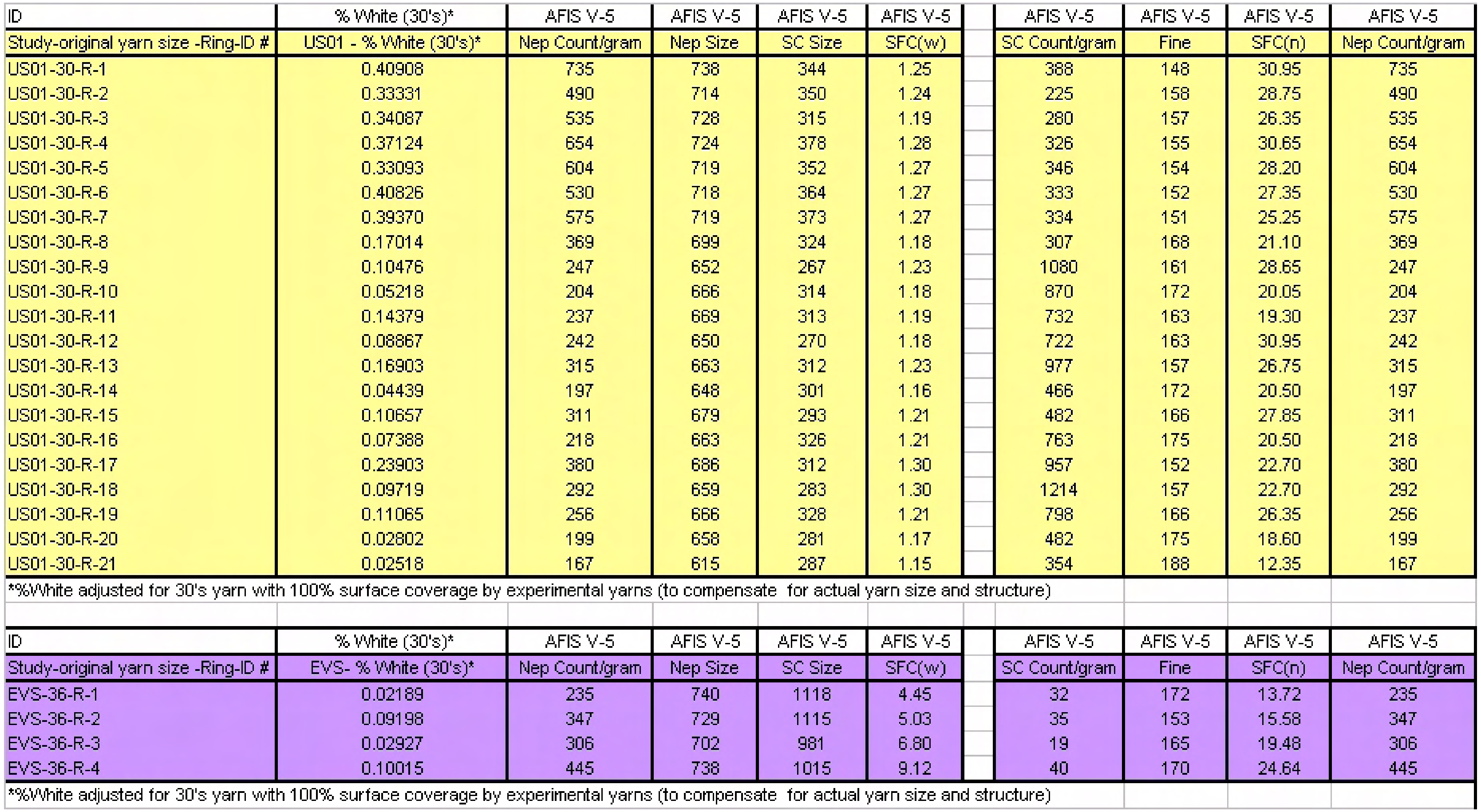
*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

AFIS Versions 2 & 4 (Au 1999 Continued)

ID	% White (30's)*	AFIS V-2	AFIS V-2	AFIS V-2		AFIS V-4	AFIS V-4	AFIS V-4
Study-original yarn size -Ring-ID #	Au99- % White (30's)*	Nep Count/gram	THETA CV	SFC(n)		Nep Count/gram	IFC	SFC(n)
A99-28-R-3	0.11023		44.27	19.00		356	6.60	20.40
A99-28-R-7	0.07281		44.77	18.40		316	7.40	23.20
A99-28-R-11	0.11302		46.80	19.50		529	8.60	23.80
A99-28-R-15	0.07388		44.84	23.20		434	7.20	27.10
A99-28-R-19	0.07719		45.88	19.50		402	7.10	24.60
A99-28-R-23	0.08934		44.62	18.60		387	7.70	22.10
A99-28-R-27	0.06441		45.41	19.90		297	7.40	24.20
A99-28-R-31	0.05129		45.69	22.10		305	7.20	25.50
A99-28-R-35	0.06082		46.03	20.80		276	7.60	27.60
A99-28-R-39	0.05302		46.50	19.60		276	7.20	24.60
A99-28-R-43	0.04919		45.50	23.30		300	6.60	25.10
A99-28-R-47	0.04678		43.68	20.80		301	6.60	22.20
A99-28-R-51	0.04819		45.48	20.30		343	6.80	23.30
A99-28-R-55	0.06057		44.33	22.20		298	7.00	29.20
A99-28-R-59	0.10060		46.92	22.30		475	7.90	28.70
A99-28-R-63	0.06557		46.41	24.70		317	6.70	26.90
A99-28-R-67	0.09963		49.82	24.10		428	7.00	21.00
A99-28-R-71	0.12243		48.05	22.40		385	7.10	22.50
A99-28-R-4	0.11025		49.60	19.80		355	7.70	26.20
A99-28-R-8	0.11132		48.84	21.50		362	7.30	26.10
A99-28-R-12	0.06012		47.96	21.60		316	7.40	27.30
A99-28-R-16	0.06761		47.24	21.20		269	6.40	25.10
A99-28-R-20	0.09022		47.47	21.30		313	7.30	26.80
A99-28-R-24	0.11424		47.16	23.10		402	7.80	30.70
A99-28-R-28	0.05601		47.18	22.40		299	6.50	28.10
A99-28-R-32	0.12249		48.18	22.00		421	6.90	26.20
A99-28-R-36	0.06855		45.07	21.40		347	6.90	27.60
A99-28-R-40	0.07327		46.29	22.60		359	7.10	28.90
A99-28-R-44	0.03284		43.93	24.00		318	6.20	25.90
A99-28-R-48	0.05366		44.51	19.90		250	5.90	22.50
A99-28-R-52	0.05832		45.37	19.50		252	5.40	20.80
A99-28-R-56	0.10328		48.02	19.80		312	6.70	24.00
A99-28-R-60	0.06164		47.83	21.00		378	6.90	22.80
A99-28-R-64	0.04584		45.21	21.50		291	5.60	22.60
A99-28-R-68	0.09421		47.37	24.90		430	6.80	24.80
A99-28-R-72	0.09899		48.02	23.50		403	7.10	24.20

***%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)**

AFIS-V5 (US 2001 & EVS)



