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A REVIEW OF THE STRUCTURE OF THE COTTON FIBER AND ITS BASE AND POTENTIAL PROCESSES TO WEAKEN THE FIBER-SEED BOND

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Abstract

This paper presents a review of the structure of the fiber and its base and possible means of weakening the fiber-seed attachment strength. Significant cotton fiber damage can occur when overcoming the bond between the cottonseed and fiber at the gin stand. Even though the fiber-seed attachment force is typically lower than the tensile strength of the fiber, many fibers still break at less than full length. Weakening the bond between the fiber and the seed would reduce stresses applied to the fibers during ginning. Literature indicates that secondary cell wall is lacking in the base of cotton fibers and that removal of the primary wall and cuticle could weaken the fiber-seed bond. Experiments in textile dyeing have shown that pectinases and cellulases, in combination with a surfactant and a chelator (such as EDTA) can be effective in removing these layers. The downside of using this approach to reducing the fiber-seed attachment strength is that damage to these layers in other parts of the fiber can reduce lubrication between fibers essential to fiber processing. Some experiments with enzymes have also shown that a reduction in the fiber-seed attachment force corresponded to a reduction in fiber strength, likely due to cellulase activity. This review points out uncertainties about the structure of the fiber and possible mechanisms for reducing the fiber-to-seed attachment force. Enzymatic or chemical processes that specifically target the fiber base, a lubricant capable of restoring layers of the fiber, or a process that only temporarily disrupts the fiber surface materials are potential developments that could lead to the reduction in energy required to gin cotton and fiber damage that occurs in the gin stand.

Introduction

Seed cotton entering the gin goes through several processes before separation into cottonseed, cotton fiber, and waste. Most of the unwanted plant parts, soil particles, and other foreign materials are first removed from the seed cotton as it passes a series of machines. Moisture may be removed, if required, before or during this process with heated air, and moisture may be restored at the end of this process. The most important part of the ginning process occurs at the gin stand where cotton fibers are removed from cottonseed. Upland cotton is typically processed through a saw-type gin where saw teeth grab cotton fibers attached to cottonseeds and pull them through narrow slots between ginning ribs. Size prevents cottonseed from passing the ribs, so the fibers are separated from the seeds. After fiber-seed separation, the fibers are cleaned pneumatically and mechanically before being packaged.

It is widely accepted that the mechanical forces in the gin stand necessary to extract the fibers from the seed roll cause fiber breakage and a shift in the fiber length distribution, though determining the length distribution of fibers on the seed can be difficult if not impossible. Fransen and Verschraege (1985) compared mechanically-ginned fibers to hand-ginned fibers and found a decrease in average fiber length and a shift from a nearly normal fiber length distribution to a negatively skewed distribution with 6 to 8 times the amount of short fibers (< 13mm) found in hand-ginned samples. Other studies have shown that increasing the rate of cotton entering the gin stand can increase the number of short fibers, neps, seed coat fragments, and damaged cottonseed (Columbus et al., 1994 and Buser, 2000).

One major goal in ginning is to remove the entire length of each fiber without breakage or damage. Fibers usually break at the surface of the seed where the strength of the fiber is low. Anthony and Griffin (2001) demonstrated that the force required to separate an individual fiber of full length from the seed was 55% of the force required to break the same fiber. In the gin stand, fibers are not removed individually, and more forces resist the extraction of the fiber than just the bond between the fiber and the seed. Values for fiber-seed detachment energy for upland cotton varieties, measured with a pendulum type tester on fiber bundles removed from the middle of the seed, have been reported to range from 20 to 80 cN*cm/mg fiber for 21 cultivars (Fransen et al., 1984), 21 to 53 cN*cm/mg fiber for 32 cultivars (Verschraege and Kiekens, 1987), and 22 to 33 cN*cm/mg fiber for 10 cultivars (Porter and Wahba, 1999), based on fibers 1.2 cm in length. If an average fiber is 1 inch long, a typical value of 40 cN*cm/mg fiber can be converted to 0.5 Wh/kg lint. The energy required by the gin stand to gin cotton, minus idling energy, has been reported to range from 12 to 15 Wh/kg lint, depending on moisture content (Anthony *et al*., 1982), and to range from

