2005 Beltwide Cotton Conferences, New Orleans, Louisiana - January 4 - 7, 2005

COTTON QUALITY: WHITE SPECK NEPS FROM FIBER TO FABRIC

Patricia Bel
New Orleans, LA
Bugao Xu
The University of Texas at Austin
Austin, TX

Abstract

White speck neps, which are composed of immature cotton, are not easily detected until the fabric is dyed, whereupon they become visible particularly in dark shades. The fabric is littered with “white specks” which makes it unusable in the fashion industry, literally costing millions of dollars in losses to the textile industry. This research first examines the biological basis for the defect, and then reviews mechanical processing effects on white specks along with field studies (from fiber to fabric). White speck predictions are developed from fiber properties as measured by several high-speed fiber measurement systems. Once the defect is detected, at the bale stage the fibers could be used to make whites or pastel shades of fabrics where the defect would not be a problem. First, a White Speck Potential (WSP) value needs to be developed from this type of research so it can be used as a tool by the mills and breeders. Bales with high WSP can be put into a special class for white fabrics only, or use for combed, vortex or rotor spun yarns, thus maximizing the fiber's potential and minimizing mill losses due to white specks. Breeders will be able to change the future of US cottons by eliminating varieties with high WSP early on in the breeding process, without going to full field studies.

Introduction

White specks are a specific type of fiber defect that result in high financial losses to the cotton industry. They were reported as early as 1874. Fiber entanglements are called neps. More than 90% of neps in finished fabric contain immature fibers (Hebert et al., 1988). White specks are dye-resistant neps, which appear on the surface of a finished fabric. When a fabric is dyed, the mechanical and biological neps formed by immature fibers appear as white specks on the dyed fabric. The white speck problem seems to be particularly bad during years with weather problems, like the 1987 U. S. cotton crop. Not all neps are white specks, but all white specks are neps. Some neps are tangles of immature and mature fibers, while many are tight masses of immature fibers. Long, fine, immature fibers have a propensity to nep during processing, so any field condition, harvesting method, gin, or mill processing that increases the level of immature fibers will increase neps in yarns and fabrics.

Figure 1: Mechanical Nep (Photomicrograph by Bruce Ingber).

White specks show up as dyeability defects. Figures 1, 2, and 3 are photomicrographs of typical white specks. Figure 1 shows an entanglement of mature and immature fibers that appeared as a white speck on the dyed fabric. Figure 2 is a coalesced white speck composed of extremely immature fibers adhered together.

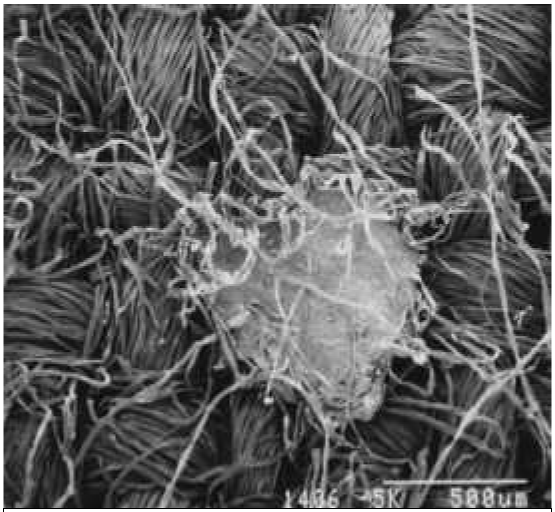

Figure 2: Coalesced white speck nep on fabric surface (low magnification) (Photomicrograph by Bruce Ingber).

In Figure 3, the white speck nep is very flat and very reflective. These white speck neps are immature fibers 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 fibers to a high shine, making them even more reflective and the problem even more obvious. The key problem is that the mill does not discover this defect until after the fabric is dyed.

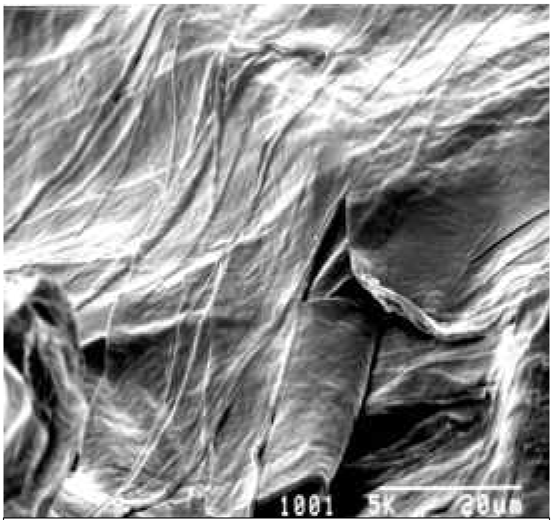

Figure 3: High magnification of a white speck nep (note the extremely immature fibers create a reflective surface) (Photomicrograph by Bruce Ingber).

The lack of maturity of cotton is a significant cause of white specks. As the cotton fiber develops, it first elongates and then its cell wall thickens as it matures.

Cross-section studies have shown that the relative thickness of the cell wall (see Figure 4) is characterized as the fiber's maturity. The more cellulose that fills in the cell wall as the fiber develops, the more mature the cotton and the more circular in shape (a perfect circle would be noted as $\theta = 1$; the smaller θ becomes, the less circular and flatter the cross-section becomes).

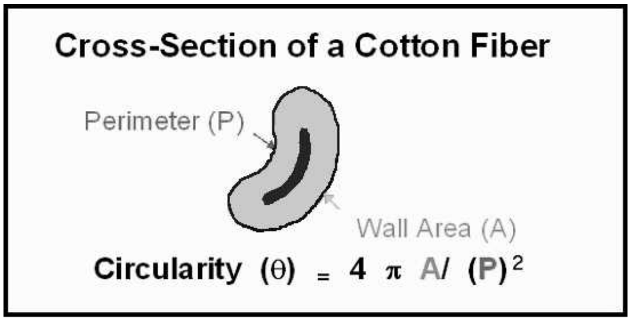

Figure 4: Maturity of the cotton fiber cross-section is dependent on its cell wall development

The textile industry needs high-speed measurement systems to predict white specks so the problem can be avoided by putting cottons with high white speck potential into the right product mix where they do not cause problems (specifically, white fabrics). The work described in this paper 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.

This paper 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 fiber measurement systems, with the intention of providing a White Speck Potential (WSP) that can be incorporated into cotton grading systems used for marketing. The research presented here is from whites speck studies, which measured cotton fiber and fabric parameters, over sixteen years, on two continents (North America and Australia). Before it is decided which values from high-speed fiber measurement systems are most predictive of white specks, the level of white specks in dyed fabric and/or the amount of immature fibers needs to be quantified by a consistent method. Several different systems are evaluated. The Autorate program developed by developed by one of the authors (Xu) is found to provide the most accurate results currently available. His program was developed specifically to measure white specks.

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 were all dyed and scanned in a batch, the contrast usually remains the same (each dye batch is slightly different and Bel has noticed that the scanner contrast has a slight drift over time). Figure 5 shows the fabric's original scan and the altered image after it is brightened and analyzed. This analysis results in a white speck count, the size of the white specks, and the percent white on the fabric.

