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BREEDING, GENETICS, & GENOMICS

Past and Current Research Activities on Seed Coat Fragments

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ABSTRACT

Seed coat fragments (SCF) are portions of cottonseed that have broken off from mature or immature seeds and might or might not have attached cotton fibers. SCF are created during cotton harvesting or ginning processes. Additional factors that contribute to SCF include genetics (cultivar), environmental issues, weathering events, and cultural practices. SCF are the second most common impurity in textile products. Neps, which are entanglements of fibers, are the most common impurity and make up most imperfections found in yarn. SCF reduce processing efficiency by causing ends-down during spinning and lead to defects in fabrics. This article presents past research and current unpublished research that has been conducted on SCF. Discussions include: chemical and physical properties of the seed coat leading to SCF; ability to use genetic information to select for genotypes with low SCF potential; opportunities in variety development and G x E interactions; modifications of mechanical processing to reduce SCF; and textile mill impacts of SCF. Based on findings from these studies, future strategies to combat SCF include better understanding of the physiology of SCF components and how formation is impacted by the environment, modeling to predict favorable harvest and ginning conditions, and modifying ginning and textile machinery to reduce the formation and increase the removal of SCF in U.S. cotton.

Seed coat fragments (SCF) in cotton are portions of cottonseed that have broken off from either mature or immature seeds during mechanical (harvesting and ginning) processes (Mangialardi, 1992). SCF that end up in the bale from the cotton gin are passed on to the textile mill. Textile yarn and fabric manufacturers are concerned about the negative impact of SCF on production and quality. SCF contribute to weak places in yarns, often resulting in ends-down during yarn production. Once in the yarn and woven or knitted into fabric, SCF create flaws in the finished product visible as dark or light specks, depending on the final product. Rough appearance of the fabric can result in a heavily discounted product.

SCF in cotton lint is not a recent phenomenon. Summers (1925) recognized from his observations while conducting research on neps and other defects in yarns that faults could be attributed to the presence of material(s) other than the normal cotton fiber. He named the fault causing impurities fuzz neps, denoting tiny fragments of seed coat with fiber attached. In 1933, N. L. Pearson wrote "Recent complaints made to the Department of Agriculture and elsewhere, by foreign and domestic manufacturers, allege that neppiness and poor preparation occur in American cotton more often than is necessary" (Pearson, 1933). Pearson differentiated 15 kinds of neps including those associated with SCF (Pearson, 1933).

Prior to the introduction of lint cleaning in cotton gins (Mangialardi, 1970), determination of the source

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of SCF in cotton lint was complicated by the presence of immature seeds and ovules (often referred to as motes) in ginned cotton lint (Pearson, 1933). During the mechanical process of ginning, coalesced motes in the seed roll are subjected to the damaging effect of the gin saws, increasing the number of individual SCF while diminishing fragment size. Differentiating SCF origin, whether mote generated or damaged mature cottonseeds, required skilled technicians with microscopes to make the determinations.

The advent of gin lint cleaning had a significant impact on post-gin-stand cleaning of lint, especially separation of motes and SCF from the cotton lint, with large motes being easier to remove than small motes (Hughs et al., 1988). Hughs et al. (1988) surmised smaller motes were less likely to come out with lint cleaner trash due to their size and weight. Small motes typically include thin-walled immature fibers that are less likely to absorb dyes. Once in the fabric these fibers form an off-colored speck or nep.

A nep, according to the American Society for Testing and Materials (ASTM), is “one or more fibers occurring and entangled into an unorganized mass” (Hebert et al., 1987). However, the ASTM definition does not account for the presence of SCF within the entangled mass. Hebert et al. (1987) distinguished the difference by referring to the fibrous nep as a “mechanical nep” versus the SCF/fibrous mass as a “biological nep” that Summers (1925) named fuzz nep and today is the definition of a seed coat nep (SCN) (Montalvo et al., 2014).

Despite the lint cleaner’s effectiveness at removing SCF, indications are that the majority removed had few fibers attached (Armijo et al., 2012). The cohesive nature of the fiber encourages SCF to remain stubbornly attached to “good” fibers (Fig. 1) making for a difficult removal. The tenacity of the attachment not only makes these SCF difficult to remove at the cotton gin but creates production problems at the textile mill where SCF are broken into ever smaller, more difficult-to-remove fragments. These small fragments eventually end up as biological neps in fabric.

There has been much discussion and speculation regarding the origin of SCF. Pearson (1939) devoted an entire manuscript to the relation of the chalazal portion of the cottonseed coat and its rupture during ginning. She concluded that the weak spongy tissue at the chalazal end constituted a likely area where chipping can occur during the ginning process. However, Bargeron and Garner (1991) found that there was a weak relationship between chalazal SCF potential and SCF in fabric. They found that for the group of cotton cultivars used in their study, chalazal detachment work accounted for 16% of the variability in the fragments on the fabric; percentage damaged seed, 1%; and seed size coefficient of variation, 73%. They concluded that seeds less than 3.73 mm in diameter, when present in seed size distribution, were the major source of SCF contamination. However, Boykin (2010), when evaluating various parameters of 63 cotton varieties, found no consistent relationship between SCF content and seed diameter distribution, and no indication that cultivars with smaller seed were prone to higher SCF content.

Figure 1. Seedcoat fragments (SCF) from the chalazal end of the seed breaking off during ginning. An example of SCF generated during the ginning process.

The identification of where SCF are created has been a topic of extensive research over the years (Anthony et al., 1988; Boykin, 2006, 2008a; Pearson, 1933, 1944, 1955). Bargeron and Garner (1989) cited three sources of SCF: damaged, immature, and undamaged mature seeds. The damaged seeds were considered seeds that had been damaged during harvesting and handling of the seed cotton prior to ginning, the immature seeds (motes from unfertilized ovules) were from harvested seed cotton that had not matured fully prior to harvesting, and the undamaged mature seeds were seeds that were considered damaged during the ginning process. Pearson (1944), Bargeron and Garner (1989), and Boykin (2006, 2008a) along with other researchers also have noted the influence of variety, environment (growing season), and harvesting method with variety and environment interaction being considered one of the most significant influences of SCF. Anthony et al. (1988) noted weather as the most significant influence in producing SCF compared to varietal factors or harvest method.

In 2020, the influence of weather on SCF became apparent with the largest number of SCF calls in the last 20 years corresponding with Hurricane Sally hitting the Alabama, Georgia, and Florida panhandle crop in September 2020 (Barnes, 2021; Hand et al., 2022) (Fig. 2). The impact of Hurricane Sally resulted in 1,085,518 samples of the 2.2 million samples classed in the Macon, GA U.S. Department of Agriculture, Agricultural Marketing Service (USDA-AMS) classing office containing SCF (Cotton Incorporated, 2024). For comparison, the Macon, GA classing office reported 60,829, 1,400, 46,733, and 7,223 bales containing SCF in 2018, 2019, 2021, and 2022, respectively (Cotton Incorporated, 2024). The combination of variety and environment can have a significant impact on seedcoat development and durability (Anthony et al., 1988; Boykin, 2006, 2008a; Pearson, 1955), and when growing conditions are less than desirable creating wet and immature seed development prior to harvest, the stresses and pressures resulting from the mechanical processing (harvesting and ginning) only exacerbate the potential for SCF.

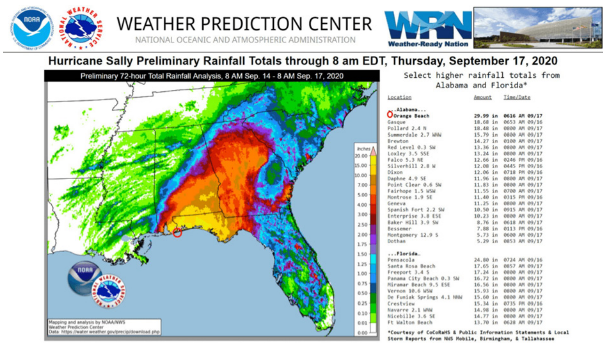

Figure 2. Hurricane Sally's rainfall in September of 2020 that greatly increased the number of seedcoat fragments (SCF) calls at the classing office in Macon, GA for the 2020-2021 ginning season. An example of a weather-related event that attributed to SCF.

Mangialardi (1988) explained how SCF are created and how their number and weight changed during various stages of processing. Boykin and Ray (2010) examined the impact of seed cotton cleaning on SCF and concluded that seed cotton cleaning prior to the gin stand (precleaning) did not result in a significant production of SCF even with additional seed cotton cleaners. Boykin (2008b) stated that 32% (by weight) of SCF created in the gin stand originate from mature seed that are "destroyed in the gin stand". Boykin added that small immature seed (without meats) accounted for 15% (by weight) of SCF, and that 7% of seed were damaged in the gin stand while remaining intact, resulting in the conclusion that damaged seed were thought to be a major source of SCF created in the gin stand.

The objective of this article is to provide the cotton industry with a single comprehensive document that not only gives a historical review of SCF research activities, but also presents the latest unpublished textile findings on SCF. The discussions are in depth and will focus on the following: (1) chemical and physical properties of the seed coat leading to SCF, (2) ability to use genetic information to select for genotypes with low SCF potential, (3) opportunities in variety development and G x E interactions, (4) modifications of mechanical processing to reduce SCF, (5) textile mill impacts of SCF, and (6) future strategies to alleviate SCF.

CHEMICAL AND PHYSICAL PROPERTIES OF THE SEED COAT LEADING TO SCF

Seed Coat Fragment. SCF is used as a generic term that covers all debris derived from the coat of cottonseed. Each side of the cottonseed coat differs in appearance (Xu et al., 1999). The inner side does not contain fiber and its shape is round with solid color, whereas the outer side is hairy and fuzzy. Seed coat can be divided into two different categories: seed coat with fibers (hairy seed coats) and seed coat without fibers (smooth seed coats) (Xu et al., 1999). The surface of mature or immature seeds can break during fiber processing especially during cotton harvesting or ginning processes. The ASTM D2496 (ASTM, 1985) and ASTM D5867 (ASTM, 2012) test methods specify SCF as a part of the cottonseed that originates from mature or immature seeds with or without attached cotton fibers to the seed coat. Figure 3 shows SCF with fibers attached to it.

Generally, SCF are white at the primary stage of development and turn dark brown at the mature stage. Any contaminant smaller than 500 µm is considered dust or microdust (Krifa et al., 2002). Seed fragments attached to fibers that are larger than 500 µm are referred to as SCN.

Recalcitrant Nature of SCF. According to the survey of the International Textile Manufacturers Federation (ITMF) (Fig. 4), approximately 32% of all cotton evaluated in 2016 was contaminated with SCF

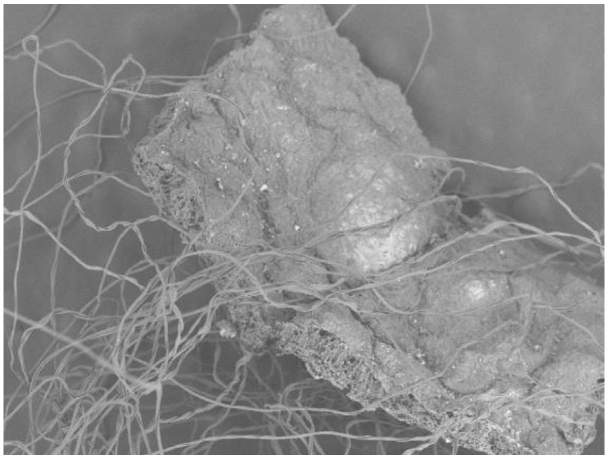

Figure 3. Seed coat fragment with fibers attached (Fiber and Biopolymer Research Institute, Texas Tech University).