17 to 24 Wh/kg lint among 65 cultivars (Boykin, 2004). Therefore, the energy required to overcome the fiber-seed bond is under 5% of the energy required to extract the fibers from the seed in the gin stand. In the study by Anthony et al. (1982) the energy required by the lint cleaner, minus idling, averaged 77% of the gin stand energy. So, cohesive forces between fibers probably contribute to the majority of the resistance to the gin saw when extracting fibers. The result of these forces between fibers and the attachment of the fibers to the seed is fiber breakage that occurs when the energy required to extract the fibers exceeds the energy required to break the fibers.

Fiber breakage and other fiber damage associated with the gin stand would be reduced by reducing the strength of the bond between the fiber and the seed or frictional forces between fibers. The great variation between cotton cultivars for fiber-seed attachment strength and gin stand energy consumption were noted earlier, so selective breeding and genetic engineering are likely options for reducing fiber damage in the gin stand. This paper explores the possibilities of reducing the fiber-seed attachment strength of cotton in a gin. This paper reports what is known about the structure of the cotton fiber and seed, and what contributes to the force connecting the two; it discusses environmental influences on fiber removal; it explores possible methods of altering and weakening the structure of the fiber base utilizing biological enzymes or chemicals; and it discusses the effects on fiber quality of utilizing these methods.

Fiber Morphology and Physiology

To understand how the fiber is attached to the seed, how the structure can be modified for easier separation, and what properties need to be protected during processing, a brief description of fiber development and the structure of the mature fiber are needed.

Fiber Development

Development of the cotton fiber begins with the rapid elongation of epidermal cells of the cotton seed (Hardin et al., 1998 and Wakelyn et al., 1998). Approximately 25% of the epidermal cells on a cotton seed will develop into fibers. During elongation, the primary cell wall, the cuticle, the cytoplasmic layer, and the large vacuole of the cotton fiber are developed. Elongation involves the expansion of the wall of the fiber, not tip growth. Towards the end of fiber elongation, the vacuole will begin to shrink as cellulose is deposited during secondary cell wall formation. The layers of the mature cotton fiber are the outside cuticle, the primary cell wall, the secondary cell wall, and the lumen, which contains the remainder of the cytoplasm and vacuole.

The Mature Fiber

The present understanding of the composition of cotton fibers has been reported in detail by DeLanghe (1986) and Wakelyn et al. (1998). Cellulose makes up 95% of the cotton fiber after ginning. The secondary wall, which is almost entirely cellulose, consists of crystalline cellulose in multiple layers, called microfibrils. About 90% of the fiber is secondary wall material. There is a winding layer, similar in structure to a layer of secondary wall, which covers the secondary wall. The secondary wall and winding layer are laid down in a spiral around the fiber axis, and the direction of the spiral reverses along the length of the fiber causing changes in the orientation of the fiber. Fiber strength is reduced around these reversals.

The thinner primary wall and cuticle cover the secondary wall and makes up roughly 5- 10% of the fiber weight. These components are formed during cell wall elongation, and their properties are much different from those of the secondary wall, which forms as the cell wall thickens. The primary wall is mainly composed of cellulose, 30% of which is crystalline and the remainder amorphous (Hardin et al., 1998). Amorphous cellulose microfibrils contain many imperfections and more cellulose chain ends than crystalline cellulose. Most non-cellulosic components of the fiber occur in the primary cell wall and cuticle. Proteins, hemicellulose (xyloglucan), pectic substances (pectic acids and pectates of calcium, magnesium, and iron), waxes, sugars (from plants and insects), organic acids (mainly malic and citric), inorganic salts (phosphates, carbonates, and oxides), and pigments can be found in the primary wall and cuticle.