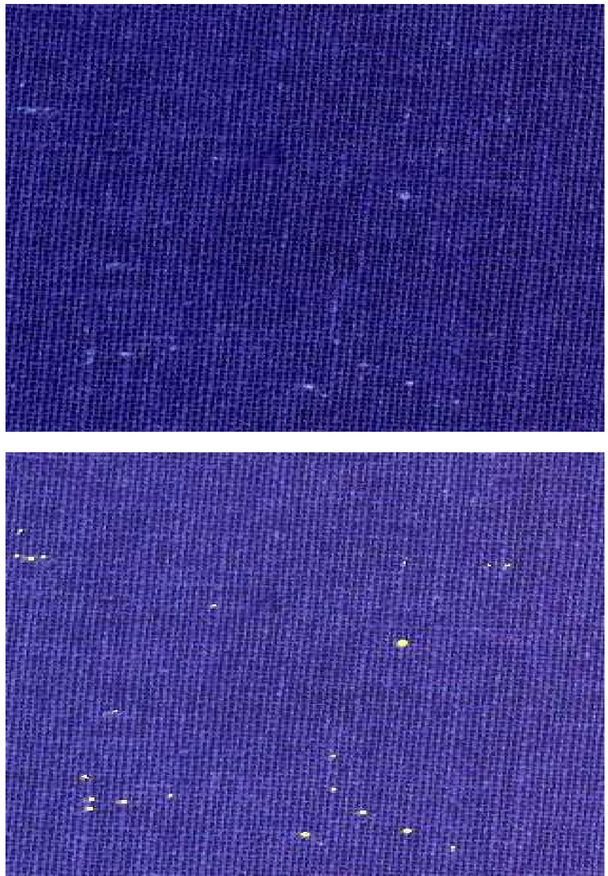

Figure 5: Top) Original scan and **(Bottom)** scan brightened to 120 and image analyzed on Autorate

Discussion

Cotton breeders want to improve fiber quality for improved future varieties, and the mills need to know what measurable fiber properties are considered the most vital for quality in processing. Producers and ginners need to be aware of these fiber properties as well, but often receive contradictory responses from the textile mills. Breeding programs have been geared to produce longer, stronger and finer cottons, with emphasis on yield. However, other elements, such as the percent immature fibers or seed coat attachment, often change along with the targeted fiber property. Seed coat attachment is strongly related to variety. 14 to 24 % of white specks are from seed coat fragments that have short immature fibers attached. The following field studies (1987 to 2001) attempt to discern the measurable fiber properties, which can be used to predict white speck neps using high-speed fiber measurement systems.

Varietal Studies

Several factors affect white specks. One of the most important is variety. It has been estimated that 30% of white speck neps are caused by the cotton variety, 30% by environmental factors during growth, and 40% by processing after harvesting (Bragg, 1992). The question is “Do some varieties have more white speck nep problems than others?”

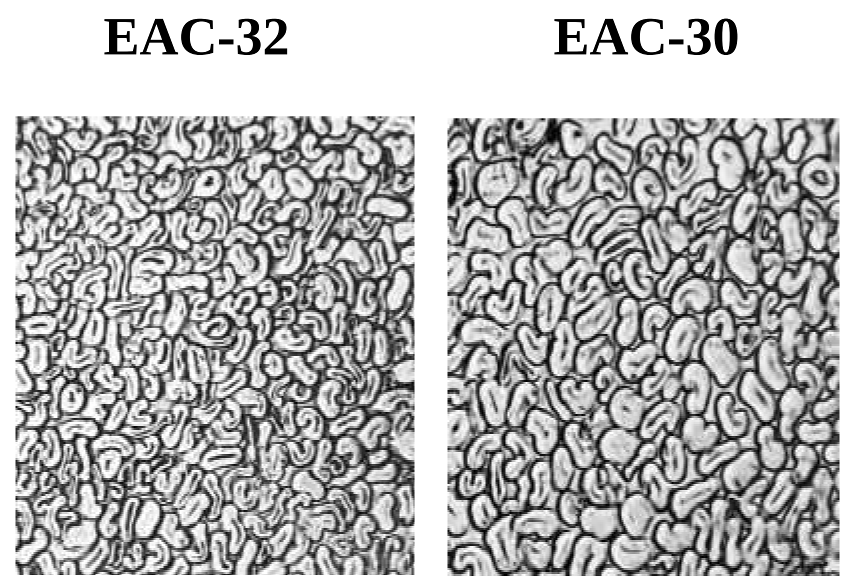

Figure 6: The two varieties are from a breeding program where the EAC-30 was bred to mature early. (Note: High level of flat, immature fibers in EAC-32)

This first study is the US EVS (Extreme Variety Study). Four varieties of cottons (DP90, STV825, EAC-30 and EAC-32) were grown in the same field, harvested, and ginned identically. The Experimental Acala varieties, EAC-30 and 32 are from a breeding program in 1987 where the EAC-30 was bred from the EAC-32 to mature earlier in the field. The pictures in Figure 6 show that the EAC-32 cotton has a much higher level of immature fibers than the EAC-30. The EAC-30 fibers are much more circular due to the thicker cell walls, whereas the EAC-32 fibers have a large level of flat (reflective) immature fibers. Breeding programs like this will help minimize the white speck, problem.

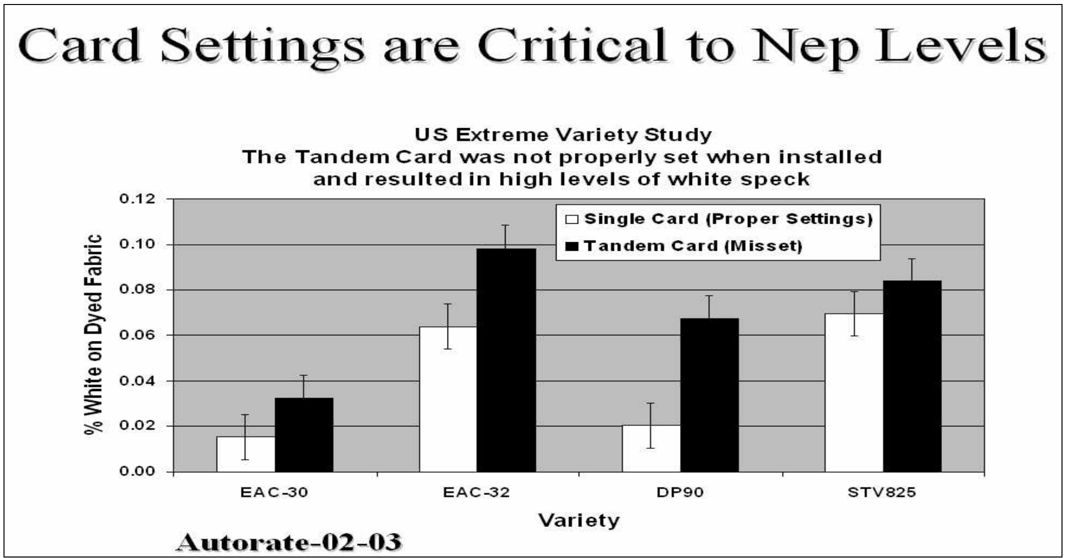

Figure 7: Improper card settings result in higher levels of white specks

The EVS study also included single and tandem carding. As it turned out the tandem card was improperly set (this was the first study after installation). One of the cylinders in the tandem card was set wide (for shipping) and accidentally was not set to the recommended settings. This provided an opportunity to see the effect of settings on the card. Normally, tandem carding reduces the level of white specks, but in this case, the improperly set card almost doubled the level of white specks, as seen in Figure 7.