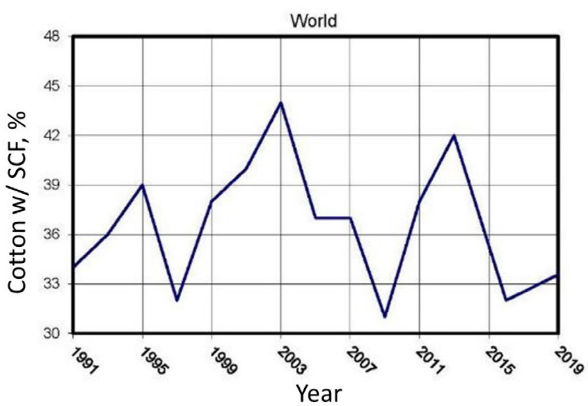

Figure 4. Percentage of all cotton evaluated during the ITMF survey for seed-coat fragments contamination between 1991 and 2019 (ITMF, 2020).

(ITMF, 2020). In most previous years, the contamination percentage was higher than 32%. SCF devoid of attached fibers can be removed easily during the opening and carding operations. However, most SCF contain a significant amount of cotton fibers and have all the features to be processed into fibers or yarn. SCF with fibers attached are the most difficult impurity to clean in cotton. Most of the time, it is difficult to remove seed coats during the cleaning process due to the attachment of substantial amount of fibers to the seed coat. The number of SCF increase in fibers during post-ginning cleaning operation by the lint cleaner, although the average size of SCF become very small. Efforts to remove the maximum number of SCF to improve cotton grade can increase the proportion of short fibers and reduce the length of cotton fibers. Therefore, yarn evenness and strength will be reduced, which could lead to yarn breakage during spinning. Moreover, opening and cleaning steps are not effective against SCF as fibers attached to SCF act as cotton tufts during beating and pneumatic flows. The discarded trash during opening and cleaning will not reduce SCF significantly. Instead, it increases the discarded proportion of good fibers that are eliminated with trash.

Increasing the number of cleaning steps to remove SCF excessively weakens fibers. Each step can deteriorate fiber quality as fiber breakage will not only increase short fiber content but also lead to poor yarn quality. The card is the last possible step to remove SCF intentionally before spinning; the card is effective in removing medium- and large-size SCN although it increases the number of SCN overall (Krifa et al., 2002). At the fabric stage, scouring is done to remove wax, pectin, and other non-cellulosic materials, but due to the recalcitrant nature of SCF and strong attachment with fibers, scouring is ineffective in removing SCF from the fabric. Even enzyme treatments cannot remove SCF as enzymes are unable to break down the complex structure of SCF (Dhandapani, 2013). Bleaching can remove SCF to some extent, but longer reaction time and higher concentration of chemicals are required to remove SCF, which can affect cellulose in the fabric and reduce fabric strength. To date, no effective solution has been identified for complete removal of SCF.

Problems Associated with SCF. Seed coat fragments are a primary source of yarn imperfection, which hampers the yarn manufacturing process and the quality of the finished products. The number of SCF present in the cotton fiber has a direct relationship with imperfection of the yarn. Neps are the main impurities in cotton followed by SCF and other

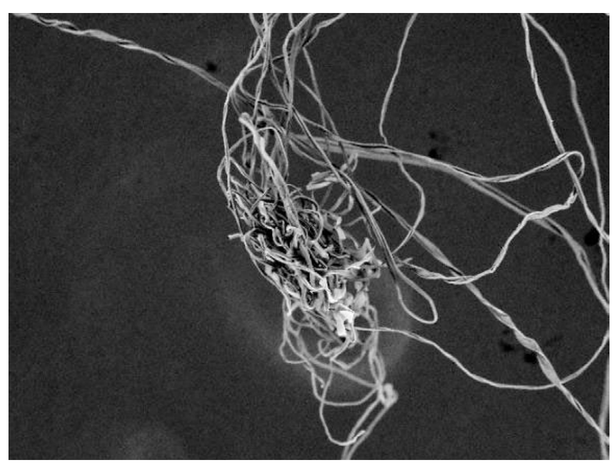

Figure 5. Fiber neps (Fiber and Biopolymer Research Institute, Texas Tech University).

non-seed impurities (Jacobsen et al., 2001). Figure 5 shows an example of fiber neps.

The tendency of neps formation increases with the increase of impurities such as SCF, husks, and leaves. Biological neps are created when trash particles entangle in cotton and create dark specks in the grey fabrics before dyeing. It has been reported that 13 to 27% of all types of neps contain SCF (Anthony et al., 1988; Hebert and Thibodeaux, 1993). The capacitive sensor evenness tester identifies SCF as neps when SCF are associated with thick and short irregularities. The mass variation threshold in ring-spun yarn and open end spun yarn is +200% and +280%, respectively. These neps are often invisible until fabric is dyed. SCF are different from cotton fibers in color and morphology. During dyeing, SCF are responsible for uneven dye uptake in fabric and make the fabric unsuitable for commercial use. Therefore, SCF can blemish the aesthetic look of fabric made from cotton and deteriorate fabric quality. Figure 6 shows an example of color variation in dyed fabric. SCF are responsible for multiple faults in the fiber manufacturing process such as abundance of short fibers and poor yarn quality. These types of defects create several weak points in the yarn structure and

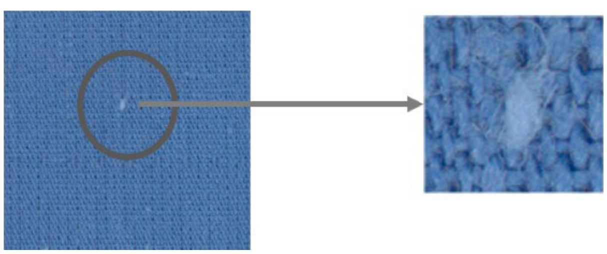

Figure 6. Shiny neps on cotton fabric (Fiber and Biopolymer Research Institute, Texas Tech University).

increase the ends-down of yarn. The specific load of rupture of yarn also decreases with the increase of SCF in cotton (Krifa et al., 2001).

Chemical Composition of SCF. Cottonseed has a high degree of micro-hardness that is almost equivalent to annealed aluminum and difficult to break (Yan et al., 2009). The seed hardness depends on several factors including temperature and environmental moisture during maturation of the seed, inorganic nutrition of the plant, and the structural features of seed coats (Paiziev and Krakhmalev, 2006). The seed coat of wild cotton is impermeable to water but the seed coat of cultivated varieties is not water impermeable. The impermeable nature of the seed coat helps the cottonseed survive in the soil before germination and protects the seed quality before harvest. The cotton seed coat is mainly composed of cellulose, lignin, pectin, and wax (Table 1).

Table 1. Chemical components present in cottonseed coat (Dhandapani, 2013)

Component	Typical Amt. (%)
Cellulose	**43-48**
Lignin	**22-26**
Pentosan	**5-10**
Wax	**5-7**
Protein	**2-4**
Calcium	**3-4**
Ash	**2.6-2.8**

Lignin is one of the major components responsible for seed hardness and the complex chemical structure of SCF (Yan et al., 2009). Lignins are three-dimensional network polymers comprising numerous linked phenylpropane units (Dhandapani, 2013). In SCF, lignin plays a major role in natural defense as it prevents the penetration of destructive enzymes through the cell wall. The main reasons for the unique and complex structure of lignin are the dominant linkage between abundance amounts of phenylpropane units and the frequency of some functional groups on these units. Polymerization reaction of lignin precursors forms a highly branched, three-dimensional interlocking network with high molecular weight. Lignin is synthesized from three different phenylpropane units depending on plant species: coniferyl alcohol, sinapyl alcohol, and *p*-coumaaryl. Softwoods contain lignins made of coniferyl alcohols, hardwoods contain lignins made of coniferyl and sinapyl alcohols, and grasses contain lignins made of all three alcohols. SCF contain lignins made of sinapyl alcohols.

A light spectroscopic analysis of SCF shows five layers in the seed coat structure: epidermal, outer pigment, colorless, palisade, and inner pigment (Fig. 7) (Yan et al., 2009). The epidermal layer mostly consists of cutin, wax, cellulose, and pectin. Lignin is the principal component of the outer and inner

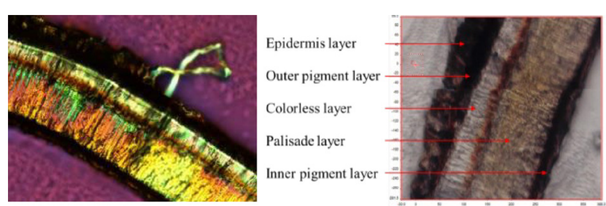

Figure 7. Cross-section of a seed coat fragment structure showing different layers.

pigment layer. The palisade layer mainly consists of pectin and hemicellulose (Yan et al., 2009). Approximately 75 to 80% of SCF contamination originates from the palisade layer and the SCF found on the fabric mainly consist of this layer. In addition, other chemical components are present in different layers of the SCF such as pectic ester, calcium pectate, and pectic acid.

Interaction of SCF with Fibers. Cotton fibers develop from the epidermal cells of the cottonseed and the association between fibers and seed is important to generate different amounts of SCF during ginning. Studies have been performed on the interaction of cotton fibers and associated seed coats (Himmelsbach et al. 2003; Yan et al., 2009). SCF break easily from the chalazal end of the seed because of the weak structure of the seed tissue located under the seed coat at the chalazal end (Boykin et al., 2012). The fiber properties and the surface chemistry of the fiber can affect the fiber-seed bond and the strength of fiber-seed bond interaction. Microscopic studies found that a cotton fiber is produced from three regions of the fiber base located in the epidermis: shank, elbow, and foot (Fryxell, 1963; Himmelsbach et al., 2003). The fiber breaks from a cotton seed at or above the surface of the epidermis, which is located near the elbow. The shank is constricted and imbedded in the epidermal cells. The foot creates an anchor close to the inner side of the epidermis (Fryxell, 1963).

The elbow is located at the intersection of the seed coat surface and the lint fiber. It contains thick primary cell wall materials that augment the strength of the fiber attachment to the seed coat (Vigil et al., 1996). The whole surface of the seed coat is covered by a protective wax layer. This layer is continuous along the surface of all fibers and provides additional attachment strength of fibers to the epidermis (Vigil et al., 1996). Studies suggest that the feet of the fiber and the outer pigment layer of cottonseed contain a large volume of pectate salts and other uronate salts (Himmelsbach et al., 2003). Therefore, pectin could be responsible for anchoring fibers in the outer pigment layer of the cottonseed.

