Measurements of seed coat fragments in cotton fibers and fabrics

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Abstract
Seed coat fragments (SCFs) are the parts of a seed coat that have been broken from the surface of either mature or immature seeds during mechanical processing. SCFs can cause spinning problems and fabric defects, which ultimately cause financial losses to the cotton industry. The objective of this study was to develop and evaluate an image-analysis tool that detects SCFs on fabrics and compares various methods of detection of SCFs in fiber and fabric. The first part of this paper looks at 12 international cottons (a broad range of cottons from distinctly different regions). The version called AFISPro is used in these studies. The SCFs in these fibers were measured by hand sorting, the Shirley Analyzer and the Advanced Fiber Information System (AFIS). The SCFs in the fabrics (made from the same cottons) were measured by hand counting and an automated image-analysis system (Autorate). The Autorate SCF fabric data had a high correlation with the hand-counting SCF fabric data. The same 12 international cotton samples and an additional 12 international cottons were used for the AFISPro studies, since AFISPro is much faster than hand sorting. Comparison of the fiber and fabric data showed a promising relationship between the AFIS SCF measurement and the SCF fabric data.

Keywords
Cotton, image analysis, seed coat fragments

Introduction
Cotton fibers often contain two different types of nep, mechanical nep and biological nep, both of which affect yarn evenness and fabric appearance.¹ Mechanical neps are entangled fiber clusters originated from the manipulation of the fibers during processing.²,³ Biological neps are those that contain foreign materials, such as seed coat fragments (SCFs), leaves, or stem material.⁴ One particularly troublesome form of biological nep is the SCF with an attached fiber (Figure 1). According to Hebert and Thibodeaux¹ and Anthony et al.,³ 13%–27% of all nepes contain SCFs. White specks (knots of immature fibers in dyed fabrics that have been identified as nepes⁵) of a dyed fabric can be composed of fibers attached to the SCFs of mature seeds or to mote fragments,⁶ sometimes resulting in both white specks and dark specks (SCFs) in the fabric, making some SCFs problematic in greige and dyed fabrics. Funiculi, motes, and SCFs (having fiber or not) are collectively called SCFs and are the main source of nepes,⁷ yarn imperfections, decreasing strength, and poor dyeability.⁸,⁹

In this study, we are concerned with SCF nepes. SCFs are the part of a seed coat that has been broken from the surface of either mature or immature seeds during mechanical processing. Some SCFs originate from the chalazal end of the seed. SCFs were broken from the seed because the seed coat was weak and easily peeled in that part.¹⁰ Some SCFs broke off the seed because the seed tissue beneath the seed coat at the chalazal end (where the fiber grows) was spongier at that end of the seed.¹¹ Other SCFs are generated from seeds being damaged in harvesting and ginning. Moore and Shaw¹² found that 7.3% of the seed entering the gin plant were damaged, with an additional 9.1% damaged before the gin stand and 7.2% at the gin stand. Their research indicated that seed damage during harvesting was equally important. SCFs are not easily removed in

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processing and can contaminate yarn and fabric. They are usually black or dark brown, which can spoil cotton fabrics’ aesthetic effect, because they differ in color and morphology from the fibers. With increasing amounts of impurities, such as husks, leaves, stalks, and SCFs, the tendency towards nep formation increases, a greater number of cleaning points are required during ginning and opening, and fiber breakage and short fiber content increases. This causes a deterioration in spinning performance, yarn quality, decreased mill production efficiencies, and a decreased marketability of problematic cottons.

Cotton genotypes can have a potential for large numbers of undesirable SCFs that cause problems in textile processing. In one study, nearly 30% of small textile imperfections were attributed to SCFs. Most seed coats have a substantial amount of fiber attached, which can make them difficult to remove during processing. Seed coats that remain after cleaning and carding can cause breaks during spinning and generally reduce the quality of the greige and dyed fabric. Some varieties are more prone to release SCFs than others due to the fiber-to-seed attachment. The SCF in ginned cotton can vary by 50% due to cotton variety, so it is important to know cultivar characteristics for this trait. Two of the most important factors contributing to the occurrence of SCF are the variety of cotton and timing of the harvest. Seed coat attachment strength is strongly related to variety.