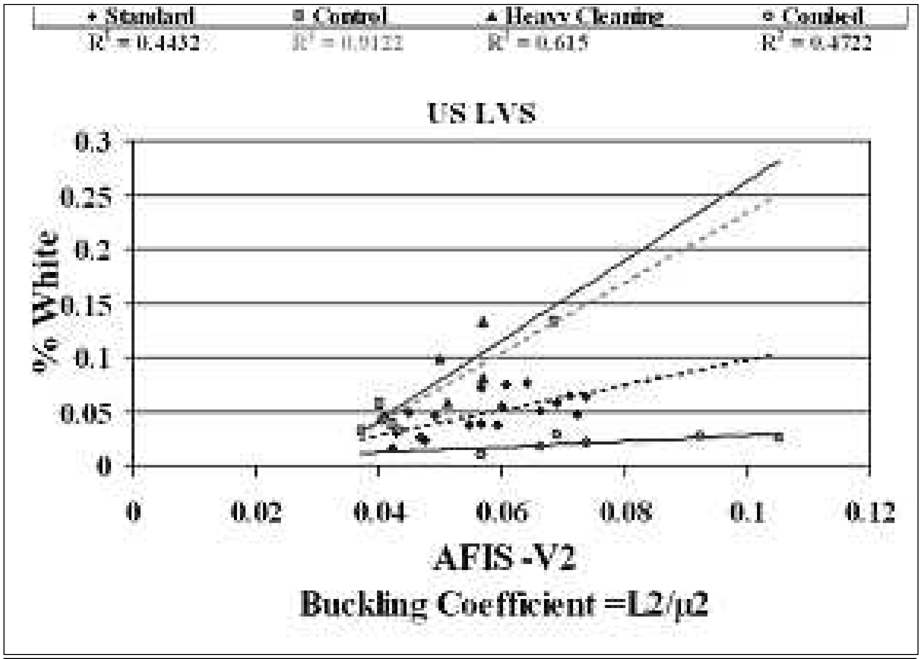

Figure 8: AFIS Bale Data vs. White Speck for the US 26 Leading Varieties and the 5 Controls

This LVS (Leading Variety Study) is research in conjunction 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 our analysis demonstrated that true varietal differences were not readily discernable because of the processing interactions, as can be seen in Figure 8.

The different levels of processing break into distinct groups, 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 the harsher the ginning process, the higher the level of white specks, given similar buckling coefficients. Combing removes neps, mainly immature fiber clusters that are the ultimate cause of white specks, and short fibers. 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 8. The standard cottons have the next highest level of white specks. These fibers 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.

Yarn Size

These cottons (Figure 9) were ring spun into two different yarn sizes (22's and 36's). The two yarn sizes track each other very well, but because the 36's are so much smaller (less weight per unit length), they have less white specks for a given length than the 22's. There are a defined number of white specks per gram so by making fine yarns; this process actually stretches the white specks out per unit length so less of the white speck shows up on the fabric per square meter. So, in discussing the different studies with different yarn sizes and different picks per inch (all filling faced sateens, with a combed warp), the level of white specks have been adjusted mathematically taking into consideration yarn size and fabric construction to normalize the field.

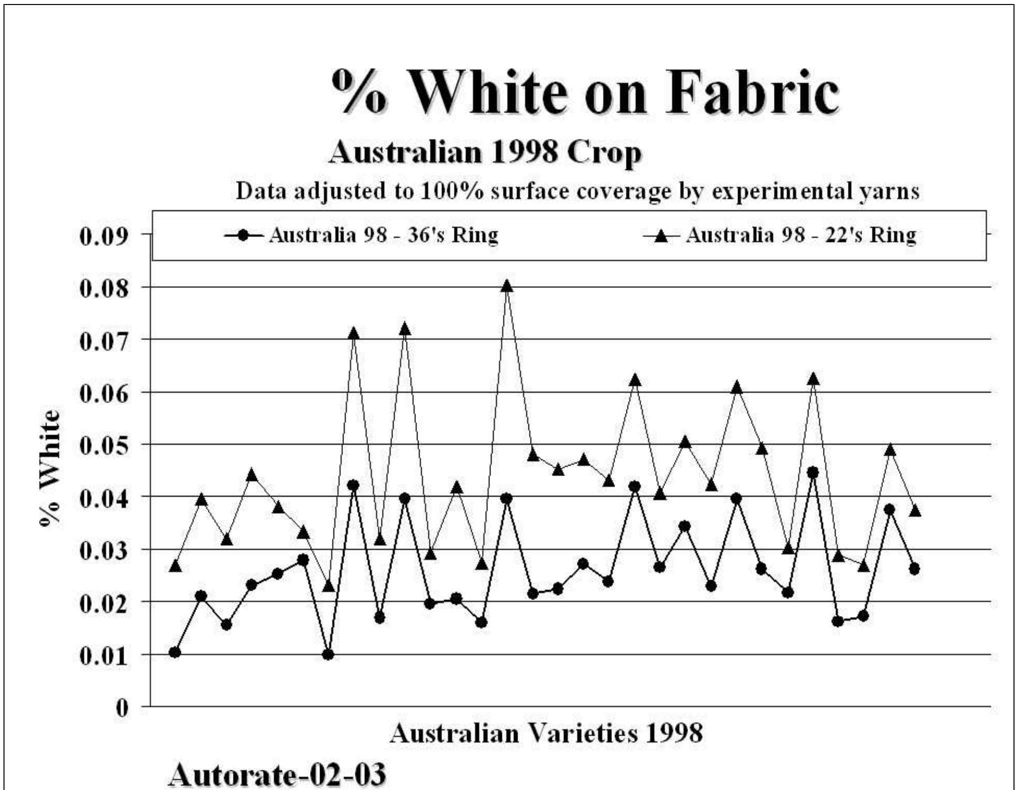

Figure 9: White speck levels for the 1998 Ring Spun Australian Cottons

Lint Cleaning

The study in Figure 10 shows smooth leaf and hairy leaf cotton varieties, which had 0, 1, 2, and 3 lint cleaners run at the gin and then processed identically in the mill. The card wire was damaged just after the study was finished. The card wire was replaced and the study was run again. This second run indicated that when the card wires are worn, more of the lint cleaning effect is evident, with white speck levels increasing with increased lint cleaning. However, when new card wires are used the effect is significantly reduced. Lint cleaning separates and opens clusters of immature fibers, and with each added lint cleaner, the separation continues, increasing both the size and the number of white specks and overall % white on the dyed fabric. Worn card wires also separate clusters of immature fibers, as well as increasing the size and number of white specks and overall % white on the dyed fabric. New card wire removes the white specks as trash. As the new card wire becomes worn, it rounds and, much like a ballpoint needle, will separate the cluster of immature fibers, rather than cutting them out as trash. The mill will see a gradual increase in neps as the wires become worn. The mills need to know when to rewire (or sharpen the card wire) or their nep levels will continue to increase. Many mills test the card sliver on AFIS and watch the AFIS Nep levels to know when to rewire. Additionally, at the gin level, because it is cost prohibitive for the mills to change card wire frequently, it is important for the gins to minimize lint cleaning as much as possible, since the lint cleaning effects on white speck are apparent at the mill as the card wire wears down.