Chemical Structure. Himmelsbach et al. (2003) used Fourier transform mid-infrared (FTIR) mapping and histochemical staining to investigate the location and the relative importance of chemical compounds at the base of cotton fibers and associated seed coat. The objective was to determine the nature of the compounds that hold cotton fibers at their base to the seed coat and other portions of SCF. Cottonseeds were embedded in resin and sectioned. Staining was performed on wax (using Oil Red O), pectin (using Ruthenium Red), lignin (using acid phloroglucinol), and tannins (using vanillin-HCl) (Himmelsbach et al., 2003). FTIR measurements were performed on thin cross-sections (6-8 μm) placed on BaF_2 slides.

The results showed that in the outer epidermal tissue waxes or long-chain alcohols were found adjacent to the shank of cotton fiber bases, whereas uronate anions were present in the epidermis and pigment layers surrounding the fiber base with a strong presence in the upper palisade layer (Himmelsbach et al., 2003). The juncture between the upper palisade and colorless layers were rich in compounds containing carbonyl functionality, acids, and bases. Tannin or pretannin-type aromatic structures were seen in the outer pigment layer, whereas lignin-type aromatic compounds were found in the colorless layer (Himmelsbach et al., 2003). The authors concluded that the results provided an understanding of fiber-seed interactions that could be used to enhance methods to separate fibers from the seeds and prevent SCF generation (Himmelsbach et al., 2003).

Yan et al. (2009) used FTIR microspectroscopy to study the cotton seed coat to understand the biodegradation of cottonseed fragments during bioscouring. In the bioscouring process, enzymes such as cellulase, pectinase, and hemicellulose are used to accelerate the degradation of hollocellulose in cotton SCF. The FTIR analysis of the cross-section of cotton seed coats (5-10 μm) revealed that cutin, wax, cellulose, and pectin were the main component of the epidermal layer, whereas pectin and hemicellulose were the main compounds of the palisade layer along with aromatic polyphenol (lignins). The outer and inner pigment layers were essentially composed of lignin. The results allowed the authors to conclude that bioscouring cotton to remove SCF could be achieved using cellulase, pectinase, xylanase, and lignin oxidase.

ABILITY TO USE GENETIC INFORMATION TO SELECT FOR GENOTYPES WITH LOW SCF POTENTIAL

Seedling Health. As mentioned earlier, SCF and neps together make up most small imperfections found in yarn. Neps are a major source of impurities followed by SCF and non-seed impurities (Jacobson et al., 2001; Mangialardi, 1992). According to Barnes

(2021), SCF outbreaks occur sporadically every 3 to 5 years in a region of the U.S. The biggest SCF outbreak in the last 20 years occurred in Alabama, Georgia, and Florida and was weather related. The interaction between variety and environment further complicates the issue. Anthony et al. (1988) reported that weather influences were more important than harvest or varietal factors.

Many researchers reported that factors to consider when dealing with SCF are rainfall, humidity, cotton variety, genetic factors, cultural practices (insect and weed control), harvesting procedures and timing, ginning, and nutrient availability. Increased mechanical handling is generally accompanied by an increase in SCF percentage in the ginned lint (Moore and Shaw, 1967; Watson and Helmer, 1964). Anthony et al. (1988) suggested selection of early maturing varieties that avoid adverse fall weathering to reduce SCF frequency.

With the recent trends towards cultivars with smaller seed, there has been some concern that increased SCF levels could result from smaller seeds that are more easily damaged or more likely to pass through ginning ribs. However, as mentioned, Boykin (2010) reported that there was no consistent relationship between SCF content and seed diameter distribution parameters. The results of his study showed no indication that cultivars with smaller seed, either overall or in the tails of the seed diameter distribution, were prone to higher SCF content.

Boykin (2010) indicated that the number of SCF in ginned lint varied significantly ($p < 0.001$) among cultivars within the early and medium maturity groups, ranging from 9.4 to 29.1 SCF/g lint. Although the result of Boykin's work did not show any strong trends in SCF content with seed properties, evidence supported the conclusion that cultivars with small seeds, either measured by mean seed diameter or seed index, do not produce ginned lint containing increased levels of SCF. In addition, cultivars with relatively larger seeds whose seed size distributions included smaller seeds were not shown to have higher SCF levels.

In an earlier work Boykin (2008a) reported that seed coats in ginned lint can be measured by manual or automated methods. SCF can be manually counted and weighed in lint (ASTM, 1985) from randomized samples by only one person. However, the analysis was slow with this method with fewer than two 3-g samples analyzed each hour. The Advanced Fiber Information System (AFIS) (Uster Technologies, Knoxville, TN) is an automated method to detect fiber properties including the number and size of seed coats in lint. Baldwin et al. (1995) described how the instrument individualized components of the fiber sample and characterized them as neps, seed coat neps, fibers, or other materials with different properties. Boykin (2008a) studied 38 moderate to early maturing cultivars in the Mississippi Regional Cotton Variety Trials from 2002 and 2003 at Stoneville and Tribbett locations with the objective of analyzing cultivar differences in SCF, motes, neps, and SCN. The samples were analyzed manually, with AFIS and with High Volume Instrument (HVI) (Uster Technologies, Knoxville, TN). Significant cultivar differences were found for SCF. The SCF number ranged from 8.9 to 27.4 SCF/g lint. The author noted that the number of SCN measured with AFIS was comparable to the number of SCF measured manually, but cultivars with large numbers of SCN or SCF compared differently for these measurements. This study pointed out the critical role cotton breeding plays in SCF prevention. Boykin (2008a) suggested that research in the future also should focus on harvesting and ginning issues. Three of the most important factors contributing to the occurrence of SCF have been shown to be cultivar selection, environmental conditions, and harvest timing. It was also suggested that environmental stress can impact SCF content.

Anthony et al. (1988) found that the number of SCF varied among five cultivars from 14 to 19 SCF/g lint and the weight varied from 12 to 21 mg SCF/g lint. Mangialardi and Meredith (1990) studied nine cultivars and found that the number of SCF ranged from 13 to 20 SCF/g lint and the weight ranged from 11 to 18 mg SCF/g lint. Because of the low number of cultivars involved in the above two studies, the results should be viewed with caution.

According to Krifa et al. (2001), SCF are parts of the cotton seed that have been torn off or shattered during ginning and are found in fibers used for yarn production. These contaminants are considered one of the primary sources of cotton yarn defects (Frydrych et al., 1999; Krifa et al., 2002). The presence of SCF has a significant deleterious effect on yarn strength, but this effect varies with fiber quality (Krifa et al., 2001).

In a 2-year study to compare 10 cotton cultivars for the number of SCF, motes, and resistance to loading force, Bolek et al. (2007) found that cultivars were not significantly different for SCF. Although cultivars were not significantly different for the number of SCFs in both years, mean values changed among cultivars and between years. Heritability for the number of SCF was 0.52 indicating almost equal genotypic and environmental effects on phenotypes.

Cotton fiber neps cause significant problems within the textile industry resulting in decreased yarn quality, decreased production efficiency, and increased production cost. A cotton contamination survey report published in 2014 by the International Textile Manufacturers Federation revealed that 42% of cotton spinners worldwide claimed that they have encountered moderate or significant amount of SCF in the cotton grown (ITMF, 2014).

Hinds et al. (2017) pointed out that SCF can arise from compacting when building modules during harvest, cleaning, and ginning the seed cotton as these processes can break the seed coats or tear-off part of the seed coat. The SCF with fibers attached are integrated in the structure of the yarn and create defects and weak spots, lowering productivity of the textile mills and market value of the yarn and fabric (Curran, 1992).

A measurement method for the determination of the SCF potential suitable for breeding does not currently exist. Such a method would provide an objective measurement for determining the genetic basis for SCF formation and would enable the development of varieties less prone to SCF formation (Hinds et al., 2017). These authors further concluded that there are clear differences in the compression force of the varieties tested using a Universal Tensile Machine and showed that this test could be used to rank germplasm within a breeding program. They suggested that cotton breeders could use this seed testing procedure to make selection decisions based on the breeding materials propensity to have SCF. Preliminary results from an additional test of fiber attachment force revealed additional information about cotton SCF and will likely complement this seed compaction test. These two experiments should be followed by spinning tests to observe the impact of SCF on textile manufacturing.

OPPORTUNITIES IN VARIETY DEVELOPMENT AND G X E INTERACTIONS

Fiber quality is best immediately after boll opening. Once the boll opens, fibers are subject to weathering until harvest, and the mechanical processes of harvest, ginning, and cleaning can all have a negative impact on fiber quality. Environmental factors, weathering events, harvesting procedures, ginning practices, and cultural practices, among many other factors, can play a role in influencing the presence of SCF in the cotton bale. Presence of seed coats in lint leads to yarn imperfections, which result in dyeing issues as well. Mangialardi (1988) published a study ascertaining the influence of varieties, harvest timing, and level of gin cleaning on the SCF content of ginned lint. Five varieties were planted in a three-way split plot design to accommodate the levels of treatments with four replications. They found that year and variety both influenced the presence of SCF, but that harvesting methods and lint cleaning did not pose significant effects. The authors concluded that early maturing varieties were better to avoid subsequent weathering effects to prevent presence of excessive seed coats in the ginned lint in their particular environment. Although earlier maturing varieties can provide the opportunity to harvest earlier, that opportunity must be capitalized upon with timely harvest.

Mangialardi and Meredith (1990) explored the relationship between fiber quality traits and SCF in ginned lint. They studied 9 to 12 varieties across three crop years, varying in micronaire values of 3.6 to 4.5 and found that SCF were significantly different for varieties and among harvest dates for two of the tested years. No significant interaction for neps was detected; however significant interactions of variety with year and harvest dates were detected for SCF weights. They showed that the number and weight of SCF tended to increase across six-week harvest intervals. The test was repeated in two years and an interaction was found between cultivar and year for the weight of SCF but not the number. This study alluded to the possibility of genetic differences existing for neps and presence of SCF and reinforced the previous conclusion that early maturing, early harvested material can be less prone to presence of SCF than later harvested cotton, possibly indicating that the genetics of the material differentially reacts to weathering events that follow later in the season. There were both varietal and physiological effects on the presence of SCF in their study showing that both genetics and agronomic management (i.e., timely defoliation and subsequent harvest) could play a role in reducing the likelihood of finding SCF in ginned lint.

Davidonis et al. (2000) noted discrepancies between reports relating mote frequency and boll location. They concluded from their study that long fiber motes were related to the timing and the intensity of environmental stresses, not specifically to harvest date and the location of a boll on the plant. They also concluded that the factors contributing to the occurrence of short fiber motes was more complicated. Because SCF can be created from motes, these results indicated that environmental stresses can also impact the content of SCF. Mangialardi et al. (1993) reported that SCF found in lint increased with the number of motes.