Cotton breeders would like to upgrade fiber quality for improved future varieties. Breeding programs have been geared to producing longer, stronger, and finer cottons, with emphasis on yield. However, other elements, such as the percentage of immature fibers or seed coat attachment, may be ignored and then change along with the targeted fiber property. While attempting to increase lint yield, cotton breeders have noticed that genotypes with a high lint percentage generally have poor seed coat quality, which is characterized by a small seed with a brittle seed coat. As breeders pursue the goal of increased lint yield, it is important that work is performed to address the measurement and prediction of SCFs. If the predicted SCF levels are too high, those bales can be used in lower quality product lines and breeders can use the predictions as a method to weed out bad varieties in order to maintain the quality of the lint produced.

The fiber-to-seed attachment plays an important role in the occurrence of SCF problems. The larger the fiber-to-seed attachment force, measured by the Fiber to Seed Attachment Force Tester, the larger the number of SCFs. No fiber properties, such as strength or elongation at break, correspond to the fiber-to-seed attachment force. Bargeron and Garner studied a pendulum apparatus to model the cotton lint-seed separation processing during ginning, showing that it took much less force to remove the SCFs from the chalazal end of the seed than that required to remove lint from the seed. SCFs disrupt cotton spinning processes by creating irregularities in the yarn and can lead to production stoppages. One of the detection methods used to classify cotton contaminants is the Uster AFISPro. The SCFs detected by this method are those to which fibers are attached and are thus known as seed coat neps (SCNs). Large SCFs devoid of attached fibers or with little lint attached are placed in the trash category. All contaminants smaller than 500 μm are considered as dust or microdust; therefore, the subcategories of SCFs by AFISPro (Pro version of AFIS) are SCN, trash (with and without fibers), and dust/microdust. According to the same authors, this division of SCFs into subcategories is necessary because SCFs devoid of attached fibers are more easily removed during spinning. Attention therefore focuses primarily on SCNs, which are more difficult to remove because of the attached fibers and are therefore more detrimental to the spinning process and to yarn quality. Gourlot et al. used the Trashcam, a rapid automated image analysis of card webs, to evaluate the SCF potential of fibers. Most research of SCFs takes place in fibers, card webs or yarn, but the problem persists in fabric.

The objective of this study was to develop and evaluate a new image-analysis system that measures SCFs in fabrics and then analyzes the relationships between SCF measurements in fibers and fabrics. This paper reports those measurements and their relationships, which may help the cotton industry to understand what measurable fiber properties are considered the most vital for quality in processing. This paper looks at a broad range of cottons from distinctly different regions, and the test results
from the Shirley Analyzer and Advanced Fiber Information System (AFIS), the Pro version (AFISPro) cotton measurement systems to determine the most significant variables that are readily available to most mills to predict SCFs in the fabric. These cottons were also hand sorted for basic information on SCFs.

Materials and methods

Twelve international cottons (30 lbs each) collected by Wakefield Inspection Services from China, Turkey, Uganda, and Uzbekistan were selected for the Shirley Analyzer and hand-sorted studies. These cottons were categorized as high, medium, and low qualities. These characterizations were relative quality characterizations based on observations and comments at the collection site by Wakefield. Additional cottons from Wakefield (high medium and low quality) from Turkey (one set = three cottons) and Brazil (three sets = nine cottons) were used for the AFISPro study. The cottons were processed at the Cotton Quality Research Station (CQRS) from 6.81 kg (15 lb) quantities in the following manner.

Opening & carding: process 6.81 kg (15 lbs) of cotton into 60 grain (gr) card slivers. Carding at 27.2 kg/h (60 lbs/hr).

First drawing: make six cans for the second drawing 58 gr. sliver at 400 m/min.

Second drawing: make up to 32 cans for roving 55 gr. sliver at 400 m/min.