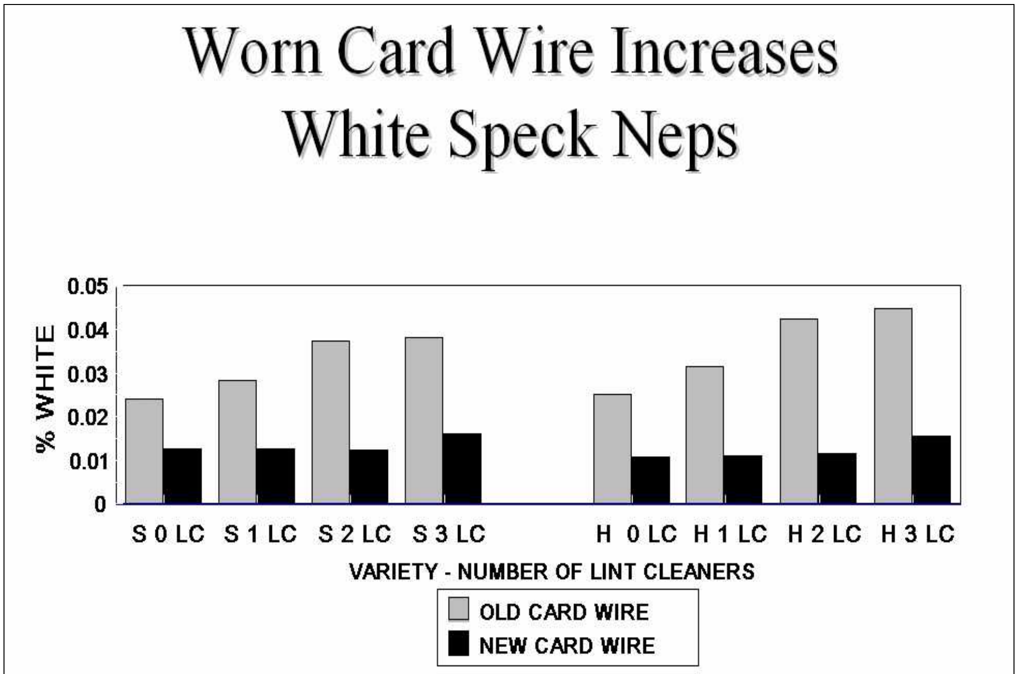

Figure 10: As Card Wire Wears Down, Lint Cleaning Effects Become Pronounced

Figure 11 shows the 1998 and 1999 Australian crops that were both run with two levels of lint cleaning (one and two lint cleaners for the 1998 crop and zero and two lint cleaners for the 1999 crop). The 1998 Australian cottons are from a good crop year and were spun in the US at CQRS (Cotton Quality Research Station), the card was in excellent condition, and there was not a significant difference between levels of lint cleaning. The 1999 cottons have a much higher level of white specks (problems with drought which relates to immaturity) than the previous year. They were spun in Australia on the new mill set up at IFC (International Fibre Centre), and the card was in excellent condition. In both cases the data from the different levels of lint cleaning track each other. However, given the data on Figure 10 we can speculate that if the cards had worn card wires, the lint cleaning effect may have shown through.

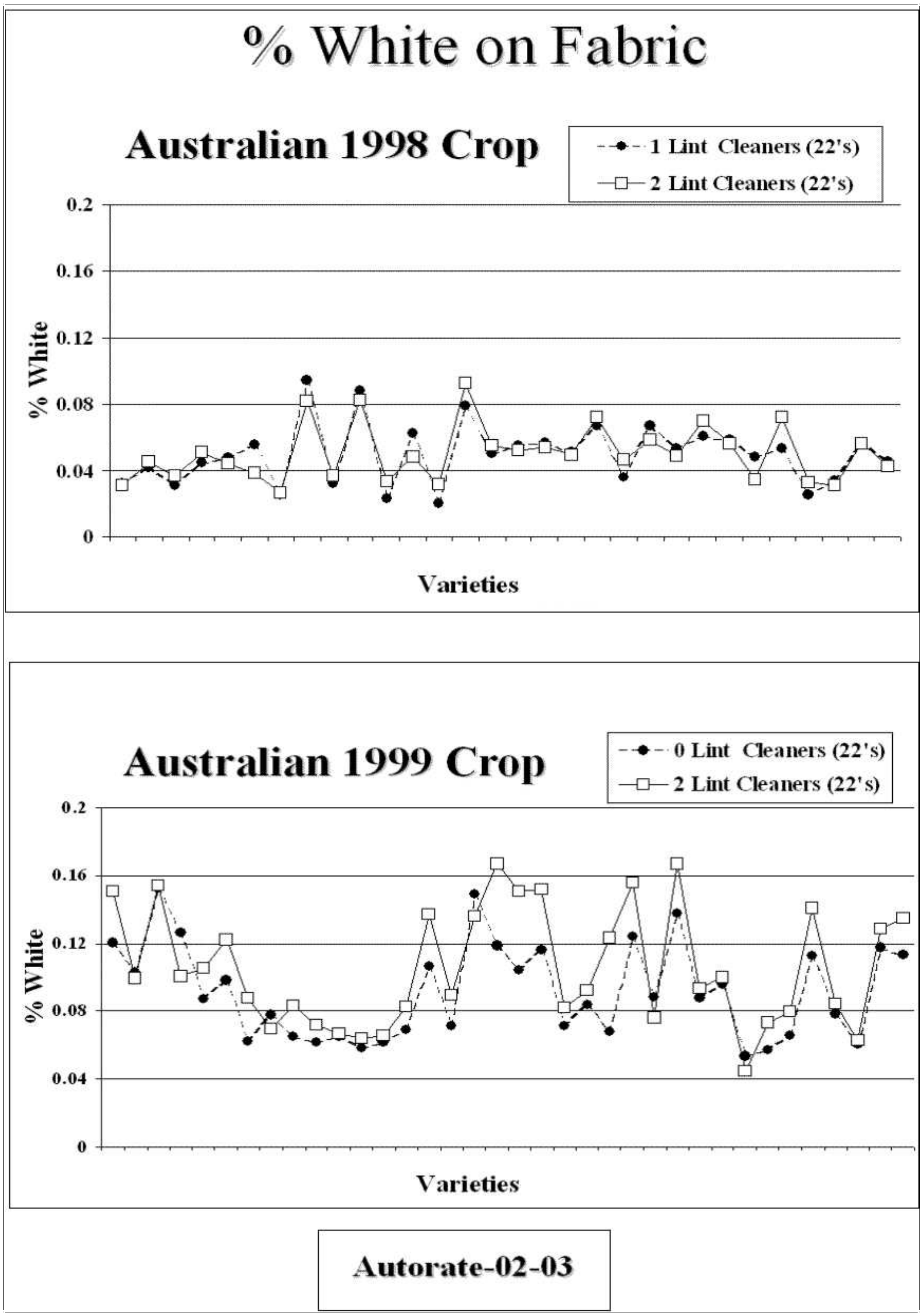

Figure 11: Lint Cleaning Effects on White Specks

Yarn Spinning System

OE spinning had a significantly lower level of white specks than ring spinning (Figure 12). Essentially, the opening system combs out the clusters of immature fibers and discards them as trash. The opening system was designed to remove trash from the fiber before feeding the individualized fibers to the rotor, to improve uniformity and increase efficiency. Very small differences are seen in fabrics produced from a large range of fiber qualities when OE spinning is employed; however, the fabric quality is much more variable when the fibers are ring spun.