Other than cellulose, pectin is the dominant component of the primary cell wall, providing the network in which cellulose microfibrils are deposited and elongated. Pectin is a polysaccharide primarily composed of galacturonic acid (Willats et al., 2001). As the pectin network is formed, the methyl esthers of nearly all galacturonic acid units are removed and the de-esterified pectins are typically cross-linked by calcium, though some other modifications

may occur. Gamble (2003) analyzed fiber pectin from two mature American Upland cottons and found 9.1% and 10.9% calcium, which were close to the 11.4% calcium reported for 100% cross-linked calcium polygalacutronate.

Hemicellulose is also present in the fiber, the most common being xyloglucan (Tokumoto et al., 2003). Xyloglucan is thought to serve as a cross-link between cellulose microfibrils and has been shown to decrease in concentration during cell elongation.

The cuticle (cotton wax) covering the primary wall was described by Wakelyn et al. (1998) as "a mixture of high-molecular-weight, long-chain, mainly saturated fatty acids and alcohols (with even numbers of carbon atoms, C28-C34), resins, saturated and unsaturated hydrocarbons, sterols, and sterol glucosides. In terms of its major components cotton wax appears to be 10-15% high-molecular-weight esters (no single ester predominates), montanol, 1-triacontanol, β-sitosterol, and a major unidentified component."

The thickness of the primary cell wall is constant across the whole length of the fiber except for the thickened area in the basal region (DeLanghe 1986 and Vigil et al. 1996). Upon desiccation, the primary wall is not able to shrink as much as the secondary wall and may become wrinkled as it alters to the underlying structure (Wakelyn et al., 1998). The primary wall and cuticle protect the fiber from moisture transfer, and provide lubrication important during fiber processing. This lubrication reduces the frictional forces between fibers. These important components of the fiber cell wall are potentially vulnerable to any attempt to weaken the fiber-seed bond.

The Fiber Base

The properties of the cotton fiber are somewhat different at the point of attachment to the seed. Understanding these differences is the key to developing a method to further weaken the bond between the fiber and the seed. Fryxell (1963), Vigil et al. (1996), and Berlin (1986) have used similar terms to describe the fiber base. The "foot" of the fiber anchors the fiber to the base of the surrounding epidermal cells, the "shank" of the fiber is the portion that is adjacent to the surrounding epidermal cells, and the "elbow" is the location of the fiber just above the seed surface where the fiber orientation turns almost normal to the seed surface. After the cotton fiber matures and starts to dry, the surrounding epidermal cells begin to compress the fiber in the "shank" and "foot" regions.

Vigil et al. (1996) used a microscope to observe cotton fibers (*G. hirsutum*) removed during saw ginning that were either broken at the seed surface or torn at some other location. He found that fibers broken at the seed surface showed very little secondary cell wall material. These findings backed up earlier observations by Berlin (1986) who also saw reduced secondary wall deposition in the base of cotton fibers (*G.* Hirsutum) and below the seed coat surface. Ryser (1992), however, showed a different structure of the fiber base, with considerable secondary cell wall deposition, when analyzing fiber from the cotton *G. aboreum*.

For *G. hirsutum*, the secondary cell wall contributes most of the strength and rigidity of the cotton fiber, and a lack of secondary cell wall in the fiber base explains why the bond strength between the fiber and the seed is much less than the tensile strength of the fiber. Vigil et al. (1996) observed that the primary cell wall is thicker at the base of cotton fibers (*G. hirsutum*). Therefore, the primary cell wall and the cuticle probably account for most of the material holding the fiber to the seed.

Two investigations of the cotton fiber cell wall revealed some differences between the fiber cell wall and the walls of surrounding epidermal cells. Vaughn and Turley (1999) analyzed developing fibers in vitro utilizing antibodies and affinity probes to observe differences in epidermal cells that elongate into fibers. They found de-esterified pectins, xyloglucans (hemicellulose), and extensin proteins in the primary wall of the fiber and the region between the fiber and surrounding cells, but they did not find pectins or extensins in the walls of the surrounding epidermal cells. They found that the wax layer coated both the fiber and the surrounding cells. Himmelsbach et al. (2003) used Fourier-transform mid-infrared mapping and histochemical staining to study the components of the fiber base and surrounding epidermal cells in mature cotton that had been conventionally grown and harvested, and they also found pectins in the fiber wall but not the outer epidermis of the seed coat. Pectin was found in the deeper layers of the seed coat, such as the outer and inner pigment layers, the upper palisade, and the inner epidermis. Waxes were found on both the fiber and the surrounding epidermal cell walls.