Roving: make as bobbins of 1.00 HR., with 1.30 TM, and 1200 RPM flyer speed for ring spinning.

Spinning ring: spin 27 tex (22/1) with a 3.96 TM, 14,750 spindle speed, and a #1 traveler.

Winding: wind 0.45–0.90 kg (1–2 lb) cones for weaving.

Cloth construction: 27 tex (22/1) experimental yarns from each lot were woven as filling into a five-harness filling face sateen with a thread count of 80 × 93, with the 20 tex (30/1) common combed warp. The warp was combed to remove defects (neps such as white specks and SCFs), so the only defects that are visible are from the experimental filling yarns. The experimental yarns cover approximately 85% of the surface of the fabric.

Three SCF separation/sorting techniques were used and compared: hand sorting, standard Shirley Analysis testing, and ‘Shirley Analysis + ’ testing. The same cottons were processed with the Shirley Standard procedures and that data was reported along with Shirley Analysis + SCF and the hand-sorted cottons. The SCFs in the fabrics were measured using an automated image-analysis system. Samples for these tests were conditioned for at least 24 hours in the standard conditions and then weighed.

Hand-sorting test

Exactly 100 grams of each cotton were weighed out as a sample. Only one lot of 100 grams was hand sorted into the three elements, SCFs (including motes), trash (leaf, stick, stem, bract, bark, funiculi, and other plant parts along with dirt and various other materials), and fiber, using tweezers (see Figure 2). Funiculi often fall out as trash during processing. Motes and SCFs with fibers are more difficult to remove than Funiculi and trash in processing. The total weight of SCFs was determined per mass of fiber according to ASTM D-2496-80.25

It typically took 2–10 days to sort each sample, depending on the levels of trash and SCFs. Our initial analysis showed very little relationship between the SCFs pulled from the samples and the SCFs in the fabric. Hence, the SCF fraction of the test was sorted again and the excess fibers were pulled off the fragment, leaving only linters on the seed coat, as seen in Figure 3.

Shirley Analysis test

The non-lint content in cotton was determined by using the Shirley Analyzer26 (five reps of 100 g) as follows.

1. Weigh 100 g of specimen for each cotton, and spread half of the sample of lint as evenly as possible over the feed table of the analyzer. When the entire portion has passed through the machine, repeat the process with the remaining half. Any large mass of fibers was pulled apart in order to make the batt even.

2. After the test specimen has passed through the machine, collect the lint from the trash pan. Shake the lint lightly over the trash pan to remove the adhering trash and process the lint through the machine.

3. Take clean lint from the lint compartment and repeat Step 2. The fibers were placed on the feed table at right angles to the position in which they are collected in the lint compartment. When nearly the entire first half has fed through the machine, feed in the remaining portion.

4. Weigh the cleaned lint and the waste from the non-lint compartment to the nearest 0.01 g separately.

5. Calculate the total waste by subtracting the clean lint weight from 100.00, then subtract the visible waste from the total waste to obtain the invisible waste. The visible waste, as shown in Figure 4,27 consists of leaf, stick, stem, bract, SCF, mote, funiculi, and other plant parts, along with dirt and various other materials (ASTM D-2496-80 test method28).
**Figure 2.** Hand-sorted seed coat fragments.

**Figure 3.** Seed coat fragment with fibers attached (a) and seed coat fragment with fibers removed (b).
The lint from the waste fraction was fed through the Shirley Analyzer twice, and the lint deposited in the lint box was removed from the instrument and added to the lint fraction previously obtained. Each time when the lint from the waste fraction was removed, the loose trash without fiber (heavy trash easily shaken out of the waste fraction) was collected in a separate weigh pan labeled trash. After the second run of the waste fraction through the Shirley Analyzer, the remaining waste fraction was spread over a 1680-micron mesh sieve and vigorously shaken for one minute, similar to Ahmedabad Textile Industry Research Association’s (ATIRA’s) SCF tests. The remaining visible waste collected by the Shirley Analyzer was SCFs with adhering fibers and remains on the screen and all other impurities that pass through were added to the trash weigh pan. The remaining waste fraction from the screen was called the SCF.