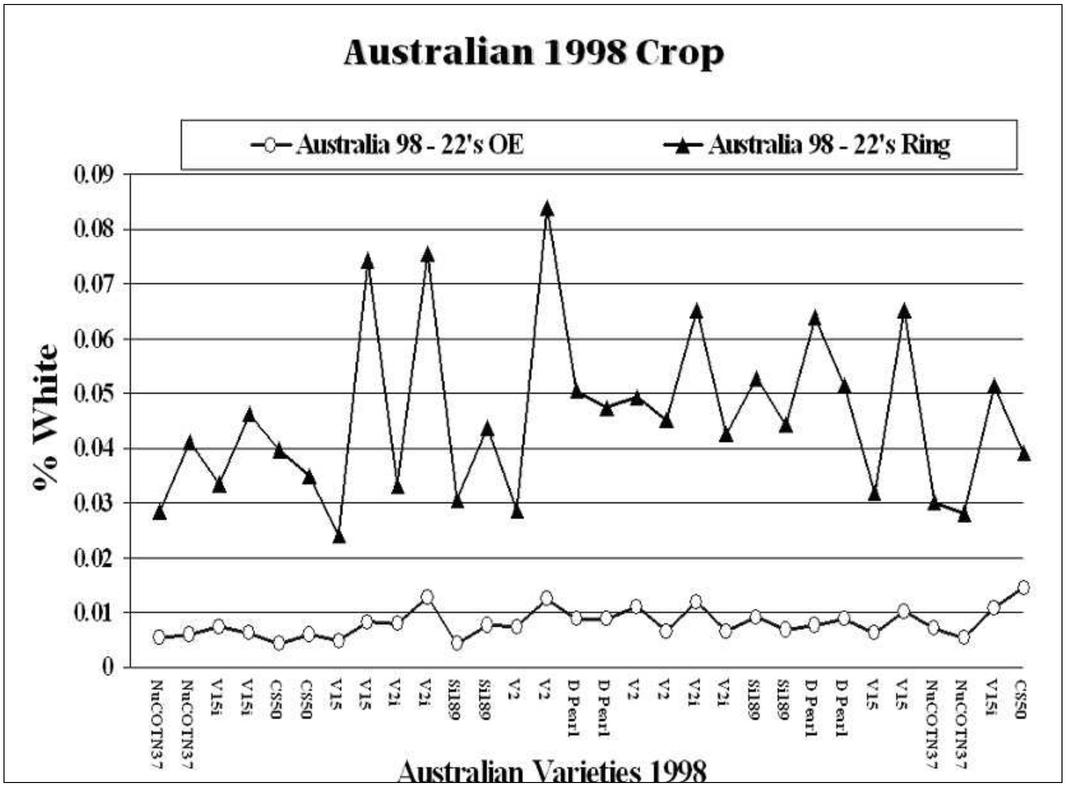

Figure 12 **Figure 12: OE spinning has minimal levels of white specks as compared to ring**

The latest processing trial used varieties grown in three different regions: Texas, Georgia, and Mississippi. These were each ginned locally and then spun on ring, rotor, and vortex systems at CQRS (Cotton Quality Research Station, in Clemson, SC). The yarns were woven as filling in filling face sateen fabrics with a combed warp (approximately 85% surface coverage by the experimental yarns) and then dyed and analyzed for white specks. Two varieties were grown in all three areas. The Texas cottons (same field) were stripper picked, which means heavy pre-cleaning in the gin followed by two lint cleaners, resulting in very heavy cleaning at the gin. The Georgia cottons (same field) were spindle picked and used one lint cleaner only. The Mississippi cottons (from the same area) were spindle picked and were all ginned at the same gin, but the specific level of ginning is unknown (ginner said he varied between one and two lint cleaners).

Figure 13 shows the white speck levels for three different spinning systems. An interesting effect is that ring spinning has a significantly higher level of white specks than open end and vortex spinning. Open-end (rotor) spinning and vortex spinning have combing systems that open and align the fiber and remove trash before spinning. The immature fiber clusters must be combed out at this point and removed as any other trash particle. This becomes part of the solution for white specks. If it is known that fibers have a high white speck potential, they can be combed, or open end or vortex spinning can be used to help minimize the situation.

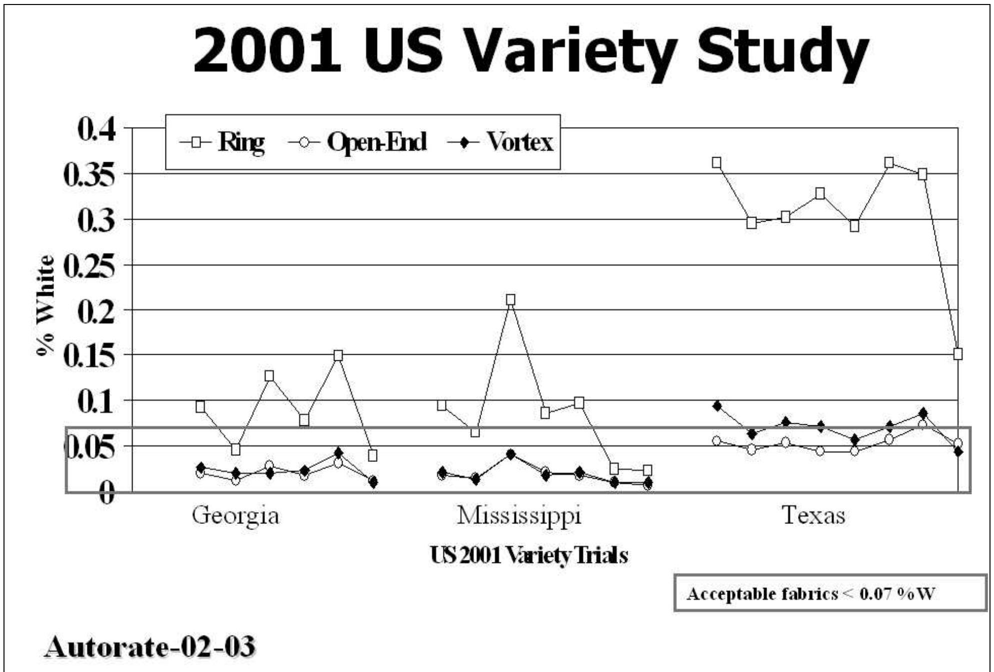

Figure 13: Comparison of Ring, Open End, and Vortex Spinning on White Specks

The fabrics in Figure 14 are the high and low of this study for white specks. The extreme difference is obvious. One is as clean as a combed cotton fabric is. However, the stripper-picked cotton is an example of a fabric showing the worst white speck condition in all of the studies discussed in this paper. However, variety, field management, weather, and processing all affect the level of white specks.