Vaughn and Turley (1999) also found plasmodesmata between the base and underlying epidermal cells, and that the cell wall around the plasmodesmata contained callose. They suggested these structures and materials help hold the fiber to the seed.

Observations made on the structure of the cotton fiber and its base suggest there are several possibilities for selectively breaking down components specifically in the basal regions to reduce the fiber-to-seed bond. If secondary wall material is reduced at the base of the fiber, selectively altering the primary wall and cuticle material in the fiber base could help reduce the fiber-to-seed bond. It is also possible that the fiber could be altered at the calose rich plasmodesmata in the fiber base.

Environmental Influences

The temperature and relative humidity during ginning, as well as the driers used in the gin, influence the moisture content of the cotton. Some experiments have been conducted to determine the effect of seed cotton moisture content on the fiber-seed attachment force. Anthony et al. (1982) found that the energy consumed by the gin stand decreased as the moisture content of the ginned lint increased in the range 3.7% to 9.4% moisture. It was thought that the fiber-seed attachment force was weakened by increased moisture, but other forces causing resistance in the gin stand, such as resistance on the side plates or friction between fibers, may have been influenced. In a study by Anthony and Griffin (2001), the attachment force of individual fibers to the seed remained unchanged in the range 3.6% to 9.4% moisture. As the moisture content was raised to 13.3% the attachment force decreased, but these higher moisture conditions are not typical in gins. The results of these two experiments suggest that typical changes in moisture do not affect the fiber-seed bond, but other frictional forces acting on the fiber decrease with increased moisture content. In any experiment designed to analyze the effects of treatments on fiber-to-seed attachment force, the moisture content should be maintained to eliminate its influence on fiber friction.

Chemical and Enzymatic Processes

Investigating potential treatments for reducing the fiber-to-seed attachment force by altering cell wall material of the fiber, the fiber base, or surrounding epidermal cells included a range of studies including chemical treatments for the removal of cell wall materials, enzymatic treatments to weaken the fiber-to-seed attachment force, and enzymatic processes used in various textile applications such as dyeing and finishing.

Chemical Scouring

Hot ethyl alcohol can be used to remove only the cotton fiber wax layer. All non-cellulosic components of the cotton fiber in the cuticle and primary wall can be removed by chemical scouring using hot dilute caustic soda (sodium hydroxide) (Li and Hardin, 1998). These processes have typically been used to prepare fabrics for subsequent dyeing or finishing in the textile industry, but are being replaced with more environmentally friendly and economical enzymatic processes (Hardin et al., 1998). Chemical scouring to remove the wax or primary wall layers of the cotton fiber could weaken the fiber-seed attachment force since it has been suggested that secondary wall material is reduced in the fiber base. Surfactants alone have been shown to alter the cuticle layer of the fiber, and the chelator EDTA has been shown to solubilize pectates in the primary wall, but these materials have been used to enhance enzyme applications and will be discussed in detail with that topic. Removal of the wax or primary wall along the length of the fiber would likely have a negative impact on other important fiber properties, such as cohesion, that are important in fiber processing. Such a treatment would need cause only a temporary disruption in these layers of the fiber, or a subsequent treatment would be needed to restore the lubricity of the fibers.

Enzymes in Seed Cotton

Several experiments have been conducted with limited success in weakening the fiber-to-seed attachment force using enzyme solutions to alter the structure of the fiber and fiber base. In one experiment Tergitol TMN-10 (surfactant) and pectinol HS (combination of pectinase enzymes) were used to reduce fiber-seed attachment strength (Columbus et al., 1992). A modified Shirley Developments Limited Cotton Attachment Tester® showed a slight reduction in the attachment strength with the addition of pectinase to the surfactant, but fiber strength was equally affected. It was suspected that some cellulase was present in the pectinase mixture causing unwanted degradation of cellulose.