ID	% White (30's)*	AFIS V-5	AFIS V-5	AFIS V-5	AFIS V-5		AFIS V-5	AFIS V-5	AFIS V-5	AFIS V-5
Study-original yarn size -Ring-ID #	US01 - % White (30's)*	Nep Count/gram	Nep Size	SC Size	SFC(w)		SC Count/gram	Fine	SFC(n)	Nep Count/gram
US01-30-R-1	0.40908	735	738	344	1.25		388	148	30.95	735
US01-30-R-2	0.33331	490	714	350	1.24		225	158	28.75	490
US01-30-R-3	0.34087	535	728	315	1.19		280	157	26.35	535
US01-30-R-4	0.37124	654	724	378	1.28		326	155	30.65	654
US01-30-R-5	0.33093	604	719	352	1.27		346	154	28.20	604
US01-30-R-6	0.40826	530	718	364	1.27		333	152	27.35	530
US01-30-R-7	0.39370	575	719	373	1.27		334	151	25.25	575
US01-30-R-8	0.17014	369	699	324	1.18		307	168	21.10	369
US01-30-R-9	0.10476	247	652	267	1.23		1080	161	28.65	247
US01-30-R-10	0.05218	204	666	314	1.18		870	172	20.05	204
US01-30-R-11	0.14379	237	669	313	1.19		732	163	19.30	237
US01-30-R-12	0.08867	242	650	270	1.18		722	163	30.95	242
US01-30-R-13	0.16903	315	663	312	1.23		977	157	26.75	315
US01-30-R-14	0.04439	197	648	301	1.16		466	172	20.50	197
US01-30-R-15	0.10657	311	679	293	1.21		482	166	27.85	311
US01-30-R-16	0.07388	218	663	326	1.21		763	175	20.50	218
US01-30-R-17	0.23903	380	686	312	1.30		957	152	22.70	380
US01-30-R-18	0.09719	292	659	283	1.30		1214	157	22.70	292
US01-30-R-19	0.11065	256	666	328	1.21		798	166	26.35	256
US01-30-R-20	0.02802	199	658	281	1.17		482	175	18.60	199
US01-30-R-21	0.02518	167	615	287	1.15		354	188	12.35	167

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

ID	% White (30's)*	AFIS V-5	AFIS V-5	AFIS V-5	AFIS V-5		AFIS V-5	AFIS V-5	AFIS V-5	AFIS V-5
Study-original yarn size -Ring-ID #	EVS- % White (30's)*	Nep Count/gram	Nep Size	SC Size	SFC(w)		SC Count/gram	Fine	SFC(n)	Nep Count/gram
EVS-36-R-1	0.02189	235	740	1118	4.45		32	172	13.72	235
EVS-36-R-2	0.09198	347	729	1115	5.03		35	153	15.58	347
EVS-36-R-3	0.02927	306	702	981	6.80		19	165	19.48	306
EVS-36-R-4	0.10015	445	738	1015	9.12		40	170	24.64	445

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

AFIS-V5 - Au98

ID	% White (30's)*	AFIS V-5	AFIS V-5	AFIS V-5	AFIS V-5		AFIS V-5	AFIS V-5	AFIS V-5	AFIS V-5
Study-original yarn size -Ring-ID #	Au98- % White (30's)*	Nep Count/gram	Nep Size	SC Size	SFC(w)		SC Count/gram	Fine	SFC(n)	Nep Count/gram
A98-36-R-1	0.00857	206	756	946	11.10		20	179	27.70	206
A98-36-R-3	0.02510	260	758	990	11.80		14	168	29.70	260
A98-36-R-5	0.01546	177	750	1106	8.40		15	169	22.60	177
A98-36-R-7	0.02822	242	751	986	11.40		16	162	28.30	242
A98-36-R-9	0.02510	249	774	1047	10.50		27	166	27.70	249
A98-36-R-11	0.03293	277	755	983	11.80		22	164	30.20	277
A98-36-R-13	0.02238	182	749	925	8.60		16	168	23.00	182
A98-36-R-15	0.04895	277	759	935	10.70		13	157	28.80	277
A98-36-R-17	0.01408	174	740	952	7.50		10	172	21.50	174
A98-36-R-19	0.04260	251	755	928	10.70		16	158	27.30	251
A98-36-R-21	0.01720	193	748	973	9.40		12	169	25.10	193
A98-36-R-23	0.03011	240	753	898	11.60		15	161	30.20	240
A98-36-R-25	0.00780	184	771	1075	8.20		21	171	22.30	184
A98-36-R-27	0.02530	311	752	897	10.40		19	152	27.20	311
A98-36-R-29	0.03840	263	752	889	12.20		12	167	30.90	263
A98-36-R-31	0.03047	280	749	959	11.80		15	158	29.30	280
A98-36-R-33	0.03091	247	762	1075	7.20		27	164	21.40	247
A98-36-R-35	0.02624	219	751	962	7.50		12	167	21.60	219
A98-36-R-37	0.04358	249	758	955	10.00		18	166	26.70	249
A98-36-R-39	0.02567	203	746	1050	8.90		13	161	23.20	203
A98-36-R-41	0.03891	271	756	927	10.40		16	159	27.50	271
A98-36-R-43	0.03182	227	758	963	9.70		16	167	26.40	227
A98-36-R-45	0.02950	286	748	1036	12.40		15	165	30.80	286
A98-36-R-47	0.03783	299	762	968	12.10		27	158	30.70	299
A98-36-R-49	0.02722	230	769	1042	8.20		19	164	21.80	230
A98-36-R-51	0.04079	319	768	1057	8.90		26	159	24.80	319
A98-36-R-53	0.00998	221	756	932	10.00		18	172	26.10	221
A98-36-R-55	0.01784	212	758	1007	10.30		23	168	26.10	212
A98-36-R-57	0.02879	253	763	1126	9.70		22	160	26.20	253
A98-36-R-59	0.03820	279	747	933	10.50		18	164	27.30	279