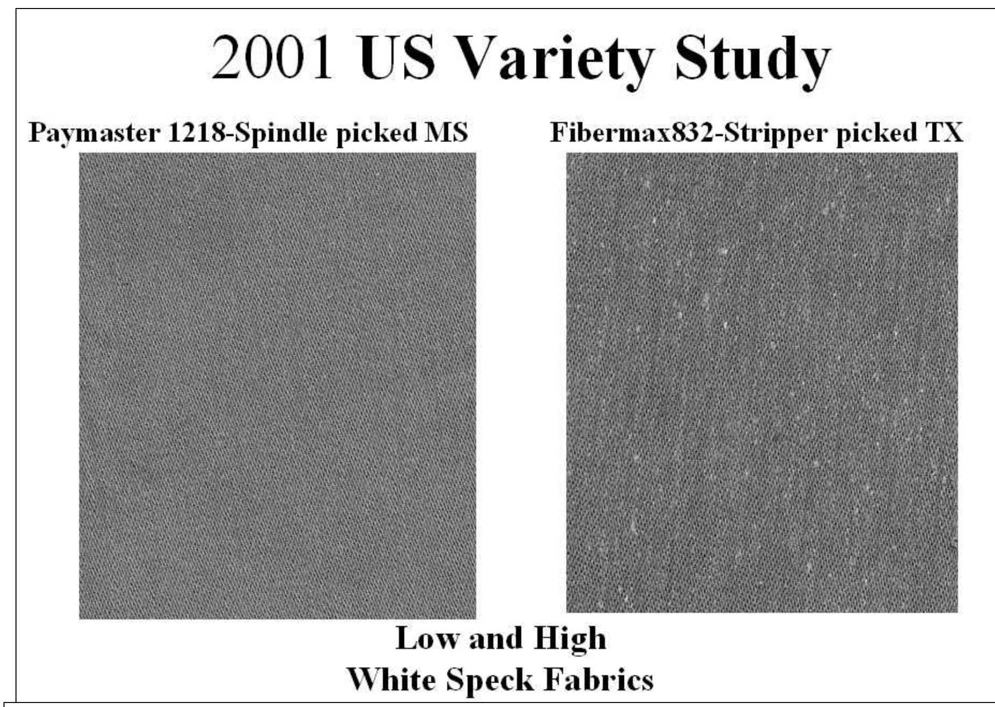

Figure 14: Lowest and Highest Levels of White Speck in the US 2001 Study

2005 Beltwide Cotton Conferences, New Orleans, Louisiana - January 4 - 7, 2005

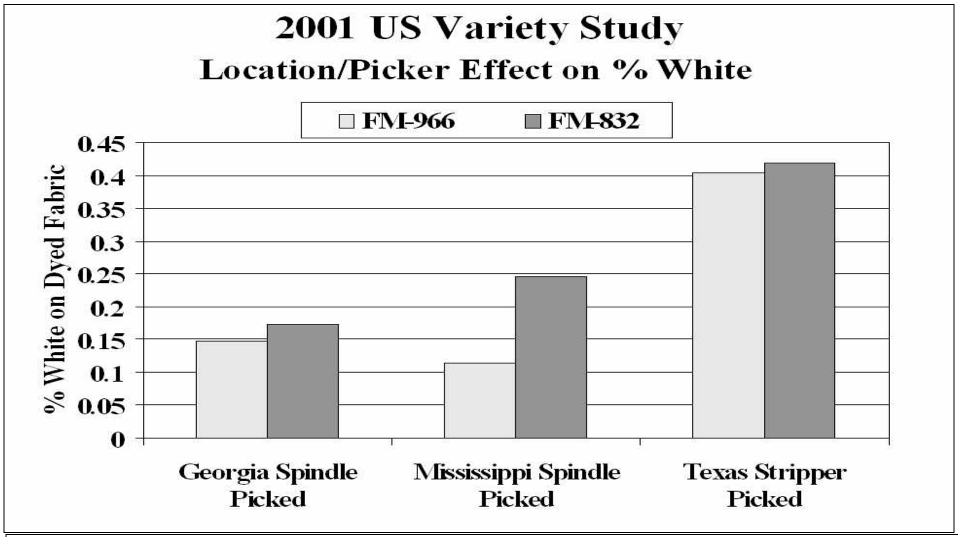

Figure 15: Stripper and spindle picking effects on white speck levels.

The U.S. 2001 variety study had two varieties that were grown at all three locations. The % white values on the fabrics are significantly higher for the stripper-picked cottons in Texas. Drought was a factor along with the stripper picking. The stripper-picked seedcottons 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 is almost double that of the other regions, due to the combination of higher levels of immature cotton and harsh processing.

In Figure 15, the Mississippi and the Georgia cottons are very similar (both are spindle picked) and the Texas cottons show the effect of stripper picking on the level of white specks. Generally, the more the fibers are processed the higher the level of white specks. Mechanical processing opens and separates the immature clusters and they become too small to remove as trash in the mill (except for combing), ultimately creating more white specks in the dyed fabrics. The Texas cottons were particularly bad that year due to drought, which is also known to affect cotton’s maturity.

Figure 16 shows five different white speck studies. The initial study (US EVS) is the only one with full warp and filling for each fabric from the experimental fibers, the following 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 which has approximately 85% surface coverage from the experimental yarns. The white speck data have been adjusted for yarn size and fabric construction so the results can be evaluated on the same basis. The first Study (US EVS) is simply the first four data points indicated by the white circles. The DP90 and EAC-30 were both excellent fabrics, while the STV825 and EAC-32 were visibly poor fabrics due to the level of white specks. The results were as expected with the level of white specks being extremely low and extremely high for the two Acalas (see cross sections in Figure 6).

The next study (US LVS) US Leading Variety study (triangles) also included a control with varieties that were expected to run the 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 as the previous extreme study. The dark gray triangles indicate the varieties with one and two lint cleaners from the 1993 Leading Variety Study conducted by AMS. The light gray triangles indicate the varieties that were combed and finally the black triangles are the varieties that were heavily cleaned (stripper harvested with 2 lint cleaners or 3 lint cleaners).