**Shirley Analysis + test**

This test starts with the SCF (five reps) from the standard Shirley Analysis test. The cotton had additional passes through the Shirley Analyzer until the lint deposited in the lint box was negligible (about 2 mg). This usually took 7–15 (Weller) additional passes, depending on the sample. The last step above was repeated and the sample was weighed as fiber, SCF, and trash. The Shirley Analysis + test, with these extra runs of the ‘waste’, resulted in a sample that

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**Figure 4.** Shirley Analysis visible wastes, including leaves, motes, seed coat fragments, sticks and stems (bark), and funiculi.27
looks similar to the hand-sorted cottons, leaving only trash, clean cotton, and SCFs. The SCFs from the Shirley Analysis + test were much less fibrous than the initial hand-sorted SCFs.

**Advanced Fiber Information System - Pro version**

The AFISPro tests individual fibers and identifies non-single fiber elements as neps, SCNs, or trash, depending on the signals when they pass the sensors. The AFISPro has two modules: AFIS-N and AFIS-L&D. The former tests the number of neps and the size of neps, while the latter tests the length and the diameter of fibers, such as fineness and length by weight ($L(w)$) and number ($L(n)$) and their CVs. Five reps of 500 mg fiber samples of the 24 international cottons were tested on both AFISPro modules simultaneously at the Southern Regional Research Center (SRRC-ARS-USDA).

**Automated Image Analyzer for counting SCFs in fabric**

A fully automated system for scanning dyed fabrics for white specks (defects on fabric), called the Automated Image Analyzer (Autorate; Figure 5), was manufactured by Fabrate, LLC, and installed at SRRC. Autorate can quickly and automatically detect and count white speck neps on dyed cotton fabrics. The system is expected to replace human evaluation of white specks on dyed fabrics because it provides reliable and repeatable measurements. When the Autorate system was modified by Fabrate, LLC, to measure SCFs (dark specks in greige fabric), a new digital camera with a built-in flash was installed for a higher pixel resolution and more uniform lighting (Figure 6). The resolution of this camera is 10 times higher resolution (10 Megapixels) than the previous camera, and its flash largely eliminates ‘hot spots’ seen in the old system. The new Autorate system was used to measure the dark specks on the greige fabrics.

The computer captures an image when the camera flashes and then analyzes it for dark specks (number of specks, percentage area of specks, and mean size of specks). The region of interest (ROI) is $143 \, \text{mm} \times 218 \, \text{mm}$. SCFs in a fabric appear much darker than the fabric, and therefore detecting SCFs is a procedure of finding dark specks. The dark speck-counting program is essentially the same as the ones used for white speck counting, except that the image needed to be converted into grayscale and inversed before the counting. The threshold for the minimal size of valid dark specks was determined with hand-count results. The minimum pixel size...
was changed and the resulting count/sq meter was compared to the hand count/sq. meter. A minimum pixel size of 5 was the best fit to the hand count. Figure 7 shows the analyzed fabric on which the dark specks are highlighted in light gray on the computer monitor.

**Figure 6.** New Autorate that incorporates a digital camera with a flash-eliminating ‘hot spots’.

**Figure 7.** An original image and the image analyzed for dark specks by Autorate.
Hand-counted SCFs in fabric

Fabrics were hand counted for dark specks by placing a plastic sheet over the fabric and marking the plastic sheet (91 mm x 193 mm) for each dark speck. The plastic sheet was then lowered a few millimeters and the operator circled the dark specks that were bark, and subtracted this number from the original count to determine SCFs (dark specks minus bark). Bark appears as a dark line woven into the fabric and can be mistaken in the image analysis as several dark specks due to the weave pattern breaking up the dark line of bark into several ‘dashes’. Bark has a lighter shade than SCFs. The next generation of Autorate will look for bark using shape and color parameters to differentiate bark from SCFs.