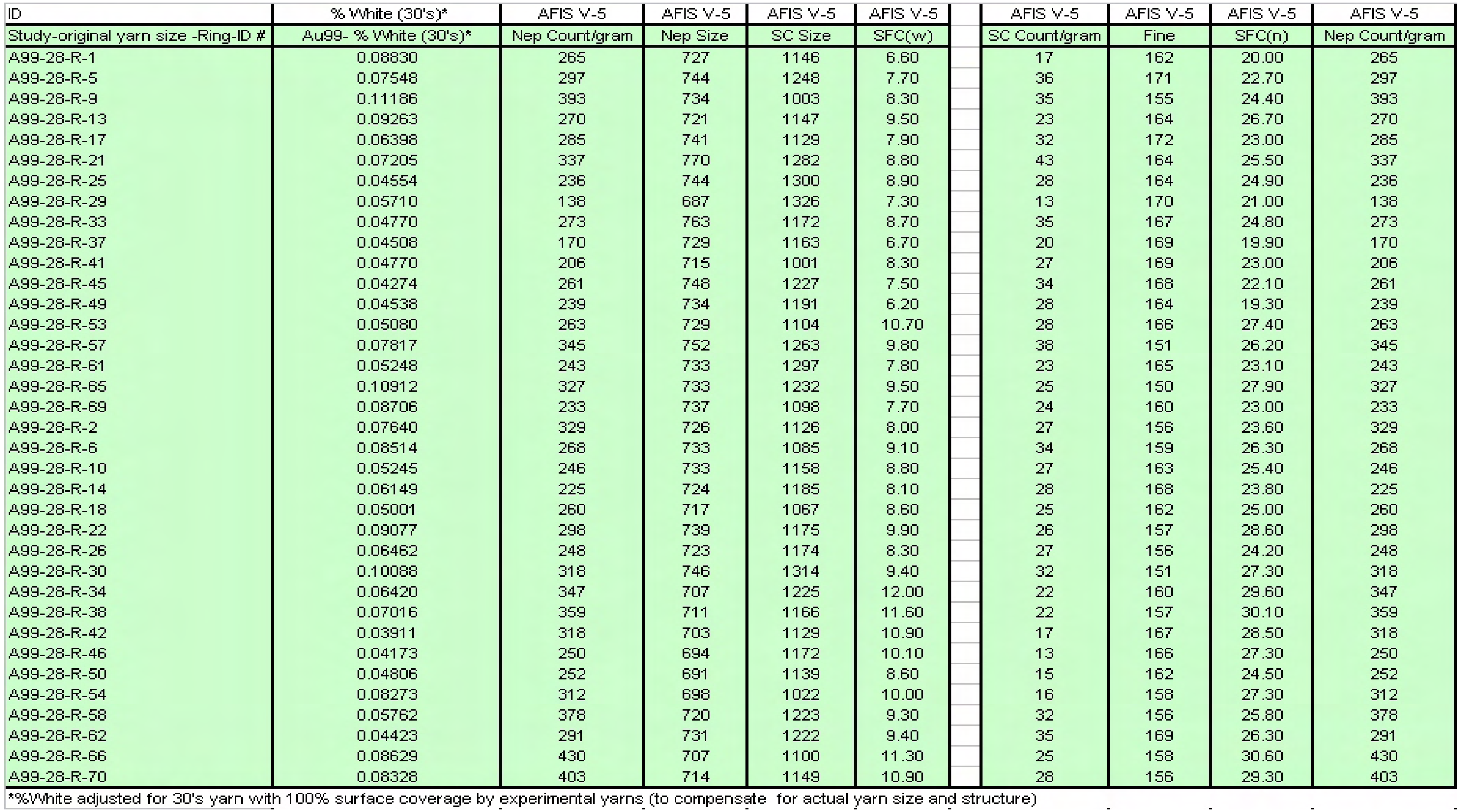
*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

AFIS Versions 5 (Au 1998 Continued)

ID	% White (30's)*	AFIS V-5	AFIS V-5	AFIS V-5	AFIS V-5		AFIS V-5	AFIS V-5	AFIS V-5	AFIS V-5
Study-original yarn size -Ring-ID #	Au98- % White (30's)*	Nep Count/gram	Nep Size	SC Size	SFC(w)		SC Count/gram	Fine	SFC(n)	Nep Count/gram
A98-36-R-2	0.01263	241	759	1127	12.00		15	176	30.10	241
A98-36-R-4	0.02601	329	760	1016	11.10		19	167	28.60	329
A98-36-R-6	0.01915	267	746	932	10.90		17	165	27.70	267
A98-36-R-8	0.02859	316	764	1022	12.70		22	165	30.60	316
A98-36-R-10	0.03111	299	746	931	10.70		15	167	27.90	299
A98-36-R-12	0.03447	373	760	972	11.70		33	162	30.20	373
A98-36-R-14	0.01199	275	751	943	8.60		25	168	23.20	275
A98-36-R-16	0.05215	349	761	1036	9.50		20	159	26.60	349
A98-36-R-18	0.02097	228	769	963	9.10		33	171	24.90	228
A98-36-R-20	0.04889	289	753	965	12.40		21	160	30.40	289
A98-36-R-22	0.02423	233	751	1028	8.50		16	170	23.60	233
A98-36-R-24	0.02543	297	741	855	11.10		18	162	28.70	297
A98-36-R-26	0.01986	214	749	973	7.90		14	171	21.30	214
A98-36-R-28	0.04902	402	744	891	9.60		21	156	25.50	402
A98-36-R-30	0.02651	321	753	1000	12.00		19	165	30.40	321
A98-36-R-32	0.02762	385	755	913	11.10		15	163	28.10	385
A98-36-R-34	0.03370	298	754	960	8.80		27	166	24.10	298
A98-36-R-36	0.02943	269	757	1032	8.50		21	170	24.00	269
A98-36-R-38	0.05194	307	752	929	11.10		22	161	29.00	307
A98-36-R-40	0.03273	259	740	884	9.20		20	165	24.10	259
A98-36-R-42	0.04227	323	754	930	9.40		19	163	25.60	323
A98-36-R-44	0.02819	315	755	1123	10.10		19	161	27.10	315
A98-36-R-46	0.04882	397	748	947	13.00		15	166	32.10	397
A98-36-R-48	0.03239	360	751	1066	12.70		14	163	31.50	360
A98-36-R-50	0.02671	257	754	1026	9.20		11	167	23.80	257
A98-36-R-54	0.02016	253	771	1015	11.20		29	167	28.10	253
A98-36-R-56	0.02117	293	755	977	11.20		27	170	28.10	293
A98-36-R-58	0.04637	333	763	997	8.90		27	159	24.20	333
A98-36-R-60	0.03249	339	762	987	10.10		23	165	26.80	339

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

AFIS-V5 – Au99



ID	% White (30's)*	AFIS V-5	AFIS V-5	AFIS V-5	AFIS V-5		AFIS V-5	AFIS V-5	AFIS V-5	AFIS V-5
Study-original yarn size -Ring-ID #	Au99- % White (30's)*	Nep Count/gram	Nep Size	SC Size	SFC(w)		SC Count/gram	Fine	SFC(n)	Nep Count/gram
A99-28-R-1	0.08830	265	727	1146	6.60		17	162	20.00	265
A99-28-R-5	0.07548	297	744	1248	7.70		36	171	22.70	297
A99-28-R-9	0.11186	393	734	1003	8.30		35	155	24.40	393
A99-28-R-13	0.09263	270	721	1147	9.50		23	164	26.70	270
A99-28-R-17	0.06398	285	741	1129	7.90		32	172	23.00	285
A99-28-R-21	0.07205	337	770	1282	8.80		43	164	25.50	337
A99-28-R-25	0.04554	236	744	1300	8.90		28	164	24.90	236
A99-28-R-29	0.05710	138	687	1326	7.30		13	170	21.00	138
A99-28-R-33	0.04770	273	763	1172	8.70		35	167	24.80	273
A99-28-R-37	0.04508	170	729	1163	6.70		20	169	19.90	170
A99-28-R-41	0.04770	206	715	1001	8.30		27	169	23.00	206
A99-28-R-45	0.04274	261	748	1227	7.50		34	168	22.10	261
A99-28-R-49	0.04538	239	734	1191	6.20		28	164	19.30	239
A99-28-R-53	0.05080	263	729	1104	10.70		28	166	27.40	263
A99-28-R-57	0.07817	345	752	1263	9.80		38	151	26.20	345
A99-28-R-61	0.05248	243	733	1297	7.80		23	165	23.10	243
A99-28-R-65	0.10912	327	733	1232	9.50		25	150	27.90	327
A99-28-R-69	0.08706	233	737	1098	7.70		24	160	23.00	233
A99-28-R-2	0.07640	329	726	1126	8.00		27	156	23.60	329
A99-28-R-6	0.08514	268	733	1085	9.10		34	159	26.30	268
A99-28-R-10	0.05245	246	733	1158	8.80		27	163	25.40	246
A99-28-R-14	0.06149	225	724	1185	8.10		28	168	23.80	225
A99-28-R-18	0.05001	260	717	1067	8.60		25	162	25.00	260
A99-28-R-22	0.09077	298	739	1175	9.90		26	157	28.60	298
A99-28-R-26	0.06462	248	723	1174	8.30		27	156	24.20	248
A99-28-R-30	0.10088	318	746	1314	9.40		32	151	27.30	318
A99-28-R-34	0.06420	347	707	1225	12.00		22	160	29.60	347
A99-28-R-38	0.07016	359	711	1166	11.60		22	157	30.10	359
A99-28-R-42	0.03911	318	703	1129	10.90		17	167	28.50	318
A99-28-R-46	0.04173	250	694	1172	10.10		13	166	27.30	250
A99-28-R-50	0.04806	252	691	1139	8.60		15	162	24.50	252
A99-28-R-54	0.08273	312	698	1022	10.00		16	158	27.30	312
A99-28-R-58	0.05762	378	720	1223	9.30		32	156	25.80	378
A99-28-R-62	0.04423	291	731	1222	9.40		35	169	26.30	291
A99-28-R-66	0.08629	430	707	1100	11.30		25	158	30.60	430
A99-28-R-70	0.08328	403	714	1149	10.90		28	156	29.30	403