In an earlier experiment (Wade and Rowland, 1979), pectinase, cellulase, and two hemicellulase were used in combination with surfactants to treat seed cotton, and their effect on fiber-to-seed attachment strength was assessed manually. Surfactants alone slightly reduced the attachment strength, and one hemicellulase (xylanase from *A. niger*) and the cellulase caused further reductions. One hemicellulase (from Rhizopus mold) and the pectinase

(fungal) did not add to the effect of the surfactant. The cellulase treatments not only reduced the attachment strength but also deteriorated the fiber. The hemicellulase (xylanase from *A. niger*) caused a drop in stelometer bundle breaking strength up to 9 to 13 percent.

Since pectin and hemicellulose (xyloglucan) are known to be present in the primary wall of the fiber and its base but absent in surrounding epidermal cells, it is unclear why hemicellulase would be more effective than pectinase in degrading cell wall material and reducing fiber strength. Enzymes from different sources act differently on their substrates, for example, only one of the hemicellulase acted on the fiber in the experiment by Wade and Roland (1979). Several explanations for the differences in the action of hemicellulose and pectin are: pectins could be less available than hemicellulose to the action of enzymes, pectin degradation could have less impact than hemicellulose degradation on attachment strength reduction, or a pectinase from a different source may be more effective. In the work by Wade and Roland (1979), there is also the possibility that the hemicellulase also had significant cellulase or pectinase activity.

Enzyme Treatment on Fibers or Fabrics

Some of the processes used in the textile industry, such as those associated with dyeing and finishing, have the potential to be modified with enzymatic processes, and some research has been focused on this area. A review of this research is important in understanding how enzymes may be used to alter the bond between the fiber and the seed. These enzymatic processes are focused on the removal of "impurities" from raw cotton such as waxes, pectins, proteins, non-cellulosic polysaccharides, inorganics, lignin-containing impurities, coloring materials, and other non-cellulosic materials, which represent about 10% of the raw cotton fiber (Csiszar et al., 2001a). Most of these materials reduce the water absorbency of cotton fibers and must be removed before dyeing. Materials can also be removed from the surface of fibers in fabrics to eliminate "fuzz" or "pills" or make the fabric softer. Enzymatic processes replace chemical processes that are typically more detrimental to the environment.

Most of the enzyme research on textiles has focused on the use of cellulases, pectinases, hemicellulases, proteases, and lipases. The most successful treatments usually include cellulase, pectinase, or their combination. These enzymes can be very effective in removing the cuticle layer and altering the primary cell wall of the cotton fiber to make cotton more water absorbent, and cellulase can remove unwanted cellulose material from the surface of fabrics (Csiszar et al., 2001 and Hardin et al., 1998).

The substances in the cuticle and primary wall exist in an amorphous state making them more susceptible to enzymatic degradation than the crystalline substances of the secondary wall (Hardin et al., 1998 and Li and Hardin, 1998). Some research has shown that combinations of enzymes can be more effective in cell wall removal than individual enzymes. For example, removal of the cuticle layer by one type of enzyme will make the primary wall more accessible to another enzyme. Also, any modification to enzymatic processes to improve the availability of the substrate to the enzyme, such as agitation or the addition of surfactants should make the process more rapid and effective (Hardin et al., 1998). The following is a description of how several important enzymes work and how they have been used by the textile industry. Modifications that improve substrate availability will also be discussed.

Much of the research on the use of enzymes in textile processes has focused on cellulase. Cellulase is most often used to remove unwanted cellulose material from the surface of fabrics. Fuzz is removed to make the fabric smooth and pills are removed that have not taken up dye.