Much of the research discussed herein was conducted in the Mid-South production region of the U.S. However, recent rises in SCF incidences have generated interest among researchers and growers in other parts of the country, particularly the Southeast. Opportunities for future collaborations exist between the USDA gin lab in Stoneville, MS and University of Georgia micro-gin in Tifton, GA, along with the expertise housed in both locations on cotton genetics and agronomics. These opportunities should be exploited to provide more up-to-date research as well as generate data in multiple locations across the cotton producing regions of the U.S.

Factors Contributing to SCF from Harvest Data. The 2020 cotton growing season was favorable for Georgia producers. With no hurricanes or overly detrimental weather, growers had an average cotton crop. However, cotton gins began to see a rise in seed coat fragmentation. As seen in the maps (Figs. 8 and 9), seed coat fragmentation in the highlighted cotton field was notated as “0” for no seed coat fragments found, and “1” for the presence of seed coat fragments. The gin report (not shown) will list the severity of the seed coat fragmentation as either code 31 (less severe) or code 32 (more severe). Higher than normal seed coat fragmentation issues in Georgia resulted in losses greater than $18 million for growers throughout the state. These maps were created with data collected from John Deere’s Harvest Identification (HID) system. The HID system created a unique RFID tag for each module created on the machine. Once created, the RFID tag has data such as module ID, creation time, and creation location. Thus, by using HID information, fiber quality from the bales created from each module can be geolocated to the creation strip of each module, as seen in the maps and therefore, modules with seed coat fragmentation calls can be tracked.

Both fields (Figs. 8 and 9) are from the Colquitt, GA area that grew cotton cultivar DP 1646 B2XF with a target seeding rate of 79,000 seeds/ha (32,000 seeds/ac). With a module typically producing four

Figure 8. Seed coat fragmentation from Big Half field, Colquitt, GA.

bales, if a single bale was marked for SCF, the whole module was marked as having it present because the exact location in the field from where these fragments came from was unknown. Seed coat fragmented bales from a module ranged from a single bale to three out of four bales in some modules. In the Big Half field (Fig. 8), 14 of 42 modules contained SCF, which averaged 5.46 bales/ha (2.21 bales/ac). As for the Hog House field (Fig. 9), 11 of 31 modules contained SCF, which averaged 4.89 bales/ha (1.98 bales/ac). At this time, the cause of SCF calls is unclear as there were no obvious patterns. There were no obvious differences in these fields. Other spatial data such as elevation and soil texture have been investigated to determine why some modules received a SCF call while others did not at a field level but have not shown correlations to SCF calls.

Figure 9. Seed coat fragmentation from Hog House field, Colquitt, GA.

MODIFICATIONS OF MECHANICAL PROCESSING TO REDUCE SCF

Since 2000, several studies have attempted to alleviate SCF at the harvester and cotton gin. Most of the studies used AFIS SCN count in ginned lint (per gram of lint) as an indicator for SCF. This is because using the manual method to count SCF is tedious and cumbersome. SCN levels in ginned lint can be categorized as follows: < 10 = very low; 11-20 = low; 21-30 = medium; 31-45 = high; and > 46 = very high (USTER Technologies, 2008). What follows are results of studies that attempted to reduce SCF during harvesting and ginning processes.

Gin Stand and Harvester Spindle Design. Hughs (2002) conducted a study to determine if experimental saw guides mounted on gin ribs in a saw gin stand could reduce cottonseed loss and SCF, two problems that occur with newer, small-seeded cotton cultivars. Figures 10 and 11 show a schematic of a typical saw gin stand and the gin ribs and saw guides used in the study, respectively. During normal operation, small cottonseed can get jammed into the gap between the gin rib and gin saw and then pulled

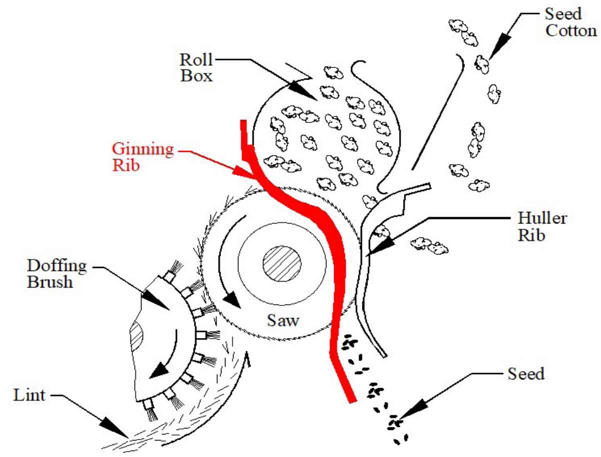

Figure 10. Conventional saw gin stand (Armijo et al., 2006a).

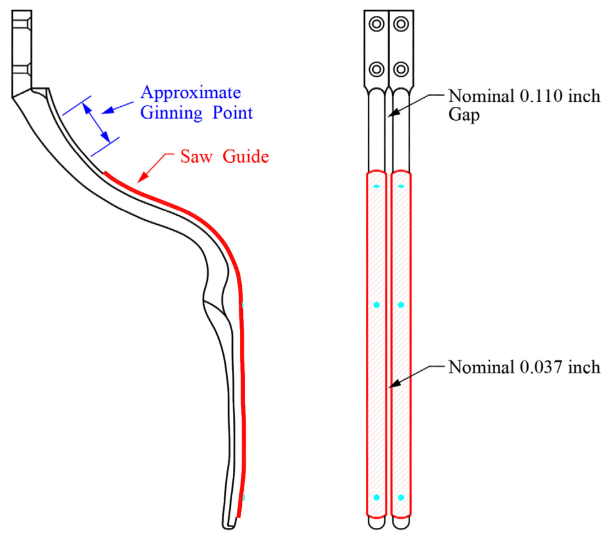

Figure 11. Experimental gin rib and saw guide (Hughs, 2002).

through with the ginned lint. If the gap could be reduced and the gin saw kept centered between the gin ribs, small seed might not be pulled through the gin rib. Spacing between the gin rib and gin saw was 2.79 mm (0.110 in.) and 0.99 mm (0.039 in.) for the conventional and experimental gin rib, respectively. The study consisted of two gin rib designs (control and experimental), four cultivars with varying degrees of cottonseed size (one cultivar was known to cause SCF problems during ginning), and four replications. Results showed that the experimental gin ribs significantly reduced cottonseed damage (5.4 versus 8.3% for the control gin ribs). Also, yarn produced from ginned lint with the experimental gin ribs was significantly higher quality for strength, evenness, and appearance than yarn produced from the control saw guides. Additionally, although SCN and SCF count were not reported, gin turnout and fiber length measurements were better with experimental gin ribs. This led to the conclusion that a more complex phenomenon was occurring at the ginning point, and that other factors such as saw-tooth design should be investigated in conjunction with the experimental gin ribs/saw guides.

In 2006, Armijo et al. (2006a) conducted a study to determine the interactions of saw and roller ginning with a cultivar known to have a fragile seed coat. The study consisted of three gin treatments, two cultivars (conventional and fragile seed coat), and three replications. The ginning treatments consisted of conventional saw ginning, saw ginning with the experimental gin rib discussed earlier (Hughs, 2002), and conventional roller ginning. Figure 12 shows a schematic of a roller gin stand. Results showed that the fragile seed coat cultivar had a higher level of SCN (59.4 versus 23.4 counts per g of lint for the conventional), but other factors such as turnout and fiber length measurements favored the fragile seed coat cultivar. As expected, turnout, fiber length measurements, and nep count were enhanced by roller ginning compared with either saw ginning treatment. However, there were no differences among ginning treatments in other fiber properties including SCN count, which averaged 43.2, 38.6, and 42.5 for conventional saw ginning, saw ginning with the experimental gin rib, and roller ginning, respectively.

Also in 2006, Armijo et al. (2006b) conducted a study to determine the interactions of spindle diameter and spindle speed on the cotton picker, and type of seed roll box and density of the seed roll on the saw gin stand in harvesting and processing ginned lint with an Upland cultivar that had a fragile seed coat. The study consisted of three harvesting treatments, four ginning treatments, one cultivar, and three replications. The harvester treatments consisted of (1) a two-row picker harvester equipped with 13-mm (0.5 in.) diameter spindles turning at 2000 rpm, (2) a one-row picker harvester with 16-mm (0.625 in.) diameter spindles turning at 2000 rpm, and (3) a one-row picker harvester with 16-mm (0.625 in.) spindles turning faster-than-normal at 2900 rpm. Figure 13 is a photograph of the spindles; a 14-mm spindle is shown for comparison. The ginning treatments on the saw gin stand consisted of (1) a traditional seed roll box with no mechanism to assist turning the seed roll (Fig. 14), (2) a seed roll box with a conveyor tube installed to assist turning the seed roll and pushing the cottonseed out the side of the band (Fig. 15), (3) a seed roll box with a conveyor tube installed

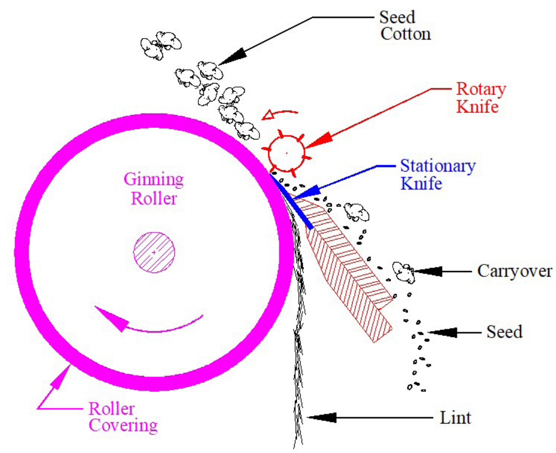

Figure 12. Conventional roller gin stand (Armijo et al., 2006a).

Figure 13. View of 13-mm (0.5 in.), 14-mm (0.56 in., used in another study), and 16-mm (0.63 in.) diameter spindles (Armijo et al., 2006b).

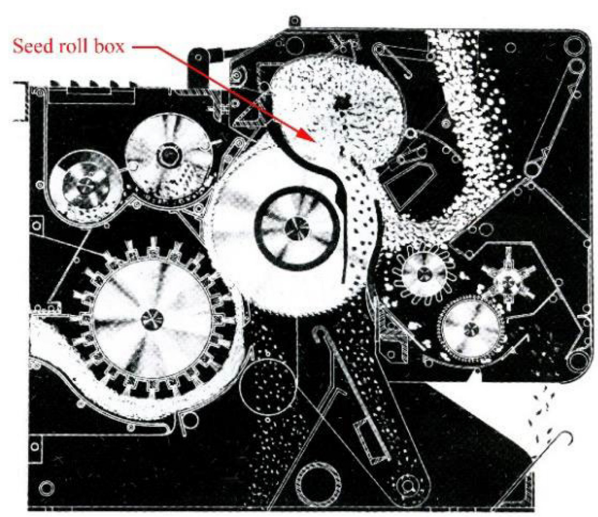

Figure 14. Saw gin stand with traditional seed roll box (Armijo et al., 2006b).