2005 Beltwide Cotton Conferences, New Orleans, Louisiana - January 4 - 7, 2005

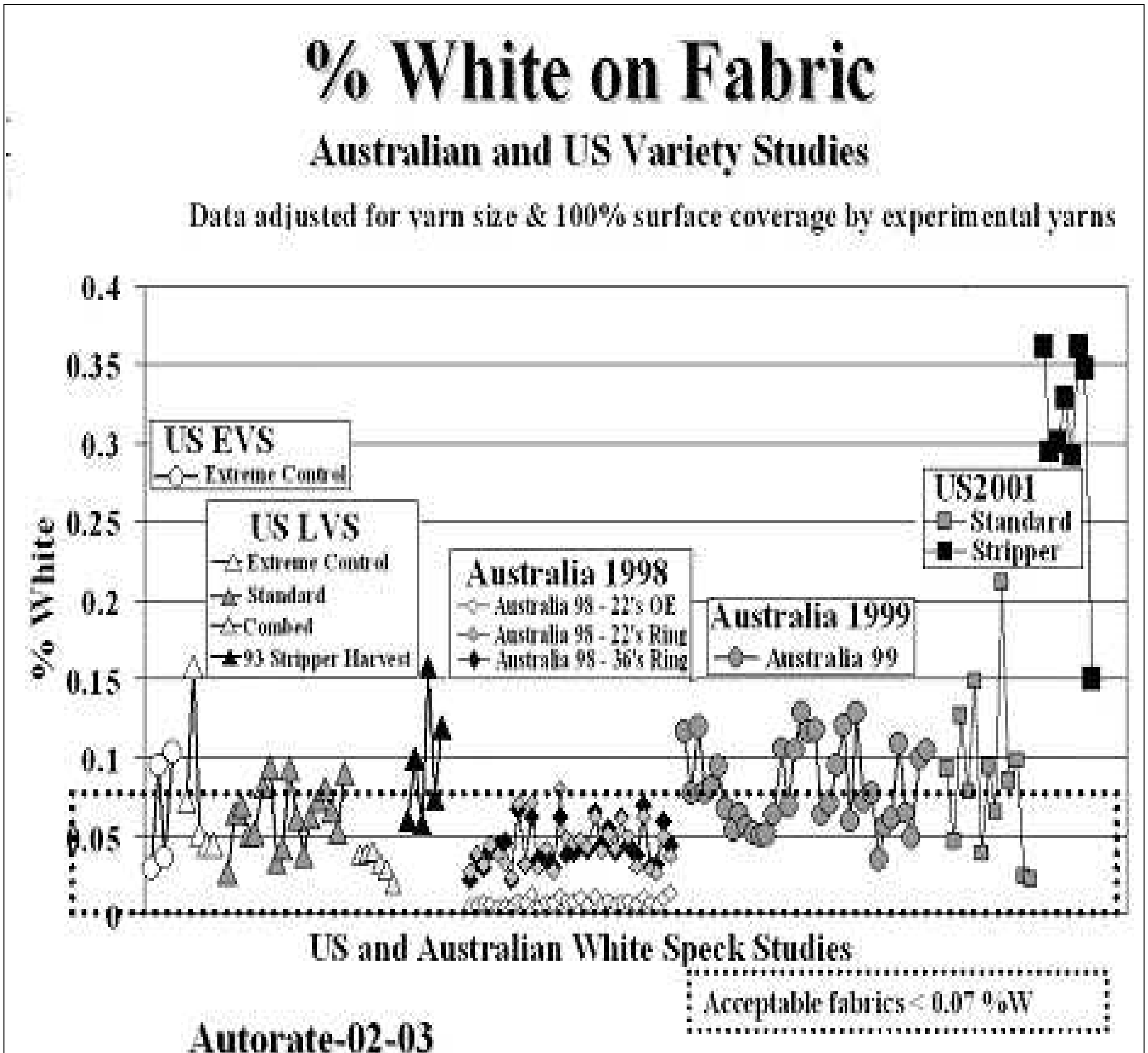

Figure 16: % White on Fabrics for Five Studies. Data has been adjusted to account for yarn size, fabric construction and extrapolated to 100% Surface coverage by experimental yarns.

The LVS study shows the significant differences that can be found in levels of white specks due to processing. Most of the cottons in the LVS fall in a range that Bel considers visibly acceptable. This dotted line box indicates the range (%White less than 0.07%) that Bel has visually picked as acceptable levels of white speck. Anything over that level is becoming problematic. The combed cottons are nice and clean, below the 0.05 percent level.

The third study, Australia 1998 (diamonds), was on cotton grown in Australia. The seed cottons were brought to the same gin and both 1 and 2 lint cleaners were used. This particular crop year produced very mature fibers and no significant difference was seen due to lint cleaning. There was a difference due to yarn sizes and type of spinning system. The difference in white specks due to yarn size is shown in Figure 9 and it can be seen that once the data were adjusted for yarn size, there is no significant difference. This is the open-end spun yarn from the Australia study and this was a very good crop year for them. They had excellent fiber properties but the fourth study, their 1999 crop (gray circles), had maturity problems due to drought and the level of white specks is significantly higher than the 1998 crop. The Australia 1999 crop's higher white speck levels are more in line with the final study, US 2001 study (gray squares), which also had weather problems that affected the maturity. The stripper-harvested crops are black squares for the US 2001 crop and Black triangles for the US LVS crop; in both cases, it can be seen that the excess cleaning significantly increased the level of white specks as compared to the varieties with standard cleaning. All of the studies were run with carding rates of 70 lbs per hour except the 2001 study which was run at

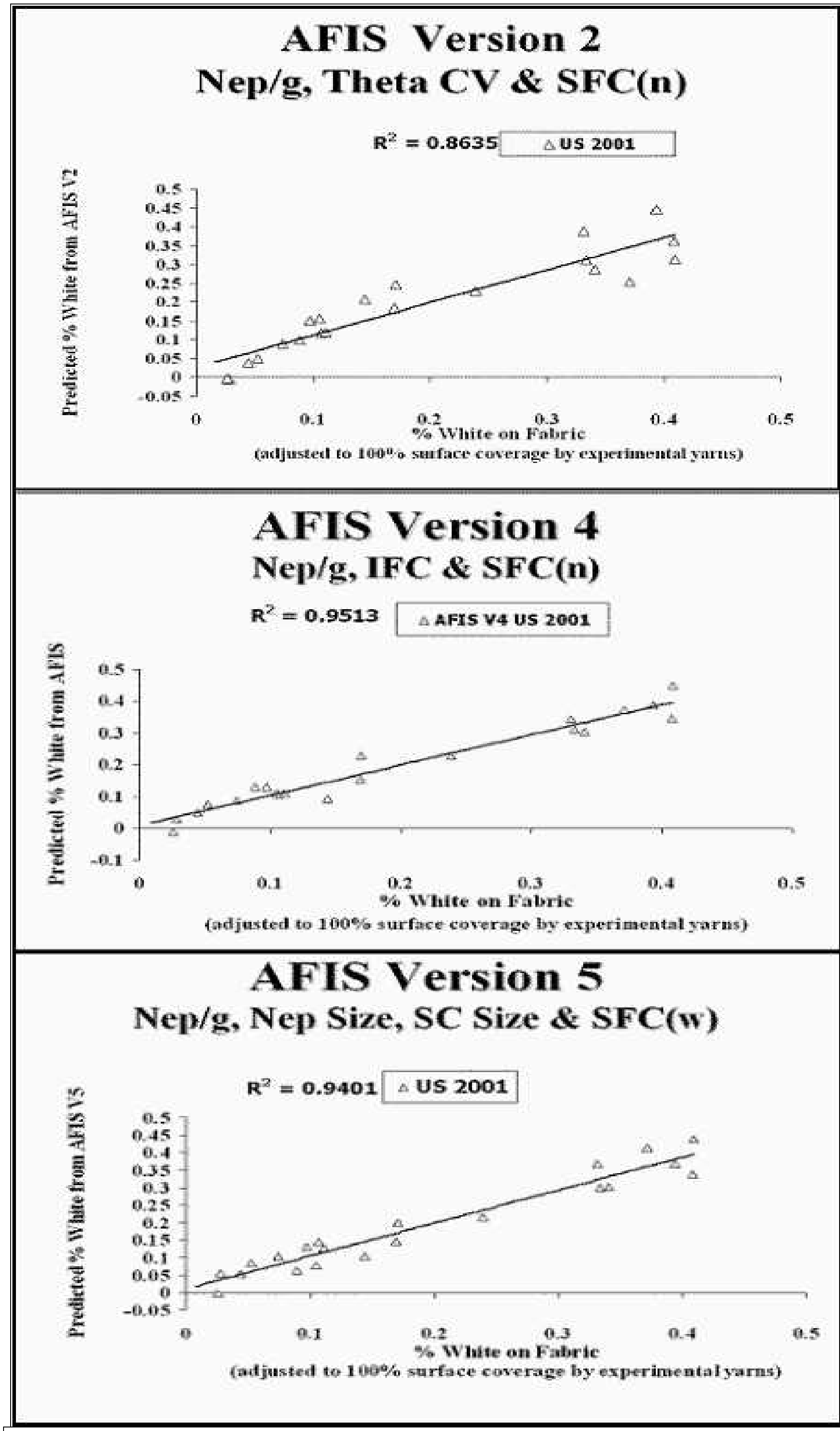

Figure 17: AFIS Versions 2, 4 & 5 - Fiber property relationships to white speck

150 lbs per hour, which results in significantly higher levels of white specks. This study was used to develop the prediction equations since it is more compatible with industry speeds.