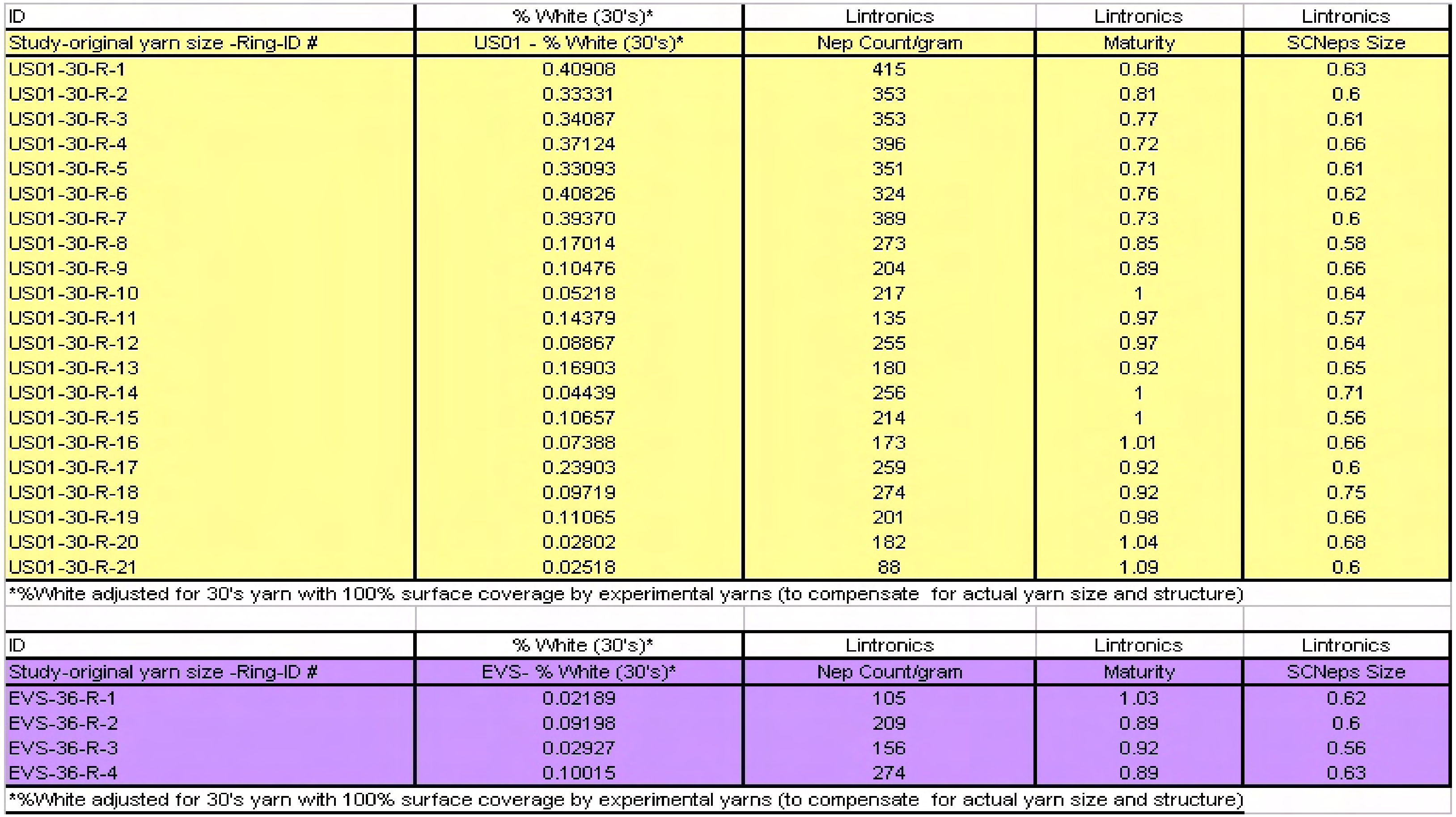
*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

AFIS Versions 5 (Au 1999 Continued)

ID	% White (30's)*	AFIS V-5	AFIS V-5	AFIS V-5	AFIS V-5		AFIS V-5	AFIS V-5	AFIS V-5	AFIS V-5
Study-original yarn size -Ring-ID #	Au99- % White (30's)*	Nep Count/gram	Nep Size	SC Size	SFC(w)		SC Count/gram	Fine	SFC(n)	Nep Count/gram
A99-28-R-3	0.11023	356	679	1134	8.40		20	160	24.30	356
A99-28-R-7	0.07281	316	692	1067	7.80		21	163	23.10	316
A99-28-R-11	0.11302	529	738	1179	9.40		46	150	26.50	529
A99-28-R-15	0.07388	434	744	1199	12.10		46	165	32.40	434
A99-28-R-19	0.07719	402	717	1086	8.50		43	165	24.60	402
A99-28-R-23	0.08934	387	697	1039	8.50		32	160	25.50	387
A99-28-R-27	0.06441	297	718	1177	9.50		27	162	26.20	297
A99-28-R-31	0.05129	305	720	1173	10.20		29	168	28.50	305
A99-28-R-35	0.06082	276	711	1136	8.80		25	166	24.40	276
A99-28-R-39	0.05302	276	711	1130	7.60		21	164	22.30	276
A99-28-R-43	0.04919	300	698	1139	8.80		23	167	25.00	300
A99-28-R-47	0.04678	301	729	1236	7.00		33	163	21.20	301
A99-28-R-51	0.04819	343	718	1159	8.20		34	163	23.90	343
A99-28-R-55	0.06057	298	706	1182	11.10		24	164	28.10	298
A99-28-R-59	0.10060	475	733	1203	11.20		41	157	29.20	475
A99-28-R-63	0.06557	317	688	1322	10.60		15	159	28.10	317
A99-28-R-67	0.09963	428	741	1168	13.70		35	153	35.10	428
A99-28-R-71	0.12243	385	709	1074	9.70		27	153	27.30	385
A99-28-R-4	0.11025	355	715	1119	11.10		32	158	29.50	355
A99-28-R-8	0.11132	362	711	1088	10.70		33	157	29.30	362
A99-28-R-12	0.06012	316	715	1198	11.50		22	158	30.70	316
A99-28-R-16	0.06761	269	691	1097	9.80		16	164	27.80	269
A99-28-R-20	0.09022	313	721	1199	10.70		21	158	29.10	313
A99-28-R-24	0.11424	402	718	1095	11.90		38	157	32.30	402
A99-28-R-28	0.05601	299	699	1249	11.30		20	160	30.00	299
A99-28-R-32	0.12249	275	746	1289	10.30		32	149	25.90	275
A99-28-R-36	0.06855	257	716	1168	9.80		20	155	26.60	257
A99-28-R-40	0.07327	268	707	1325	10.50		23	155	27.30	268
A99-28-R-44	0.03284	237	725	1228	8.80		25	163	24.80	237
A99-28-R-48	0.05366	211	711	1307	8.30		12	161	23.90	211
A99-28-R-52	0.05832	254	713	1048	7.40		15	163	22.30	254
A99-28-R-56	0.10328	309	718	1162	8.90		23	155	24.60	309
A99-28-R-60	0.06164	198	720	1198	6.90		22	154	21.40	198
A99-28-R-64	0.04584	336	737	1095	9.40		39	166	27.60	336
A99-28-R-68	0.09421	290	704	1213	10.10		14	152	27.80	290
A99-28-R-72	0.09899	421	717	1160	29.30		33	151	2.07	421