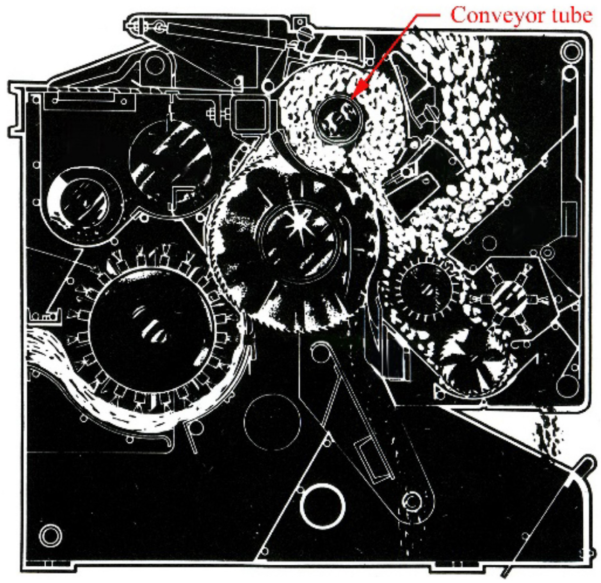

Figure 15. Saw gin stand with conveyor-tube roll box (Armijo et al., 2006b).

to assist turning the seed roll and pushing the cottonseed out the side of the stand running at reduced ginning rate, and (4) a seed roll box with a paddle roll installed to assist turning the seed roll (Fig. 16). Lint cleaning was performed with a conventional lint cleaner. As in Armijo (2006a), the fragile seed coat cultivar used in this study had excellent fiber quality features, but it also had higher SCN counts (63.3). Results showed that SCN was lowest at (58.3) with the 13-mm (0.5 in) spindle running at standard speed (2,000 rpm). Increasing the spindle diameter and spindle speed worsened SCN; the 16-mm (0.625 in.) spindle running at 2,000 rpm averaged 61.7 SCN

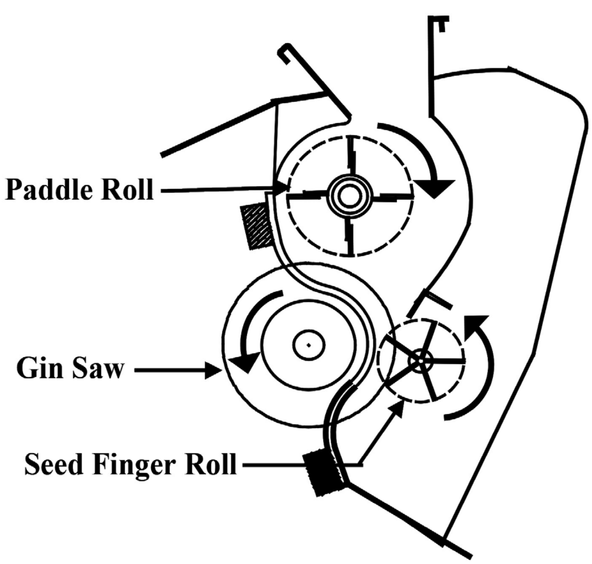

Figure 16. Saw gin stand with paddle-roll seed roll box (Armijo et al. 2006b).

and running this spindle at 2,900 rpm resulted in 69.8 SCN possibly due to the higher centrifugal force and surface velocity of the larger spindle. With respect to the ginning treatments, the paddle-roll seed roll box had the fewest SCN at 49.3. The other ginning treatments were not different from each other and averaged 67.9 SCN.

Boykin (2007) conducted ginning energy research in the micro-gin at the USDA Cotton Ginning Research Unit in Stoneville, MS to determine the amount of energy required to gin among differing cultivars and study the relationship between ginning energy and fiber properties. Boykin used a watt-hour meter monitor that started measurement when the gin stand breast was engaged. This research found that fiber-seed attachment force explained differences in gin stand energy among cultivars. Also, overcoming entangled fibers within the gin stand seed roll and friction from turning the roll added to the consumed energy. Cultivars requiring less energy had less fiber damage. Cotton genotypes with lower fiber-seed attachment strength required less force to remove the fiber from the seed compared to genotypes with higher fiber-seed attachment strength (Boykin et al., 2011). Less force reduced the energy needed to gin. Results of the study showed a strong correlation ($r = 0.87$) between net gin stand energy and fiber-seed attachment force. Seed coat nep count (an indicator of SCF) and net gin stand energy both increased as fiber-seed attachment force increased. The findings validated the assumption of net gin stand energy as a predictor for fiber-seed attachment force.

Boykin (2008a) studied the relationships among 19 cultivars in SCF, motes, neps, and SCN with primary focus being SCF and SCN. The cultivars were grown in Mississippi Regional Cotton Variety Trials in 2002 and 2003. Each cultivar was replicated in six plots, blocked by replication, picked by spindle harvester, and ginned on a micro-gin. Results showed that SCF of the cultivars ranged from 6 to 35 and averaged 13 SCF per g of lint, and SCN ranged from 6 to 22 and averaged 11 SCN per g of lint. Figure 17 shows the relationship between the number of SCF (manually counted) and SCN (determined by AFIS); there was a significant positive correlation between SCF and SCN ($R^2 = 0.70$). Although the measurements of manually counted SCF and AFIS SCN were different, this relationship was strong, and should provide similar results (Baldwin et al., 1995). However, this was not the case. Figure 18 shows a negative trend that indicated AFIS either transformed

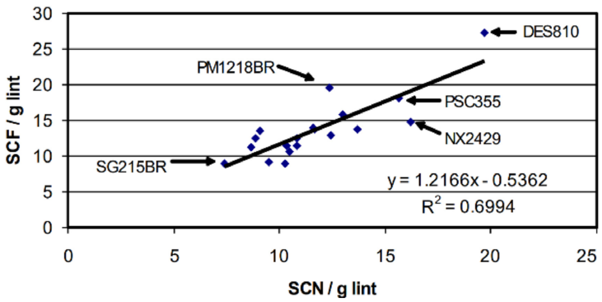

Figure 17. The number of seed coat fragments (manually counted) plotted with the number of seed coat neps determined with the AFIS for cultivars averaged across the three test groups (Boykin, 2008a).

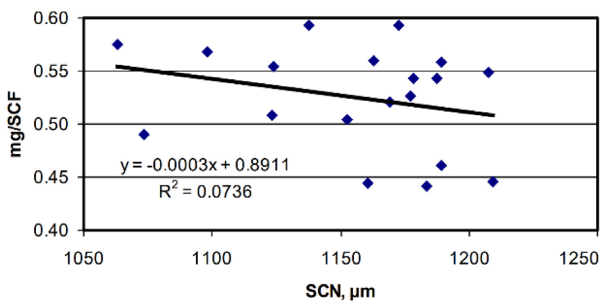

Figure 18. The average weight of individual seed coat fragments (manually fractionated) plotted with the average seed coat nep size determined with the AFIS for cultivars averaged across the three test groups (Boykin, 2008a).

or omitted larger SCF found by the manual method. This might be due to AFIS classifying SCN and neps by size, and an increase in the number of SCN and SCF might have increased the number of small SCN characterized as large neps. It was also found that poor correlation between SCF and SCN was related to the method of determination and not to variability of the sample.

In another study by Boykin (2008b), Boykin identified where SCF were formed, altered, and removed during the ginning process. Two cultivars were used in the study, one with a low SFC, and the other with a moderate level of SCF. Figure 19 is a flowchart showing where SCF originated, their content, and removal at different locations in the cotton gin. Results showed that although SCF were present before the gin stand (4.5 mg SCF per g lint), SCF were formed at a much higher rate at the gin stand (15.3 mg SCF per g lint, which included SCF content in the gin stand waste). The SCF formed at the gin stand were thought to originate from cottonseed, immature cottonseed, and motes damaged at the gin stand. Thirty-two percent (by weight) of SCF formed at the gin stand came from cottonseed (with meats), and 15% (by weight) of SCF formed

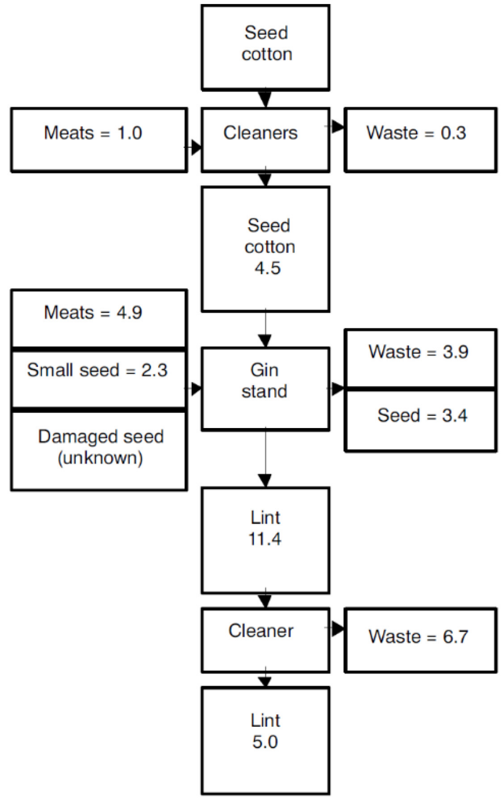

Figure 19. Flowchart showing the origin, content, and removal of seed coat fragments (SCF) in a cotton gin. Units for all numbers are mg SCF per g lint (Boykin, 2008b).

came from immature seed (without meats). Results by Boykin (2008b) also suggested that SCF removed by the lint cleaner were larger and were broken into smaller pieces that are more difficult to remove.

Seed Cotton Cleaner and Harvester Spindle Design. Armijo et al. (2009) conducted a study to determine the interactions of picker spindle diameter and spindle speed and the amount of pre-cleaning of seed cotton in a cotton gin with an Upland cultivar that has a fragile seed coat. The study consisted of three harvesting treatments, three seed cotton cleaning treatments, one cultivar, and three replications. The harvesting and ginning treatments in this study (Armijo et al., 2009) are different than the treatments in the Armijo et al. (2006b) study, previously discussed. The harvesting treatments consisted of (1) a two-row harvester with 13-mm (0.5 in.) diameter spindles turning at 2000 rpm, (2) a one-row harvester with 14-mm (0.56 in.) diameter spindles turning at 1500 rpm, and (3) a one-row harvester with 14-mm (0.56 in.) diameter spindles turning at 2400 rpm. Figure 13 shows the 13- and 14-mm spindles. The ginning treatments consisted of (1) no seed cotton cleaners (i.e., no pre-cleaning prior to being ginned),

(2) three seed cotton cleaners (two 6-cylinder inclines and a one stick machine), and (3) six seed cotton cleaners (three 6-cylinder inclines and three stick machines). Figures 20 and 21 show a cross-section of a typical 6-cylinder inclined cleaner and stick machine, respectively. Ginning and lint cleaning were performed on conventional machines. Results showed that AFIS SCN count was not different among harvester or seed cotton cleaning treatments. SCN count averaged 36.3 neps per g of lint, which is in the high category of 31 to 40 SCN per g of lint. In addition, a manual count of SCF showed that fragment count was also not different among harvester or seed cotton cleaning treatments and averaged 132 counts per g of lint.