Fiber to Fabric Relationships

Many high-speed fiber measurement systems are trying to characterize maturity and several have been analyzed and are discussed in the next few figures. Three different Versions of AFIS have been studied: Versions 2, 4 and 5. The SAS Forward selection model was used for all of the systems studied and it give us predictions of 86%, 95%, and 94% for the 2001 crop.

All three versions of AFIS (Figure 17) require Nep measurements along with a factor of processing severity (SFC - Short Fiber Content, the more processing in the gin the higher the level of short fiber) to predict white specks. Versions 2 and 4 also include maturity measurements to improve their predictions of white specks.

The HVI micronaire predicts about 92% of the white specks for the 2001 study (Figure 18). The Buckling Coefficient is a predictor of neps as described by Alon and Alexander (1978). The longer and finer the fiber, the more prone it is to nepping and the finer fibers are usually the immature fibers that create white specks. When an indicator of processing (Uniformity Index) and an indicator of maturity (RD – immature fibers are highly reflective) are added to the nep factor (Buckling Coefficient) from HVI data white specks can be predicted.

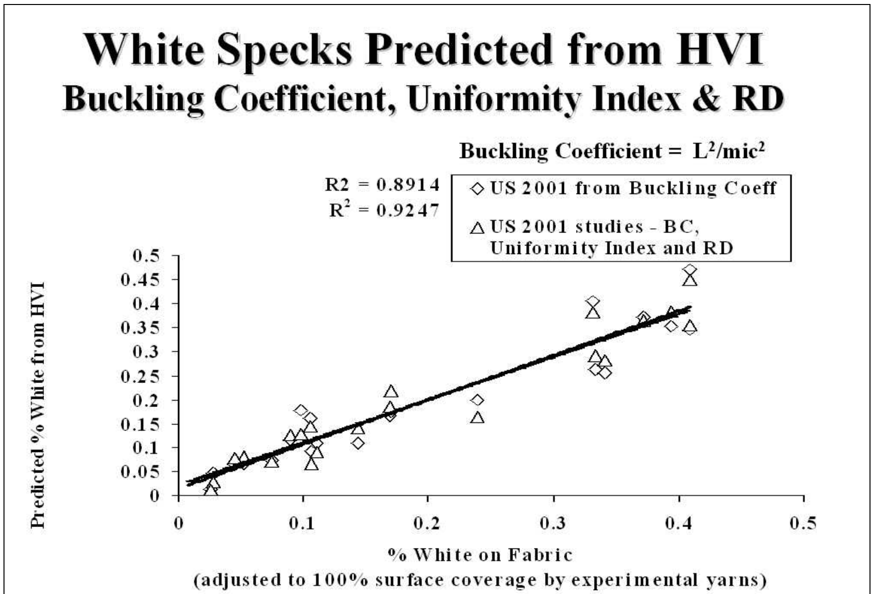

Figure 18: HVI fiber properties that predict White Specks

Lintronics, the latest system studied, also shows great promise. The 2001 study has 92% prediction of white specks from the fiber data. The SAS Forward selection model indicated that Nep count/gram, Nep Area/gram, Seed Coat fragment size (SC Size) and Maturity were the best predictors of % White for Lintronic's Fiberlab system. Nep count/gram and Nep area/gram were covariant and to minimize the number of variables Nep count /gram was chosen as it gave slightly higher R-square values. 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, so it seems to follow the trend of having nep, maturity, and processing severity components as seen in the other systems. The trend lines from the regressions are shown in Figure 19.

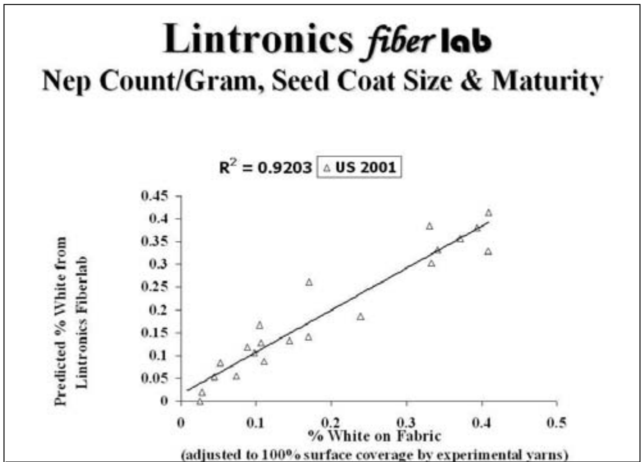

Figure 19: Lintronic's fiber to fabric relationships.

The equations that were developed from the SAS Forward selection model for each of these fiber measurement systems are shown in Figure 20. These are preliminary equations for White Speck Potential (WSP) and will be validated or improved with a larger scale study.

Prediction Equations for % White

- **HVI** R-Square = 0.9247
  %W = 3.3682 *(UQL²/mic²) + 0.02169 * Uniformity Index + 0.00848 * Rd- 2.51531
- **AFIS-V2** R-Square = 0.8635
  %W = 0.0000936 * Nep/g - 0.02054 * SFC(n) + 0.04053 * Theta CV – 1.27841
- **AFIS-V4** R-Square = 0.9514
  %W = 0.000484 * Neps/g + 0.07983 * IFC – 0.01006 * SFC(n) - 0.13291
- **AFIS-V5** R-Square = 0.9401
  %W =0.000904 * Nep Size + 0.00047 * Nep/g + 0.00059 * SC Size + 0.2283 * SFC(w) – 1.0662
- **Lintronic's fiber lab** R-Square = 0.9203
  %W =- 0.87865 * Maturity + 0.000212 * Nep Count/g – 0.55105 * SC Size + 1.269765

Figure 20: White speck prediction equations for high-speed fiber measurement systems.

Summary

SRRC plans to conduct a long term study with at least as many samples as these studies combined but with everything done exactly the same in the mill and known lint cleaning levels at the gin. Predictions will be developed from this large database (everything is held constant as far as mill processing). Once a White Speck Potential (WSP) is developed, it can be used as a tool by the mills and by the breeders. The breeders will be able to eliminate varieties early on that have a propensity to white speck. 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, such as whites where dyeability is not a problem, both the producers and the mills will have avoided a major problem. Shirting, undergarments, sheets, and toweling are big markets that consume large quantities of cotton. These markets 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. Then, if the cards are in good running order, the mills may comb the cotton or use open-end or vortex spinning to minimize the problem.

[1.] This manuscript has been referred for the 2005 Beltwide Proceedings

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