***%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)**

Lintronics (US 2001 & EVS)



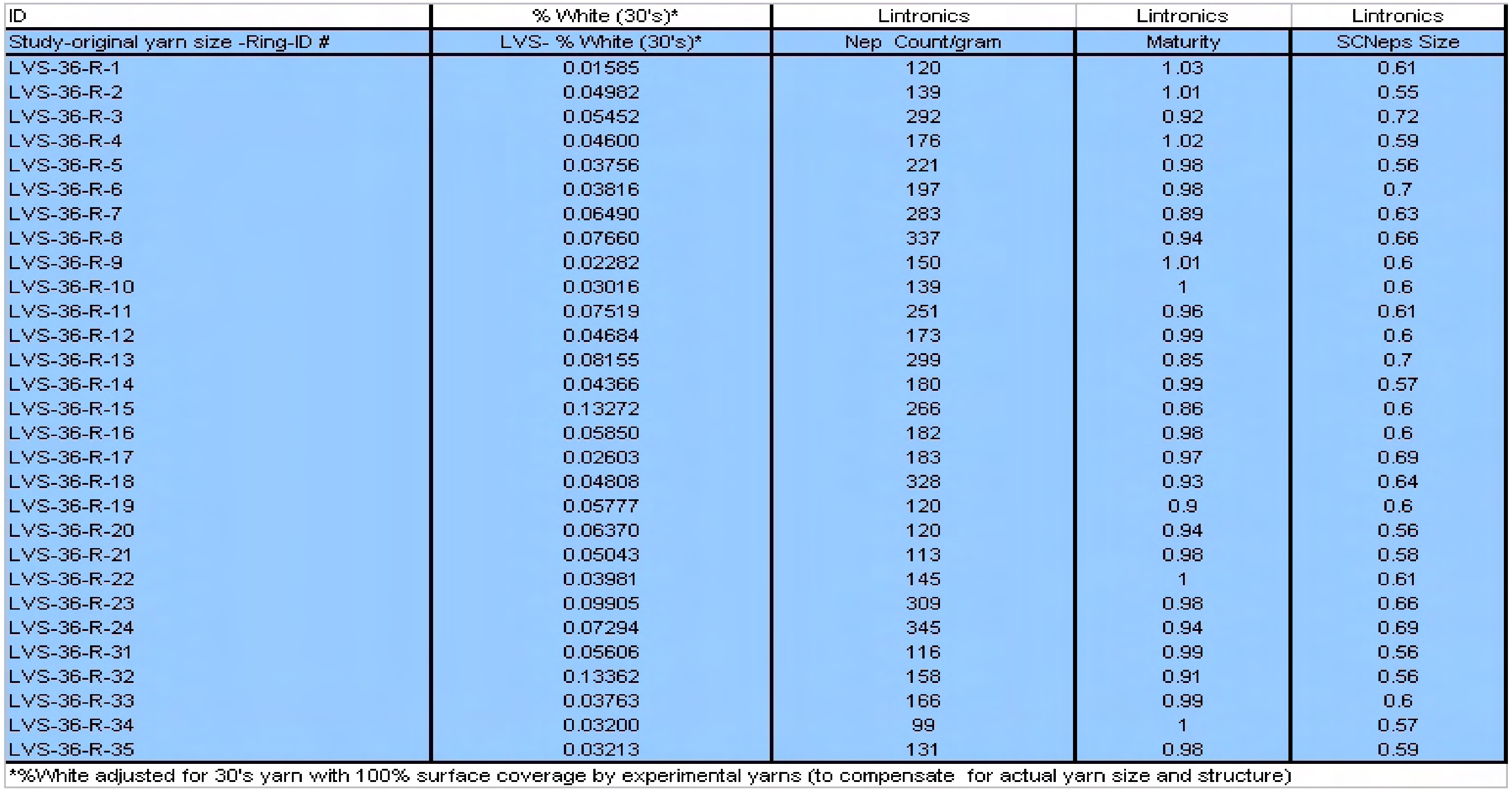
ID	% White (30's)*	Lintronics	Lintronics	Lintronics
Study-original yarn size -Ring-ID #	US01 - % White (30's)*	Nep Count/gram	Maturity	SCNeps Size
US01-30-R-1	0.40908	415	0.68	0.63
US01-30-R-2	0.33331	353	0.81	0.6
US01-30-R-3	0.34087	353	0.77	0.61
US01-30-R-4	0.37124	396	0.72	0.66
US01-30-R-5	0.33093	351	0.71	0.61
US01-30-R-6	0.40826	324	0.76	0.62
US01-30-R-7	0.39370	389	0.73	0.6
US01-30-R-8	0.17014	273	0.85	0.58
US01-30-R-9	0.10476	204	0.89	0.66
US01-30-R-10	0.05218	217	1	0.64
US01-30-R-11	0.14379	135	0.97	0.57
US01-30-R-12	0.08867	255	0.97	0.64
US01-30-R-13	0.16903	180	0.92	0.65
US01-30-R-14	0.04439	256	1	0.71
US01-30-R-15	0.10657	214	1	0.56
US01-30-R-16	0.07388	173	1.01	0.66
US01-30-R-17	0.23903	259	0.92	0.6
US01-30-R-18	0.09719	274	0.92	0.75
US01-30-R-19	0.11065	201	0.98	0.66
US01-30-R-20	0.02802	182	1.04	0.68
US01-30-R-21	0.02518	88	1.09	0.6

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

ID	% White (30's)*	Lintronics	Lintronics	Lintronics
Study-original yarn size -Ring-ID #	EVS- % White (30's)*	Nep Count/gram	Maturity	SCNeps Size
EVS-36-R-1	0.02189	105	1.03	0.62
EVS-36-R-2	0.09198	209	0.89	0.6
EVS-36-R-3	0.02927	156	0.92	0.56
EVS-36-R-4	0.10015	274	0.89	0.63