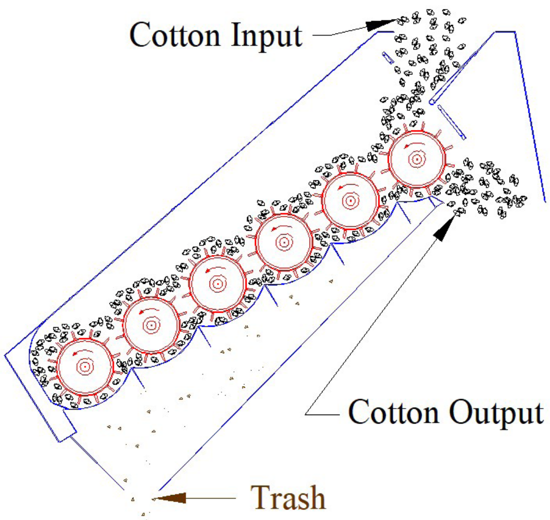

Figure 20. Six-cylinder seed cotton cleaner (Armijo et al., 2009).

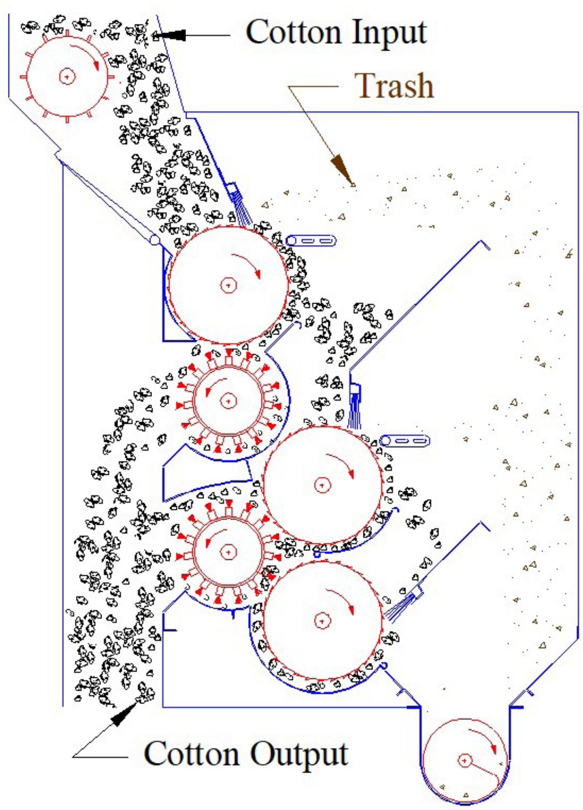

Figure 21. Three-saw stick machine (Armijo et al., 2009).

Boykin and Ray (2010) performed a study to determine if SCF levels increase with more pre-cleaning machines; SCN count was also part of the study. The study consisted of five ginning treatments conducted on a micro-gin equipped with conventional machinery: (1) extractor feeder/gin stand only, (2) cylinder cleaner with extractor feeder/gin stand, (3) stick machine with extractor feeder/gin stand, (4) extractor feeder/gin stand with two saw-type lint cleaners (no pre-cleaning machines), and (5) cylinder cleaner, stick machine, cylinder cleaner, extractor feeder/gin stand, and two saw-type lint cleaners. Figure 22 shows a typical ginning machinery sequence. A total of eight cultivars were used at two moisture levels: 5.6 and 6.4%. Results showed that adding either a cylinder cleaner or stick machine to an extractor/feeder without lint cleaners did not change the levels of SCF; results were inconclusive with SCN count as the stick machine inconsistently reduced SCN for certain cultivars and moisture content levels. Also, adding two cylinder cleaners and one stick machine to an extractor feeder/gin stand with lint cleaners did not change the SCF content; however, AFIS neps were increased. The study did not conclude or imply that seed cotton cleaners do not produce SCF, only that adding more cleaners did

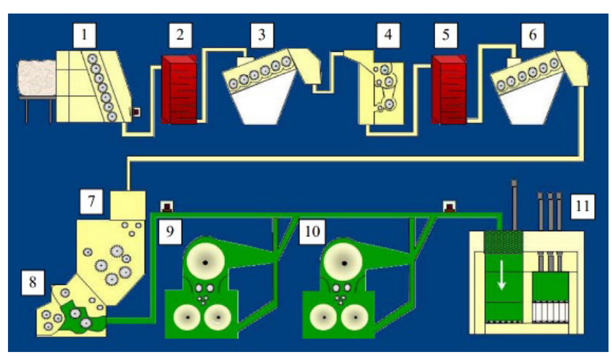

Figure 22. Typical ginning machinery for spindle-picked upland cotton includes a module feeder (1) followed by first stage dryer (2), first cylinder cleaner (3), stick machine (4), second stage dryer (5), second cylinder cleaner (6), extractor-feeder (7), gin stand (8), one or two lint cleaners (9,10), and bale press (11) (Boykin and Ray, 2010).

not produce more SCF in comparison to the extractor feeder/gin stand. This distinction is important due to the widespread use of seed cotton cleaners to remove other foreign matter from seed cotton.

Lint Cleaner. Armijo et al. (2011) conducted a study to determine how a single SCF reacts after colliding with different designs of grid bars mounted on a lint cleaner simulator. A high-speed video camera was used for analysis. Figure 23 shows the lint cleaner simulator, which also shows the fiber bundle and attached SCF. Figure 24 shows the designs of the experimental lint cleaner grid bars. The designs included grid bars with single and double edges, a groove following an edge, rounded (no edge), and various angles that the edge made from vertical. The study included two Upland cultivars, one that contains a fragile seed coat. Results showed that grid bars with an included angle of the sharp toe of the grid bar larger than the included angle of a conventional grid bar adequately removed SCF. Also, grid bars with a second corner a short distance from the toe of the grid bar removed SCF from the fiber bundle

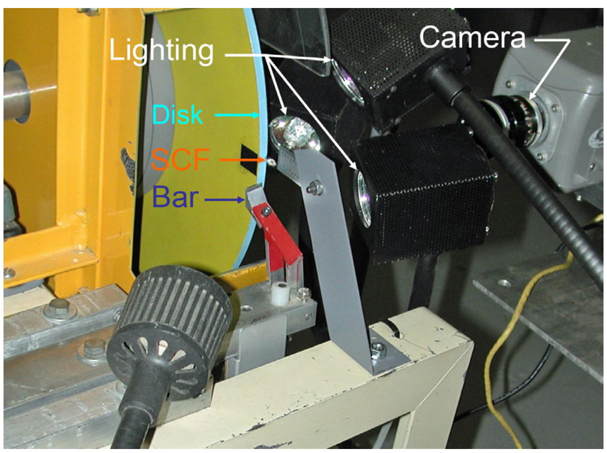

Figure 23. Lint cleaner simulator (Armijo et al., 2011).

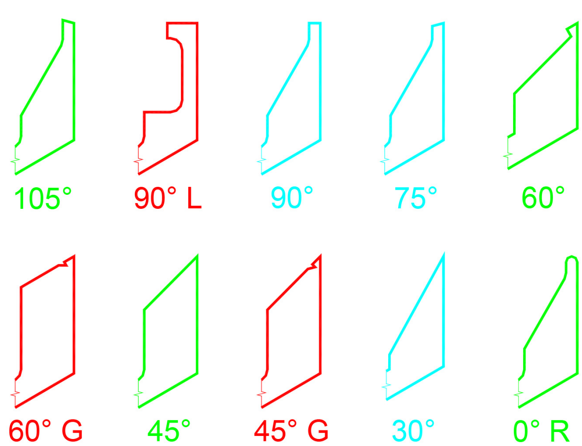

Figure 24. Experimental grid bars (Armijo et al., 2011).

more quickly and completely, and the momentum of the separated SCF continued for a longer time. Figure 25 shows the path of the separated SCF using a grid bar with a second corner. Videography showed that

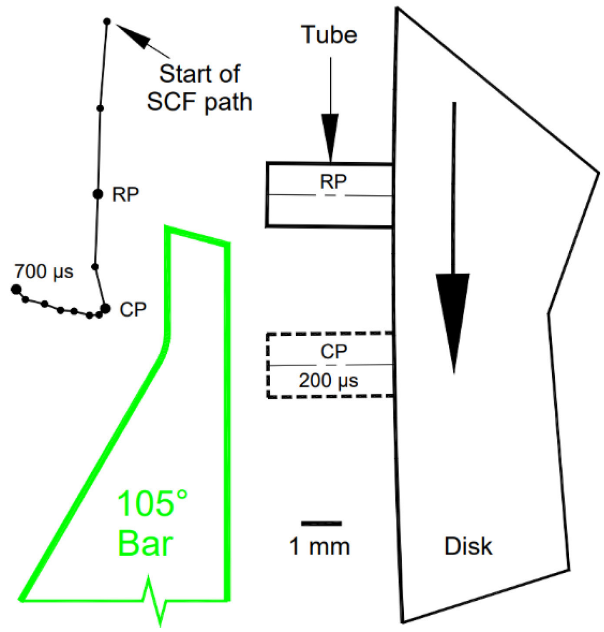

Figure 25. Grid bar: 105º. The distance from the toe to the 2nd corner is 1.55 mm (0.061 in). The seed coat fragment was removed on the second corner (Armijo et al., 2011).

if SCF made a quick and clean break from the fiber bundle, they retained more energy and the momentum continued for a longer period. If SCF did not make a clean break away from the fiber bundle, the energy was dissipated, and the momentum of the SCF reduced. After considering the position of SCF 700 µsec after impact with the grid bar, the 105º, 60º, 45º included angle from the toe of the grid bar, and the rounded grid bar with a 0.76-mm (0.030 in.) radius (0º R) (see Fig. 24) best removed SCF and warranted further testing on a full-size lint cleaner.

Armijo et al. (2016) conducted a study to determine if newly designed lint cleaner gid bars better removed SCF from ginned lint. The study consisted of five experimental grid bars and one conventional (control) grid bar, two cultivars (one had a known fragile seed coat), and three replications. The grid bars were tested on a conventional full-size lint cleaner. Figure 26 shows the design of the experimental grid bars. The grid bars were identified as to the included angle from the sharp toe (angle from vertical) of the grid bar. The 105º and 60º grid bars contained a second edge to help remove SCF. The 45º grid bar had only a single edge whereas the 0º

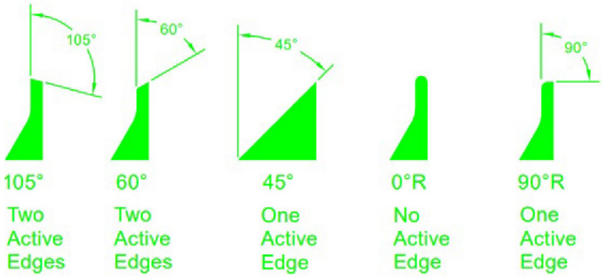

Figure 26. Cross-section of the five experimental grid bars used in the study (Armijo et al., 2011).