There are several good reviews of cellulose degradation by cellulase (Finch and Roberts 1985, Walker and Wilson 1991, and Henrissat 1994). These reports describe how the structure of cellulose is important to enzymatic degradation and how several different components of cellulase work together to break down the cellulose structure. As mentioned earlier, the cotton fiber wall contains a very complex network of cellulose chains, which are polymers of β-1,4-linked D-anhydroglucose units. These chains associate to form microfibrils that form macrofibrils, which are organized into the cell wall. So, portions of the cell wall cellulose are more available to enzymatic degradation. Cellulases break down cellulose by hydrolyzing the bond between anhydroglucose units. There are three categories of cellulases, endoglucanases, cellobiohydrolase (exoglucanases), and β-glucosidase, which are attracted to different areas of the cellulose chain and typically work together as a "total cellulase" to degrade cellulose. Endoglucanases can hydrolyze any unit of cellulose resulting in glucose, cellobiose (two glucose units), or cello-oligosaccharides (larger fragments of cellulose). Cellobiohydrolases degrade cellulose by sequentially removing two glucose units from cellulose chain ends producing cellobiose. β-glucosidase degrades cellobiose to glucose.

Commercially available cellulases are largely produced by *Humicola insolens* (most active at pH7) and *Trichoderma reesei* (most active at pH5) (Cavaco-Paulo, 1998). Organisms may produce a total cellulase containing endoglucanase, exoglucanase, and β-glucosidase, but the enzymes vary between organisms and behave quite differently. Some organisms will produce several different cellulases in each category to more effectively utilize its substrate. There is synergism between categories of cellulases and within categories of cellulases which allow different combinations of cellulases to be much more effective in degrading cellulose.

Experiments with total cellulase (Rousselle et al. 2002) and components of cellulase (Rousselle et al. 2003) showed their effect on the molecular structure of cellulose. They found that cellulase did not selectively attack either the highly ordered or disordered cellulose components of the fiber, and the structure of the resulting microfibril was smaller but mostly unchanged after enzymatic treatment. Cellulose chains were found to be removed and rapidly degraded.

Pectic enzymes have also received much attention in the treatment of cotton textiles. There are several types including pectin methyl esterase, pectin lyase, pectate lyase, endo-polygalacturonase, and exo-polygalacturonase, which differ in the way they attack the polygalacturonic backbone of pectin. Pectin methyl esterase hydrolyzes the ester groups from methylated galacturonic acid units in esteified pectins. The 1,4-α-D-galacturonan linkages in esterified pectins are cleaved by pectin lyase, which also acts on de-esterified pectins (pectates) to a lesser extent. Pectate lyase cleaves this link in de-esterified pectins (pectates) only, but polygalacturonase will hydrolyze the linkage in both forms of pectin (Mayans et al., 1997). If cotton fiber pectin were composed almost entirely of de-esterified pectin, then pectate lyase or polygalacturonase would be the most successful in hydrolyzing cotton fiber pectin.

Hartzell and Hsieh (1998) exposed cotton fabric, which had been pretreated with boiling water, to several categories of pectinases with non-ionic surfactant. They found that total pectinase from three sources of *Aspergillus niger* effectively degraded the primary wall as well as alkaline scouring, but total pectinase from a Rhozopus species, pectin lyase from *Aspergilllus japonicus*, and two pectinesterase from orange peel were not effective. Their results indicate that pectinase from *Aspergillus niger* is suited to cotton pectin. The lack of activity in pectinesterase and pectin lyase treatments support earlier statements that cotton fiber pectin is de-esterefied. It is unclear why Rhozopus pectinase failed to degrade pectin.

Li and Hardin (1998) used pectinase or cellulase to treat raw fibers and found that either the addition of a surfactant or the removal of the wax layer by alcohol extraction both improved the activity of the enzymes. Sawada and Ueda (2001) exposed cotton fabric that had been boiled in water for one hour with pectinase from *Aspergillus niger* and found that the pectinase in combination with surfactant and the surfactant alone reduced wax levels from four percent to almost zero, but treatments reduced pectic substances only when pectinase was added to the surfactant. These reports show the wax layer can act as a barrier to enzyme treatments, but that surfactants can dissolve the wax layer over the fiber, improving the activity of the enzyme.