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

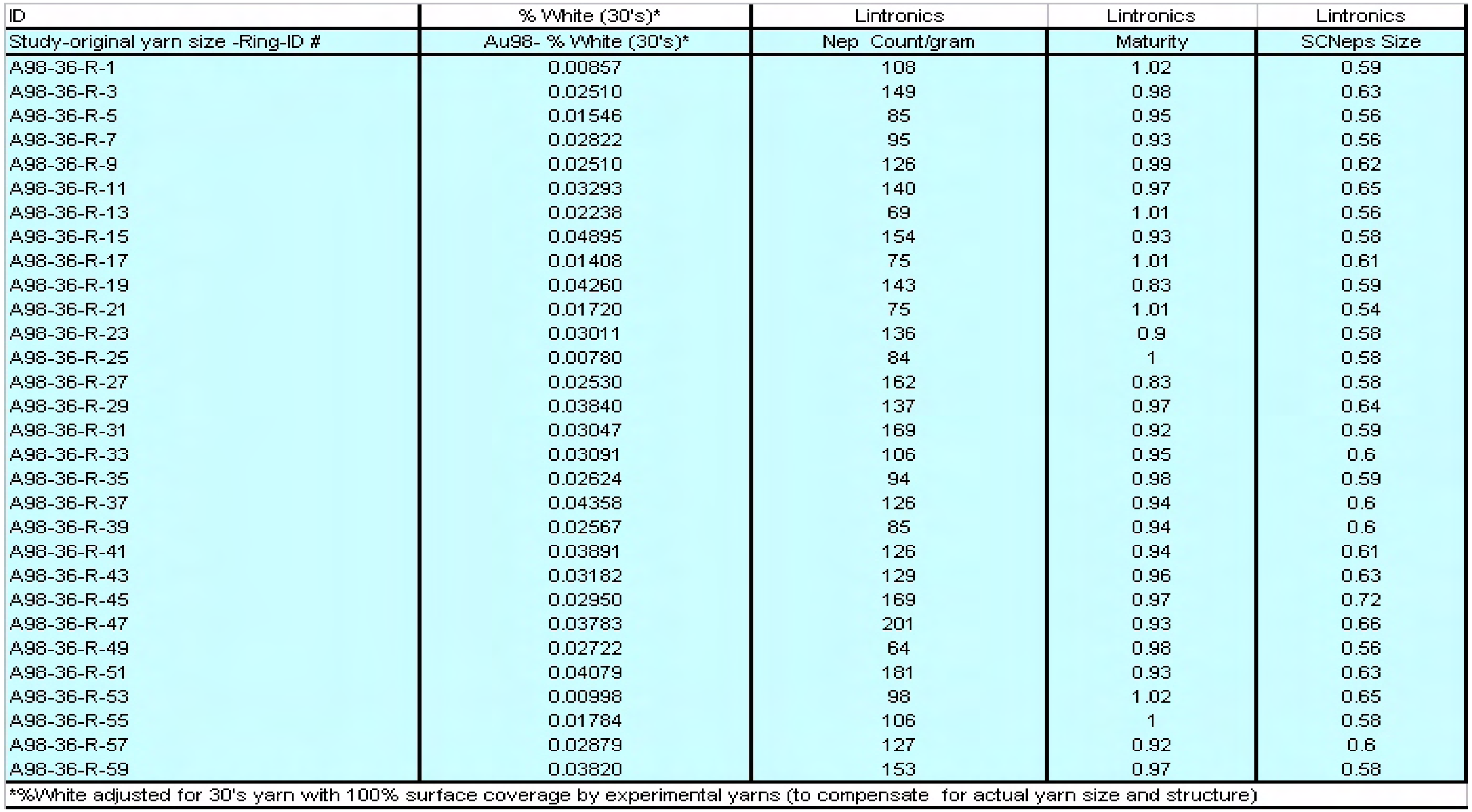
Lintronics - LVS



ID	% White (30's)*	Lintronics	Lintronics	Lintronics
Study-original yarn size -Ring-ID #	LVS- % White (30's)*	Nep Count/gram	Maturity	SCNeps Size
LVS-36-R-1	0.01585	120	1.03	0.61
LVS-36-R-2	0.04982	139	1.01	0.55
LVS-36-R-3	0.05452	292	0.92	0.72
LVS-36-R-4	0.04600	176	1.02	0.59
LVS-36-R-5	0.03756	221	0.98	0.56
LVS-36-R-6	0.03816	197	0.98	0.7
LVS-36-R-7	0.06490	283	0.89	0.63
LVS-36-R-8	0.07660	337	0.94	0.66
LVS-36-R-9	0.02282	150	1.01	0.6
LVS-36-R-10	0.03016	139	1	0.6
LVS-36-R-11	0.07519	251	0.96	0.61
LVS-36-R-12	0.04684	173	0.99	0.6
LVS-36-R-13	0.08155	299	0.85	0.7
LVS-36-R-14	0.04366	180	0.99	0.57
LVS-36-R-15	0.13272	266	0.86	0.6
LVS-36-R-16	0.05850	182	0.98	0.6
LVS-36-R-17	0.02603	183	0.97	0.69
LVS-36-R-18	0.04808	328	0.93	0.64
LVS-36-R-19	0.05777	120	0.9	0.6
LVS-36-R-20	0.06370	120	0.94	0.56
LVS-36-R-21	0.05043	113	0.98	0.58
LVS-36-R-22	0.03981	145	1	0.61
LVS-36-R-23	0.09905	309	0.98	0.66
LVS-36-R-24	0.07294	345	0.94	0.69
LVS-36-R-31	0.05606	116	0.99	0.56
LVS-36-R-32	0.13362	158	0.91	0.56
LVS-36-R-33	0.03763	166	0.99	0.6
LVS-36-R-34	0.03200	99	1	0.57
LVS-36-R-35	0.03213	131	0.98	0.59