R grid bar had no edge but a 0.79-mm (0.031 in.) radius. The 90º R grid bar had one edge and a radius of 90º. Result showed that SCN count (a possible indicator for SCF) on the fragile seed coat cultivar and conventional Upland cultivar averaged 58.3 and 35.0 counts per g of lint, respectively, confirming that the fragile seed coat cultivar might be more prone to SCF. Surprisingly, there were no differences in fiber properties, including SCN count and a manual count of SCF, among grid bar treatments. High-speed videography showed that SCF impacting the grid bars were being pulled back into the lint stream by attached fiber. It is possible that an auxiliary device, such as an air knife, might help remove SCF from the lint stream.

TEXTILE MILLS IMPACTS OF SCF

The USDA-Agricultural Marketing Service classifies cotton bales that are observed by a human classer to have excess SCF with an extraneous matter (EM) code of 31 or 32, depending on the level of severity with 32 being more severe than 31 (Delhom et al., 2020). Extraneous matter calls are determined by a human classer visually examining multiple surfaces of a bale sample. The use of instrumentation to examine cotton samples for the presence of SCF is a more laborious practice that is not part of cotton classification. The Trashcam instrument was developed in the 1990s to allow for automated detection and counting of SCF in carded web (Giner et al., 1997; Hequet et al., 1999). The AFIS instrument reports numeric counts of both neps and SCN per gram of cotton fiber tested. The AFIS uses a pinned cylinder rotating at high speeds along with centrifugal force to individualize fibers from a prepared sliver and separate heavier non-lint content from fiber. An optical analysis is performed to characterize the shape of the non-lint particles, and larger particles with fiber attached are classified as SCN and are likely to be SCF (Baldwin et al., 1995). Boykin (2008a) found good agreement between manual methods and the AFIS results for SCF but found that the AFIS could misclassify SCF as neps as opposed to SCN. Uster Technologies (2008) claims representative values for SCN in American Upland ginned lint are 11 to 20 count/g (low) and 31 to 40 count/g (high) (Von Hoven et al., 2016). However, Krifa et al. (2002) explained that large seed coats that are mainly devoid of lint will be classified as "trash" by the AFIS and all contaminants smaller than 500 µm in optical diameter are classified as "dust". Baldwin et al. (1995) justified the classification of some SCF as trash or dust because these SCF were more easily removed prior to spinning.

Seed coat fragments reduce processing efficiency by causing ends-down during spinning (Gupta and Vijayshankar, 1985; Krifa et al., 2001; Price, 1988) and lead to defects in fabric (Bargeron and Garner, 1991). Seed coat fragments are difficult to separate from ginned lint during the opening, cleaning, and carding textile processing operations due to the fibers connected to the fragment of seed coat (Bargeron and Garner, 1988; Krifa et al., 2002). The impact of SCF is considerable despite the total mass of SCF in an impacted bale being quite small (Mangialardi, 1992). Aggressive attempts to remove SCF can cause fiber damage, which increases short fiber content and results in reduced yarn uniformity and increased yarn breaks during the spinning process (Newton et al., 1966). Increasing the amount of total material removed during cleaning operations has not been shown to eliminate SCF (Frey and Schneider, 1989), and aggressive carding can result in fragmentation of SCF reducing the average size of the fragments but increasing the total number of fragments (Krifa et al., 2002). Seed coat fragments can have pieces of seed meat or seed oil on the interior side of the fragment. The presence of excessive seed meat and oil contaminants from SCF can mimic the stickiness behavior normally associated with insect activity (Perkins, 1971). The buildup of residue from SCF can lead to lapping on rollers during drawing and spinning, which results in both lost processing time and decreased yarn evenness.

Neps are usually immature and are a common source of non-dyeing fibers (white specks) in textiles (van der Sluijs and Hunter, 2016), with SCF as the second most common impurity in textile products (Jacobsen et al., 2001). Baldwin et al. (1995) found that carding removed most medium to large SCN, as classified by the AFIS, but a slight increase in small SCN was observed. Jones and Baldwin (1996) reported that opening and cleaning systems did not significantly remove SCN, and only the carding process was significantly effective with 44 to 86% removal rates depending on the cotton sample. Krifa et al. (2002) found a relationship between the length of fiber attached to SCF and the removal rate by the card with SCF with shorter fibers being more readily removed by the card. Despite this relationship between SCF removal and fiber length, the carding and cotton interaction was highly significant with different cotton samples responding differently to carding with some cottons experiencing an increase in SCF counts, whereas others were significantly reduced. After carding, regardless of the SCF, the average size of the SCF was found to decrease.

The 2020-21 cotton crop in the U.S. experienced an unprecedented rate of SCF, especially in the southeastern growing region. To address the concerns of the cotton industry, a processing study was conducted to compare commercial-scale processing of SCF containing cottons produced in the southeast with similar bales that did not rate an extraneous matter call for SCF.

Materials and Methods. Six bales of cotton of similar quality were purchased from the southeastern cotton growing region, with two bales representing control bales (no SCF EM calls) and four bales representing test bales (all containing EM calls at the 31 level). The bales were all from the 2020-21 growing season. The six bales were transported to Cotton Incorporated (Cary, NC) for testing and processing trials. Bales were characterized with HVI (Table 2) and AFIS (Table 3). In addition to standard fiber quality tests, subsamples of at least 680 grams from five of the six bales were sampled and tested using a minicard. An in-house method of evaluating cotton stickiness using a scale of 1 to 10 was used in lieu of the 0 to 3 scale used by Brushwood and Perkins (1993). A rating of 1 indicates no residue buildup or lapping of fibers on the minicard, whereas a rating of 10 indicates severe stickiness. Trained textile equipment operators were used to provide the subjective rating, which included inspecting the carding components for SCF and observations on the tendency for the fiber web to lap and cause processing faults (Table 4).

Samples of the six bales were processed on a commercial processing line consisting of a B 3/4 opener (Rieter, Winterthur, Switzerland), CL-P coarse cleaner, CL-U fine cleaner, TST5 contamination detector, and TC 11 card (Truetzschler, Monchengladbach, Germany). Carding produced 5000 tex (70 grain/yd) sliver at a production rate of 60 kg/hr (130 lb/hr). Fiber samples for AFIS testing were collected after each stage of opening and cleaning. Card sliver was drawn on a Rieter SB-D40 (breaker drawing) and RSB-D45 (finisher drawing) to produce 5000 tex (70 grain/yd) finisher sliver. Finisher sliver was converted to 740 tex (0.80 hank) roving with a twist of 46.5 turns/m (1.18 turns/in).

Carded ring spun yarns of 27 tex (Ne 22/1) were produced with a 3.6 twist multiple at 12,000 rpm on a Zinser (Saurer AG, Arbon, Switzerland) 351 spinning frame. Yarn quality was assessed by monitoring the number of ends-down (yarn breaks) during spinning, characterizing yarn appearance and uniformity on an Uster Technologies Tester (ASTM, 2020), and tensile testing on an Uster Technologies Tensorapid (ASTM, 2015).

Single-knit fabrics were produced using 18 kg (40 lb) of each control and test yarn. Knitting was performed on an 18-gauge, 0.56-m (20-in.), 12-feed Monarch (Monroe, NC) Sec-Mini knitting machine. Knit samples were visually inspected for SCF in the greige and dyed states. Dyeing was performed using a reactive Novacron Blue in a medium shade that is commonly used to highlight quality issues in

Table 2. High Volume Instrument properties

Bale	Micronaire	UHML (mm)	Uniformity Index (%)	Strength (g/tex)	Rd	+b	Color Grade	Trash Count	Trash Area (%)
Control 1	4.53	28.7	81.9	29.9	74.9	8.3	41-1	42	0.54
Control 2	4.62	29.2	83.1	29.2	74.3	8.6	41-3	42	0.52
Test 1	4.54	29.2	82.4	29.3	73.6	7.7	41-1	38	0.42
Test 2	4.55	29.0	82.4	29.7	71.8	8.0	41-2	63	0.64
Test 3	4.56	29.2	83.1	29.4	72.1	8.2	41-4	59	0.65
Test 4	4.52	29.0	81.7	29.1	73.3	7.9	41-2	43	0.67
Avg. Control	4.58	29.0	82.5	29.6	74.6	8.5		42	0.53
Avg. Test	4.54	29.0	82.4	29.4	72.7	8.0		51	0.60

Table 3. AFIS results for raw cotton

Bale	UQL (mm)	SFCw (%)	Maturity Ratio	Neps (#/g)	SCN (#/g)	SCN Size (µm)	Dust (#/g)	Trash (#/g)
Control 1	30.0	10.7	0.92	204	26	1141	356	83
Control 2	29.5	11.7	0.91	186	16	1113	413	101
Test 1	29.5	11.1	0.91	216	21	1152	538	138
Test 2	30.0	10.9	0.90	223	28	1117	756	147
Test 3	29.5	11.2	0.90	210	27	1080	526	116
Test 4	29.5	11.2	0.89	240	28	1117	485	102
Avg. Control	29.8	11.2	0.92	195	21	1127	385	92
Avg. Test	29.6	11.1	0.90	222	26	1117	576	126

Table 4. Minicard ratings

Bale	Rating	Seed coats on carding components	Seed coats that caused lapping	Processing Observations
Control 1	3	14	4	Minimal lapping
Control 2	3	11	4	Sporadic lapping
Test 1	2	8	3	Consistent lapping
Test 2	5	25	12	Sporadic lapping
Test 3	3	11	4	Minimal lapping

finished fabric (van der Sluijs and Delhom, 2017). Dyed fabrics were produced with and without enzyme treatment. Cellulase enzyme treatments can be used by textile mills as a final effort to reduce white specks and remove SCF.

Results and Discussion. Examination of the bale HVI data (Table 2) for the six bales did not reveal any notable differences in primary fiber characteristics. The fiber properties were all representative of average or better fiber qualities, which would indicate successful processing into yarn. The trash count was slightly higher, on average, for the test bales with 51 trash particles compared to 42 for the control bales. The trash area followed a similar trend with 0.60% of the measured area on the HVI representing trash for the test bales compared with 0.53% of the control bales; however, the average rating for both sets of bales was a leaf grade of 4. The only clear indicator of a potential problem with the test bales was the issuance of a 31 EM call during classification.

All the bales in this study were relatively high in non-lint content by visual analysis. AFIS testing (Table 3) provided more detailed information on the makeup of the non-lint content. AFIS testing identified 26 SCN per gram, on average for the test bales, compared to 21 for the control bales. (However, one of the test bales was found to have fewer SCN than one of the control bales.) Experienced textile equipment operators at Cotton Incorporated have reported that fiber processing issues similar to stickiness began to appear when SCN counts exceed 25. No significant differences were found for SCN size or nep counts, but the seed coat bales contained almost 50% more dust and trash than the control bales.

Minicard testing (Table 4) determined if the samples were likely to exhibit sticky-cotton tendencies; during testing, on a 1 to 10 scale, no bale tested higher than 5, with the control bales both rating a 3, which was in line with most of the test bales. One test bale was found to leave 25 seed coats stuck to carding components, with 12 of those seed coats leading to sporadic lapping of the fiber during processing. The control bales performed in a comparable manner to the remaining test bales.