Calafell and Garriga (2004) showed that pectinase (polygalacturonase) from *Aspergillus niger*, which was probably lacking pectate lyase activity, was successful in removing the primary wall cotton fiber fabric. The work also showed the importance of a non-ionic surfactant addition and pH control.

Csiszar et al. (2001a) exposed cotton fabric and spinning blowroom waste (consisting of stalks, leaves, seed coat fragments, and fiber) to enzyme solutions with high cellulase (*Trichoderma reesei*), high pectinase (*Aspergillus* sp.), or high xylanase (*Bacillus* sp.) activities. The cellulase, β-endoglucanase, xylanase, and β-glucosidase activities were reported for these enzymes (Csiszar et al. 2001b). The pectinase was active in the β-endoglucanase category, indicating its ability to utilize cellulose, the cellulase was active in each category, and the xylanase was active in the xylanase category only. The treatments were repeated with and without the addition of ethelynediaminetetraaceatic acid (EDTA) as a chelating agent for calcium in the pectate component. In the fabric treatments, they found that the pectinase and cellulase activities were about the same without EDTA and only slightly better than EDTA alone (at pH 5), and they found that EDTA improved the activity of cellulase only. This shows that EDTA was effective in removing some of the primary wall, but may not have improved to the pectinase treatment. The addition of EDTA to the cellulase treatment increased the availability of cotton cellulose in the primary wall to the enzyme by degrading the pectic fraction of the primary wall. The addition of EDTA to the xylanase treatment increased the

activity of the solution, but without much improvement over EDTA alone. In the spinning blowroom waste, EDTA alone at pH 7 degraded the material, but the most degradation was seen when combined with xylanase. The difference between these results and those seen with fabric indicate an increase in hemicellulose and pectin in either the lower levels of the seed coat or in the leaf or stalk material. As mentioned earlier, the pigment layers, upper palisade layer, or inner epidermis of the seed coat have been shown to contain pectin or hemicellulose (Himmelsbach et al., 2003). This paper shows the importance of the chelator, EDTA, in pectinase activity, and that EDTA alone will likely remove calcium pectates in cotton fibers. As mentioned earlier, calcium cross-links pectin to form calcium pectate, which gels. EDTA binds the calcium from pectate and dissolves the pectin. EDTA also has the ability to bind other materials linking pectate, such as magnesium or iron. There are other chelating agents, but EDTA is the most common, particularly with calcium (Sawyer et al., 1994).

Degani et al. (2002) scoured cotton fabric with combinations of surfactant (non-ionic), cutinase (*Pseudomonas mandocino*), and pectinase. They found that the surfactant greatly reduced the wetting time of the fabric. Cutinase, pectinase, and their combination, alone and with surfactant solution, provided further reductions in wetting time.

Importance of Fiber Surface in Processing

The role of fiber surface wax plays a vital role in fiber processing by providing lubrication between other fibers and machinery and by preventing static problems. Cui et al. (2002) found that fiber breakage during carding, which is one step involved in converting fiber to yarn, did not correlate with wax content for different cotton varieties, but they speculated that all the varieties had sufficient wax to lubricate the fiber. But, when the wax layer was removed from these fibers, fiber length reduction was ten times greater for dewaxed fibers. Cohesion values for dewaxed fibers were three times higher than values for regular fibers. As a result of changes in the specific surface area of the fiber, micronaire was inversely related to wax content. El Mogahzy et al. (1998) found that friction between fibers increased as the wax content was reduced, and results were unrelated to micronaire. So, it is important that in any process designed to reduce fiber-to-seed attachment force, the wax layer should be protected or restored after removing fibers from the seed.