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

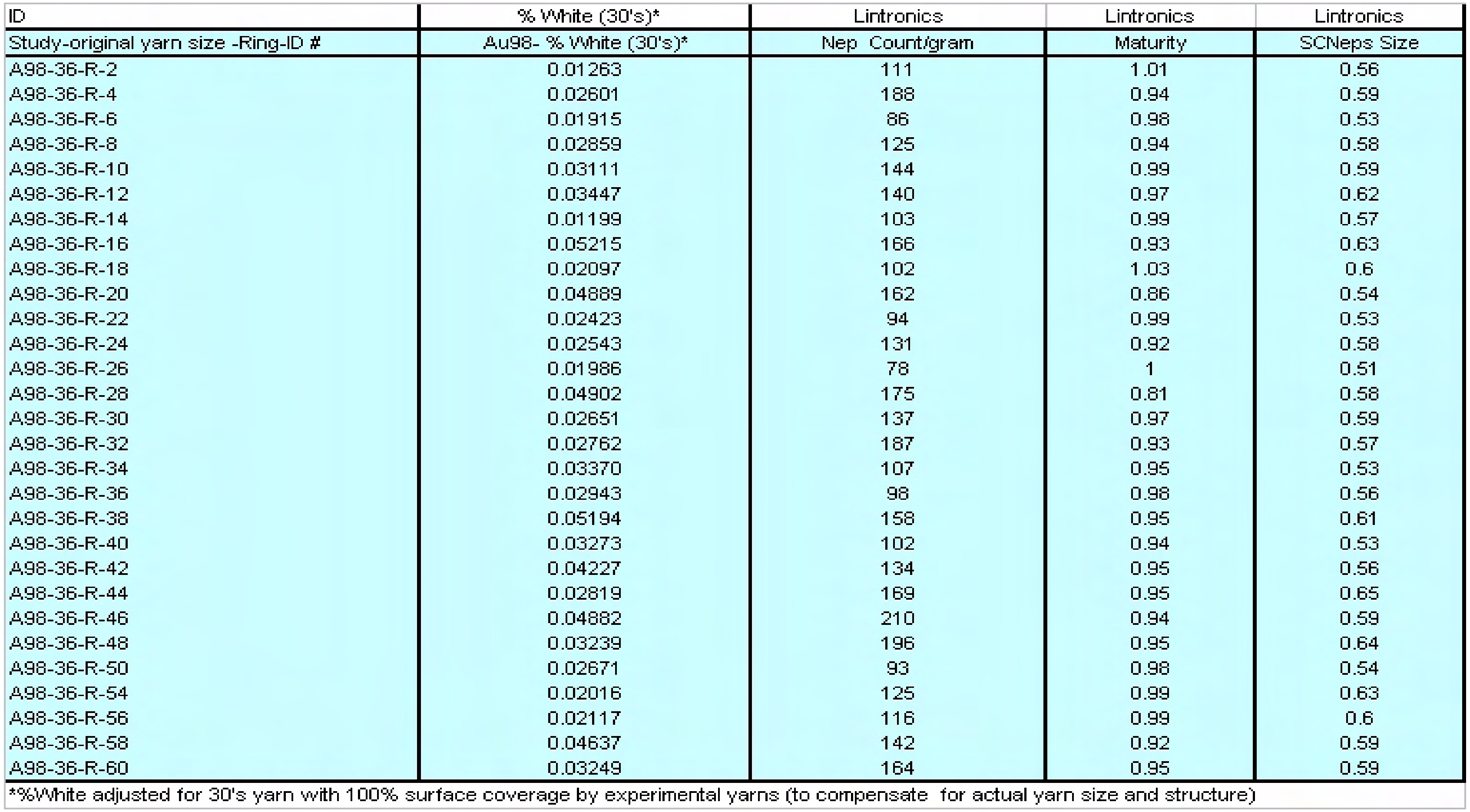
Lintronics - Au98



ID	% White (30's)*	Lintronics	Lintronics	Lintronics
Study-original yarn size -Ring-ID #	Au98- % White (30's)*	Nep Count/gram	Maturity	SCNeps Size
A98-36-R-1	0.00857	108	1.02	0.59
A98-36-R-3	0.02510	149	0.98	0.63
A98-36-R-5	0.01546	85	0.95	0.56
A98-36-R-7	0.02822	95	0.93	0.56
A98-36-R-9	0.02510	126	0.99	0.62
A98-36-R-11	0.03293	140	0.97	0.65
A98-36-R-13	0.02238	69	1.01	0.56
A98-36-R-15	0.04895	154	0.93	0.58
A98-36-R-17	0.01408	75	1.01	0.61
A98-36-R-19	0.04260	143	0.83	0.59
A98-36-R-21	0.01720	75	1.01	0.54
A98-36-R-23	0.03011	136	0.9	0.58
A98-36-R-25	0.00780	84	1	0.58
A98-36-R-27	0.02530	162	0.83	0.58
A98-36-R-29	0.03840	137	0.97	0.64
A98-36-R-31	0.03047	169	0.92	0.59
A98-36-R-33	0.03091	106	0.95	0.6
A98-36-R-35	0.02624	94	0.98	0.59
A98-36-R-37	0.04358	126	0.94	0.6
A98-36-R-39	0.02567	85	0.94	0.6
A98-36-R-41	0.03891	126	0.94	0.61
A98-36-R-43	0.03182	129	0.96	0.63
A98-36-R-45	0.02950	169	0.97	0.72
A98-36-R-47	0.03783	201	0.93	0.66
A98-36-R-49	0.02722	64	0.98	0.56
A98-36-R-51	0.04079	181	0.93	0.63
A98-36-R-53	0.00998	98	1.02	0.65
A98-36-R-55	0.01784	106	1	0.58
A98-36-R-57	0.02879	127	0.92	0.6
A98-36-R-59	0.03820	153	0.97	0.58

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

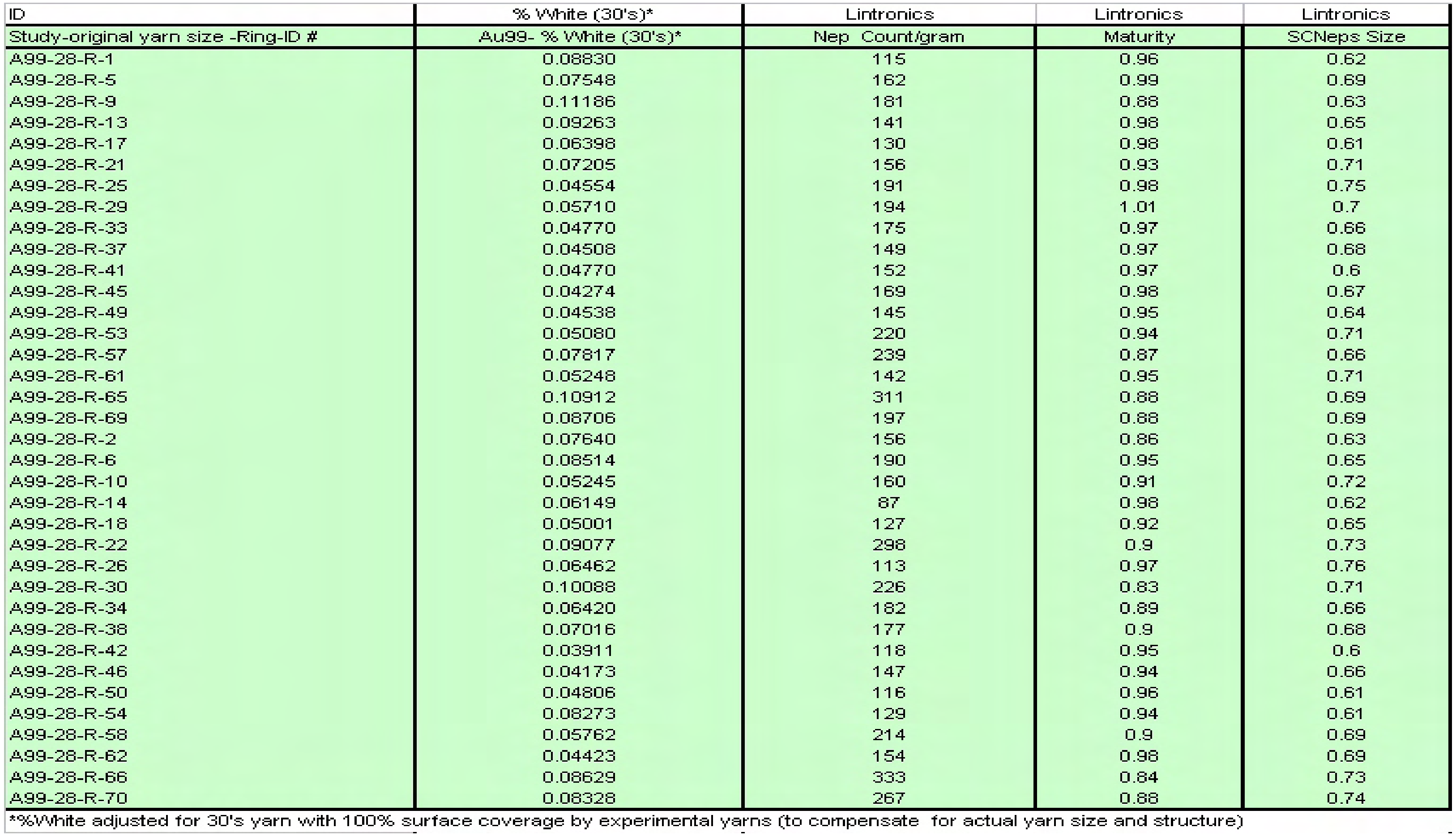
Lintronics – Au98 (continued)