Regression analysis was performed using Statsoft and Microsoft Excel on the collected data to reveal trends between fabric SCFs and AFIS fiber properties. In the multiple linear regressions, the dependent variable was SCFs and the three independent variables were AFISPro SCN, trash count/gram (trash), and visible foreign matter percent by weight (VFM).

Results

In Figure 8, the standard Shirley Analysis %SCF was generally higher that both the hand-sorted %SCF and the Shirley Analysis + %SCF. The Shirley Analysis + and the hand-sorted %SCF were similar, but the hand sorted was higher due to the lint still being attached to the SCFs. Visually, the hand-sorted SCF with lint attached has much higher levels of lint than the delinted SCF and the Shirley Analysis + SCF (Figure 9), as expected. The actual Shirley Analysis + SCF sample looked very similar to the delinted hand-sorted SCF sample (Figure 9). Figure 10 shows that the trash collected from the Shirley Analysis + was much finer (ground-up during Shirley Analyzer testing) than the hand-cleaned cotton trash (the amount remained the same for delinted SCF as for the SCF with lint). In Figure 11 the hand-sorted delinted SCF regression shows that the relationship to Standard Shirley SCF had an $R^2$ of 0.2368 and the Shirley Analysis + ’s $R^2$ (0.5462) was almost double that of the standard Shirley Analysis, but neither Shirley Analysis has a strong relationship to the delinted SCF.

Autorate counted all dark specks (including those caused by barks). Figure 12 compares the numbers of dark specks on fabrics obtained from hand counting and those measured by Autorate, resulting in an $R^2$ of 0.9412.

In Figure 13, the number of dark specks/square meter by Autorate is compared to the percent of SCF by weight from Shirley Analysis, Shirley Analysis + and hand-sorted SCFs (with lint and delinted). Shirley Analysis + SCF with an $R^2$ of 0.5302 and the hand-sorted delinted SCF with an $R^2$ of 0.686 both show some promise in predicting a SCF problem in the fabric.

The AFISPro was the next measurement system that we studied, and since it is much faster than hand sorting and Shirley Analysis and Shirley Analysis +, extra samples were run to improve the statistical data. This included one extra set of samples from Turkey (high, medium, and low quality) and three sets of samples (high, medium, and low quality) from Brazil for a total of 24 samples (the original 12 and the additional 12). The relationship between fabric dark specks/m$^2$ and fiber SCF as measured by the AFISPro SCN/g (Figure 14) has an $R^2$ of 0.5962 (adjusted $R^2=0.577$), with the following equation:

\[
\text{Fabric SCF} = (114.169 \times \text{AFISPro SCN}) - 579.441.
\]

This $R^2$ is increased to 0.733 (adjusted $R^2=0.691$) when the AFISPro trash count/gram and VFM are included (Figure 15) with the following equation:

\[
\text{Fabric SCF} = (84.286 \times \text{AFISPro SCN}) - (69.018 \times \text{Trash}) + (3682.699 \times \text{VFM}) - 436.5.
\]
Figure 9. Seed coat fragments from Shirley Analysis +, hand sorted with lint attached and hand sorted with lint removed (delinted).

Figure 10. Trash particles from the Shirley Analysis (a) and hand cleaning (b).
break some of the seed coats, increasing both the trash and the VFM, which is why they are significant in the final equation. Figure 3 shows the excess trash that occurs when the fibers are gently removed using tweezers and the effect of the opening rolls in the AFISPro would probably produce much more trash and VFM than this hand method.

Conclusions

This paper explored possible correlations between nep and trash measurements in fiber and SCFs in fabric. It was found that: (1) SCFs made by the Autorate had a good correlation with hand counting of dark specks (SCFs) in fabric; (2) the best AFISPro fiber measurement used to predict SCFs in fabric was the AFISPro SCN, but a better correlation could be achieved when it was coupled with AFISPro trash count and VFM; and (3) Shirley Analysis is not a good indicator of SCFs in fabric.

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Conflict of interest statement

None declared.
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References


Figure 15. Autorate versus the Advanced Fiber Information System (AFISPro).

$R^2 = 0.733$