There has been some interest in restoring the lubricating effect of the wax layer to washed cotton. Different methods of washing cotton have been explored to prevent byssinosis (Perkins et al., 1986 and Sasser et al., 1986). The results of these procedures were the removal or partial removal of the primary wall and cuticle. Numerous fiber finishes were analyzed for their ability to restore lubricity to the fibers and eliminate static charge build-up during processing through the carding equipment. None of the finishes restored the fibers to their natural state, though some were successful in reducing static and allowing material to process smoothly through the carding machine. Potassium salts added with the finish reduced some of the static problems. Allen (1999) found that a 1% finish of sodium acetate eliminated static friction between scoured fibers but did not affect dynamic friction. He found that 0.25% to 1% butoxyethyl stearate (BES) and 1.7% Sebosan AS (Stockhausen Inc.) provided lubrication and reduced dynamic friction between fibers, but the application of Sebosan AS yielded a non-absorbent product. With any of the finishes, fibers were still damaged in the carding machine.

Slade (1998) has provided a comprehensive review of fiber finishes used in all areas of the textile industry. Lubricants used in textile processing are water soluble materials such as ethylene oxide-propylene oxide copolymers or water insoluble materials (esters, alkanolamides, mineral oils, long chain fatty acids or alcohols, fluorocarbons, and silicones) which require an emulsifier to be applied in water. Cohesive agents (softeners), antistats, and emulsifiers can sometimes provide lubrication. When applying lubrication to fibers, it is important to not over-apply since some cohesion between fibers is essential in fiber processing. Research has shown a positive relationship between the ability of a lubricant to lower fiber friction and its ability to wet the fiber. Friction has not been shown to change between acid and alcohol groups in the molecular structure of lubricants but was lowered when an amide group was added. Fiber to metal friction is thought to be directly related to the viscosity of the lubricant.

Summary

A cotton fiber is a single elongated fiber, developed from an epidermal cell of the cottonseed that consists of the outside cuticle, the primary wall, the secondary wall, and the hollow lumen. It is mainly the primary wall and cuticle that contribute to the attachment strength of the fiber to the seed. Removing these layers with chemicals or enzymes may reduce the attachment strength, therefore reducing fiber damage occurring in the gin stand. Waxes in

the cuticle can be removed with cutinase, and surfactants alone have been shown to dissolve wax. Pectate lyase or polygalacturonase (*Aspergillus niger*) are likely candidates for primary cell wall removal, but it is essential to combine a non-ionic surfactant or cutinase to disrupt the wax barrier. A chelator, such as EDTA, has been shown to facilitate the removal of primary wall and is probably effective alone. Cellulases can be used to break down the cellulose structure if needed. The consequence of removing the cuticle, primary wall, or cellulose material is a reduction in the lubrication or strength of the fiber. To work around this problem, processes are needed that either target the base of the fiber only, restore the fiber surface, or cause only a temporary disruption to the fiber surface materials.

In order to target the base of the fiber, materials associated only with the base of the fiber need to be degraded. It has been suggested that hemicellulose (xyloglucan) and callose are concentrated in the base of the fiber and may be degraded to weaken the fibers attachment force, but such a process would have to penetrate the wax layer. New materials need to be developed or tested to restore the wax layer and primary wall, and processes that remove these layers can be used to weaken the attachment force of the fibers. Enzymes typically degrade their substrate, but some chemicals can be used to alter the properties of those material. Such a chemical solution could be used to temporarily solubilize the primary wall and cuticle to help release the fiber from the seed. Upon drying, the layers should reform on the fiber. A surfactant could be used to penetrate the wax layer, and EDTA or some other chelator could be used to solubilize the pectin, but it is not known what the long-term changes would be to the surface characteristics of the fiber.

After a process has been developed to weaken the fiber-seed attachment force, methods will need to be developed to incorporate the process into production practices. Enzymatic treatments would likely be time consuming and need to be applied as a spray in the field before or during harvest. Chemical treatments would be more rapid and need to be applied as a spray when the cotton enters the gin or in the conveyor distributor above the extractor-feeder/gin stand. Finishes that restore the lubrication to fibers would most likely be applied immediately after or with the removal of the cuticle or primary wall, either in the field or as a spray within the gin.

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