No processing issues were observed during opening and carding of any of the bales. However, AFIS testing of samples collected during processing revealed the test bales were not of the same quality as the control bales (Table 5). All measures of non-desirable properties were higher for the test bales than the control bales with neps, visible foreign matter (VFM), dust, and trash remaining higher for the test bales at all points. The one exception was that in card sliver the control bales averaged 3 SCN per gram compared to only 2 in the test bales. The resultant card sliver was of relatively low nep levels (less than 50 neps per gram), but the test sliver had 50% more dust particles.

Carding resulted in nep removal efficiency of 90.2% for the control bales and 86.9% for the test bales. Seed coat nep counts were reduced by 83.3 and 91.3% for the control and test bales, respectively. The average size of SCN was reduced for both sets of bales. The removal of neps and SCN came at the cost of a nearly 50% short fiber content increase, by weight, during carding for the test bales, with the short fiber content increasing from 7.8 to 11.6% (Table 5). The control bales exhibited a more typical 15% increase from 8.0 to 9.2%. Card sliver for both control and test bale sets contained elevated levels of VFM, with the test bales containing twice the level as the control bales.

During breaker drawing, some level of lapping was observed for both control and test bales. The lapping observed was in general agreement with results observed during the mini-card testing, with neither set of bales performing in a normal manner. No bales experienced lapping during finisher drawing, but the mechanical action of the finisher draw frame allowed for better control of fiber movement, which could eliminate the low-level stickiness behavior otherwise observed. No lapping or processing difficulties were experienced during the roving process for any of the bales.

Yarn breaks during spinning are problematic due to loss of production time, the potential creation of a defect, and loss of material while the end is down. Neither sets of samples spun with low levels of ends-down, which are reported as the number of yarn breaks per 1000 spindle hours (Table 6). However, the test bales exhibited an almost five times higher breakage rate than the control bales. The test bales exhibited some lapping at the occurrence of an end-down, which resulted in broken aprons due to the buildup of sticky residue on the spinning frame components.

Table 6 includes reference values for the 50% level of Uster Statistics, a dataset from Uster Technologies (Uster Technologies, 2018) in which 50% represents the mean values observed commercial for 100% carded cotton Ne 22/1 ring spun yarns. Yarns from both sets of bales were considerably weaker than the Uster Statistics 50% value and were

Table 5. Average AFIS results for processing samples

Bale	Sample	Neps (#/g)	Nep Size (µm)	SCN (#/g)	SCN Size (µm)	VFM (%)	Dust (#/g)	Trash (#/g)	SFCw (%)
Control	B 3/4	217	695	21	1147	2.15	357	85	8.5
Test		229	687	26	1145	2.71	486	117	8.0
Control	CL-P	226	689	20	1178	1.71	275	83	8.1
Test		252	694	25	1173	1.86	384	78	8.0
Control	CL-U	277	665	15	1097	1.48	204	66	8.0
Test		314	660	21	1183	1.58	312	82	7.7
Control	Batt	338	661	18	1124	1.64	209	62	8.0
Test		373	673	23	1285	2.20	276	85	7.8
Control	Sliver	33	600	3	725	0.03	21	1	9.2
Test		49	626	2	1008	0.06	34	3	11.6

Table 6. Yarn production and quality

Parameter	Control Bales	Test Bales	Uster Statistics (50%)
Ends Down /1000 spindle hours	13	60	-
Breaking Strength (grams-force)	374.13	385.27	439.64
Mass Uniformity (CV%)	14.33	15.13	14.38
Thin -50% (#/km)	1	3	8
Thick +50% (#/km)	120	194	115
Neps +200% (#/km)	52	88	163
Hairiness	6.38	6.38	6.30

ranked below 90% of all yarns of the same size and construction. The mass uniformity, in which low variation represents more uniform and consistent yarn mass, was better than the Uster Statistics 50% value for the control bales, but not the test bales. Thin spots, defined as areas of at least 50% less mass than the average yarn, and neps, defined as short spots at least 200% as thick as the average yarn mass, were both better than the Uster Statistics 50% value; however thick spots of at least 50% greater mass were higher for both bales. The test bales were considerably higher in both thick spots and neps than the control bales.

Knit fabrics produced from both bale sets were visually inspected by laboratory staff with and without enzyme treatments. The greige fabrics from both bale sets (Figs. 27 and 28) both revealed substantial amounts of SCF. The dyed fabrics were found to be commercially acceptable for both bale sets and with or without enzyme treatments (Figs. 29 and 30). Visually, the control bale fabric without enzyme treatment appeared to have marginally more white specks than the test bale fabrics.

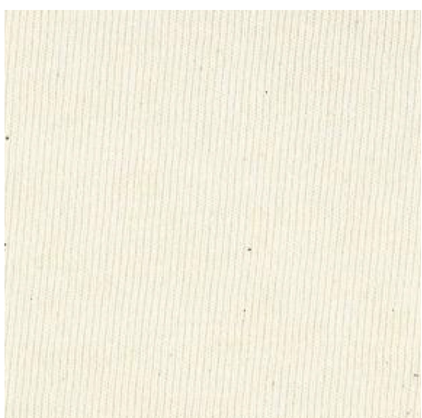

Figure 27. Greige fabric knit from control bale sample (dark spots are seed coat fragments).

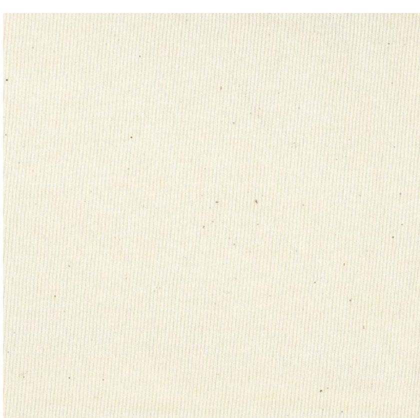

Figure 28. Greige fabric knit from test bale sample (dark spots are seed coat fragments).

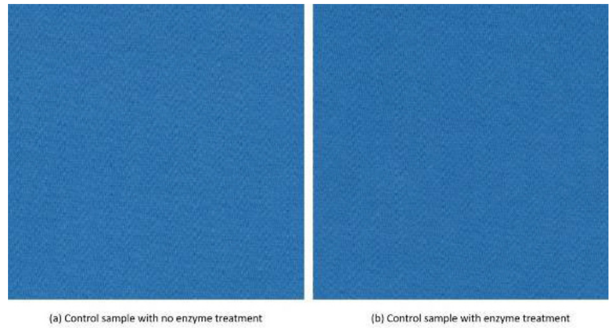

Figure 29. Control bale sample with (a) no enzyme treatment and (b) enzyme treatment (both are acceptable).

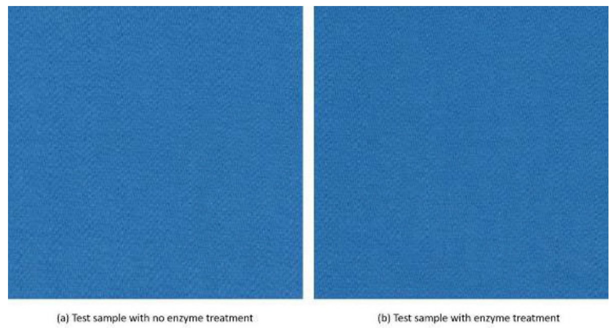

Figure 30. Test bale sample with (a) no enzyme treatment and (b) enzyme treatment (both are acceptable).

The test bales were observed to leave more trash and SCF on the knitting machinery during processing. Knitting operators reported the occurrence of several “press offs,” which led to holes in the fabric. Press offs are often attributed to foreign matter interfering with the movement of needle components during the knitting process and can be exacerbated by weak yarn. The holes resulting from press offs and other knitting issues will potentially cause problems for the cut and sew operations on the knit fabric. Negative effects on knitting efficiency are not readily quantifiable but should be considered carefully by the end user. Overall, none of the dyed fabrics revealed any quality concerns related to appearance.

Summary. Bales obtained from the southeastern region with unprecedented levels of SCF during the 2020-21 growing season were evaluated for impact on textile processing. Bales from the same region, without SCF classer calls, were observed to have higher levels of non-lint content than normal. Although all the bales were quite similar in fiber quality, the bales with SCF calls tended to process with more difficulty and loss of efficiency than the bales without EM calls for SCF. Carding removed a large percentage of SCF, but that did not resolve processing issues. There were indications of stickiness present in both control and test samples. Increased ends-down levels like those observed for the test bales would be problematic for a commercial spinning mill with thousands of spindles in production. Yarns from both sets of bales were significantly weaker than the average Ne 22/1 carded cotton ring spun yarn. However, the final product, dyed knit fabric, was commercially acceptable for both bale sets, and no appreciable differences between the samples. Seed coat fragments interfere with efficient processing of cotton fiber into yarns and fabrics; however, the result can be of suitable quality if care is taken during carding and spinning. It is important to note that this was a small test conducted under ideal fiber processing conditions, but there was sufficient evidence to indicate the potential for productivity and quality issues in fiber receiving the seed coat calls.

FUTURE STRATEGIES TO ALLEVIATE SCF

Additional research on understanding the cause and correction of SCF is needed. The genetic-by-environment interaction on the occurrence of SCF makes controlled studies difficult to design and the ability to collect seed cotton from variety trials in years and locations with seed coat outbreaks should be maintained. Work should continue to increase understanding of the physiology of the seed coat components and how formation is impacted by the environment. With more than 20 years of data on SCF calls at the state and classing office levels, it can be possible to use publicly available weather records to identify environments that lead to SCF occurrence. A model to predict conditions favorable to SCF formation could be used to alert growers and ginners that extra care might be needed at the end of the season (e.g., timely harvest, reducing ginning rate for varieties known to be prone to SCF). Although harvest systems do not have the largest impact on SCF formation, it has been established that larger diameter spindles can increase SCF and equipment manufacturers should consider this in spindle design considerations.

Other tools and measures are needed to allow breeders to consider SCF risk in their variety selection. One measure that could be useful and fairly easy to implement is ginning energy. Testing the compressive and or shear strength of the cottonseeds also could be useful for screening for varieties prone to SCF; however, faster ways to measure such properties are needed before they could become practical in a breeding program.

At the gin, current data suggest seed cotton cleaning machinery does not have a big impact on SCF levels. As the gin stand is where the fiber is pulled from the seed, it is not surprising the gin stand is the largest contributor to SCF formation. A better understanding is needed of how saw-tooth design and rib spacing can impact SCF levels. The presence of fiber on the seed coat makes it a challenge to remove both at the gin and textile mill; however, it has been demonstrated that SCF removal can be increased at the lint cleaner without negatively impacting other fiber properties. Final identification of the ideal grid bar design is needed.

New tools are also needed to help spinning mills remove SCF without excessively damaging the fiber. Bioscouring cotton to remove SCF using cellulase, pectinase, xylanase, and lignin oxidase has shown some promise. Also, better prediction of the impact SCF variations have on the spinning mill is needed. For example, sometimes SCF contain residual cottonseed oil that can lead to stickiness issues that are significant. Properly identifying the probable problems from SCF in a bale could better link the price discount to the increased processing cost at the mill.

DISCLAIMER

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