ID	% White (30's)*	Lintronics	Lintronics	Lintronics
Study-original yarn size -Ring-ID #	Au98- % White (30's)*	Nep Count/gram	Maturity	SCNeps Size
A98-36-R-2	0.01263	111	1.01	0.56
A98-36-R-4	0.02601	188	0.94	0.59
A98-36-R-6	0.01915	86	0.98	0.53
A98-36-R-8	0.02859	125	0.94	0.58
A98-36-R-10	0.03111	144	0.99	0.59
A98-36-R-12	0.03447	140	0.97	0.62
A98-36-R-14	0.01199	103	0.99	0.57
A98-36-R-16	0.05215	166	0.93	0.63
A98-36-R-18	0.02097	102	1.03	0.6
A98-36-R-20	0.04889	162	0.86	0.54
A98-36-R-22	0.02423	94	0.99	0.53
A98-36-R-24	0.02543	131	0.92	0.58
A98-36-R-26	0.01986	78	1	0.51
A98-36-R-28	0.04902	175	0.81	0.58
A98-36-R-30	0.02651	137	0.97	0.59
A98-36-R-32	0.02762	187	0.93	0.57
A98-36-R-34	0.03370	107	0.95	0.53
A98-36-R-36	0.02943	98	0.98	0.56
A98-36-R-38	0.05194	158	0.95	0.61
A98-36-R-40	0.03273	102	0.94	0.53
A98-36-R-42	0.04227	134	0.95	0.56
A98-36-R-44	0.02819	169	0.95	0.65
A98-36-R-46	0.04882	210	0.94	0.59
A98-36-R-48	0.03239	196	0.95	0.64
A98-36-R-50	0.02671	93	0.98	0.54
A98-36-R-54	0.02016	125	0.99	0.63
A98-36-R-56	0.02117	116	0.99	0.6
A98-36-R-58	0.04637	142	0.92	0.59
A98-36-R-60	0.03249	164	0.95	0.59

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

Lintronics – Au99



ID	% White (30's)*	Lintronics	Lintronics	Lintronics
Study-original yarn size -Ring-ID #	Au99- % White (30's)*	Nep Count/gram	Maturity	SCNeps Size
A99-28-R-1	0.08830	115	0.96	0.62
A99-28-R-5	0.07548	162	0.99	0.69
A99-28-R-9	0.11186	181	0.88	0.63
A99-28-R-13	0.09263	141	0.98	0.65
A99-28-R-17	0.06398	130	0.98	0.61
A99-28-R-21	0.07205	156	0.93	0.71
A99-28-R-25	0.04554	191	0.98	0.75
A99-28-R-29	0.05710	194	1.01	0.7
A99-28-R-33	0.04770	175	0.97	0.66
A99-28-R-37	0.04508	149	0.97	0.68
A99-28-R-41	0.04770	152	0.97	0.6
A99-28-R-45	0.04274	169	0.98	0.67
A99-28-R-49	0.04538	145	0.95	0.64
A99-28-R-53	0.05080	220	0.94	0.71
A99-28-R-57	0.07817	239	0.87	0.66
A99-28-R-61	0.05248	142	0.95	0.71
A99-28-R-65	0.10912	311	0.88	0.69
A99-28-R-69	0.08706	197	0.88	0.69
A99-28-R-2	0.07640	156	0.86	0.63
A99-28-R-6	0.08514	190	0.95	0.65
A99-28-R-10	0.05245	160	0.91	0.72
A99-28-R-14	0.06149	87	0.98	0.62
A99-28-R-18	0.05001	127	0.92	0.65
A99-28-R-22	0.09077	298	0.9	0.73
A99-28-R-26	0.06462	113	0.97	0.76
A99-28-R-30	0.10088	226	0.83	0.71
A99-28-R-34	0.06420	182	0.89	0.66
A99-28-R-38	0.07016	177	0.9	0.68
A99-28-R-42	0.03911	118	0.95	0.6
A99-28-R-46	0.04173	147	0.94	0.66
A99-28-R-50	0.04806	116	0.96	0.61
A99-28-R-54	0.08273	129	0.94	0.61
A99-28-R-58	0.05762	214	0.9	0.69
A99-28-R-62	0.04423	154	0.98	0.69
A99-28-R-66	0.08629	333	0.84	0.73
A99-28-R-70	0.08328	267	0.88	0.74

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

Lintronics – Au99 (continued)

ID	% White (30's)*	Lintronics	Lintronics	Lintronics
Study-original yarn size -Ring-ID #	Au99- % White (30's)*	Nep Count/gram	Maturity	SCNeps Size
A99-28-R-3	0.11023	125	0.98	0.55
A99-28-R-7	0.07281	189	1	0.75
A99-28-R-11	0.11302	212	0.88	0.58
A99-28-R-15	0.07388	215	0.97	0.6
A99-28-R-19	0.07719	133	0.97	0.56
A99-28-R-23	0.08934	194	0.94	0.61
A99-28-R-27	0.06441	161	0.97	0.63
A99-28-R-31	0.05129	200	1	0.59
A99-28-R-35	0.06082	174	0.98	0.57
A99-28-R-39	0.05302	132	0.96	0.56
A99-28-R-43	0.04919	169	0.97	0.57
A99-28-R-47	0.04678	150	0.97	0.59
A99-28-R-51	0.04819	152	0.94	0.6
A99-28-R-55	0.06057	156	0.96	0.68
A99-28-R-59	0.10060	273	0.87	0.58
A99-28-R-63	0.06557	160	0.95	0.59
A99-28-R-67	0.09963	299	0.89	0.63
A99-28-R-71	0.12243	221	0.88	0.57
A99-28-R-4	0.11025	212	0.85	0.66
A99-28-R-8	0.11132	217	0.93	0.59
A99-28-R-12	0.06012	215	0.91	0.59
A99-28-R-16	0.06761	95	1	0.56
A99-28-R-20	0.09022	160	0.9	0.61
A99-28-R-24	0.11424	260	0.92	0.63
A99-28-R-28	0.05601	129	0.97	0.56
A99-28-R-32	0.12249	240	0.85	0.63
A99-28-R-36	0.06855	208	0.88	0.57
A99-28-R-40	0.07327	234	0.9	0.65
A99-28-R-44	0.03284	149	0.98	0.6
A99-28-R-48	0.05366	138	0.95	0.57
A99-28-R-52	0.05832	123	0.99	0.61
A99-28-R-56	0.10328	154	0.94	0.59
A99-28-R-60	0.06164	228	0.92	0.58
A99-28-R-64	0.04584	151	0.99	0.61
A99-28-R-68	0.09421	327	0.86	0.67
A99-28-R-72	0.09899	261	0.87	0.61

*%White adjusted for 30's yarn with 100% surface coverage by experimental yarns (to compensate for actual yarn size and structure)

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