All plants contain fibrous bundles that give strength to the stem and root, pliability to the leaves, and cushioning or protection to developing seeds. In some plants, these fibrous bundles can be removed from the plant in an easy and economical process and used in textile products. These natural cellulosic fibers are classified according to the plant component from which they are removed (Table 1): seed, stem (bast), leaf, or miscellaneous component (root, bark, husk, or moss). While hundreds of plant fibers have been used since humans first discovered how to work with fibers, this chapter will focus on the ones that are significant in the global textile complex or that offer potential for future growth as plant fibers. Figure 1 shows where the fibers in this chapter are produced.

**Table 1 Natural Cellulosic Fibers**

<table>
<thead>
<tr>
<th>Seed Fibers</th>
<th>Bast Fibers</th>
<th>Leaf Fibers</th>
<th>Miscellaneous Fibers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cotton</td>
<td>Flax</td>
<td>Piña</td>
<td>Rush</td>
</tr>
<tr>
<td>Kapok</td>
<td>Ramie</td>
<td>Abaca</td>
<td>Sea grass</td>
</tr>
<tr>
<td>Coir</td>
<td>Hemp</td>
<td>Sisal</td>
<td>Maize</td>
</tr>
<tr>
<td>Jute</td>
<td>Milkweed</td>
<td>Henequen</td>
<td>Palm fiber</td>
</tr>
</tbody>
</table>

*Multiple colors indicate production of more than one fiber.

**Figure 1** Countries where natural cellulosic fibers are produced.
Cotton, a seed fiber, grows within a pod or boll from developing seeds. Flax, a bast fiber, is obtained from the stem and root of the plant. Sisal, a leaf fiber, is removed from the veins or ribs of a leaf. Fiber from other plant components such as Spanish moss and cedar bark were used by Native Americans, but are not currently used in commercial products.

These fibers are all cellulosic, but they differ in the percentage of cellulose present and in their physical structure. While the arrangement of the molecular chains in these fibers is similar, it varies in orientation and length. Thus, performance characteristics related to these aspects differ. Fabrics made from these fibers differ in appearance and hand but have a similar reaction to chemicals and require similar care. Properties common to all cellulosic fibers are summarized in Table 2.

All cellulose fibers contain carbon (C), hydrogen (H), and oxygen (O). The basic monomer of cellulose is glucose. The figure to the right shows two glucose units (the second one is inverted) that repeat thousands of times to form cellulose. This two-glucose repeating unit is called cellobiose. The chemical reactivity of cellulose is related to the hydroxyl groups (–OH) of the glucose unit. The hydroxyl group reacts readily with moisture, dyes, and many finishes. Chemicals such as chlorine bleach damage cellulose by attacking the oxygen atom between the two ring units or within the ring, rupturing the chain or ring.

This chapter discusses major natural cellulosic fibers and those of more limited use that may be present in imported goods or that may be encountered during travel or in certain careers. While several of these fibers may not be common in apparel, they are important in the interiors industry and may be used as reinforcement fibers in composites. Many other natural cellulosic fibers will not be discussed because of their minimal commercial use.

Some fibers that are derived from plants (bamboo, corn starch, and soy fibers) are not included in this chapter because they are made from noncellulosic parts of the plant or are not found in fiber form in the plant. They must undergo several chemical and manufacturing steps to become fibers.

Table 2 Properties Common to All Cellulosic Fibers

<table>
<thead>
<tr>
<th>Properties</th>
<th>Importance to Consumer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good absorbency</td>
<td>Comfortable for warm weather wear and activewear and interiors</td>
</tr>
<tr>
<td>Good conductor of heat</td>
<td>Good for towels, diapers, and activewear</td>
</tr>
<tr>
<td>Ability to withstand high temperature</td>
<td>Sheer fabrics cool for warm-weather wear</td>
</tr>
<tr>
<td>Low resiliency</td>
<td>Fabrics can be sterilized; no special precautions necessary in pressing</td>
</tr>
<tr>
<td>Low loft; good compressibility</td>
<td>Fabrics wrinkle badly unless finished for wrinkle recovery</td>
</tr>
<tr>
<td>Good conductor of electricity</td>
<td>Dense, high-count fabrics possible</td>
</tr>
<tr>
<td>Heavy fibers (density of 1.5)</td>
<td>Wind-resistant fabrics possible</td>
</tr>
<tr>
<td>Harmed by mineral acids, minimal damage by organic acids</td>
<td>No static buildup</td>
</tr>
<tr>
<td>Attacked by mildew</td>
<td>Fabrics are heavier than comparable fabrics of other fibers</td>
</tr>
<tr>
<td>Resistant to moths, but eaten by crickets and silverfish</td>
<td>Remove acid stains immediately</td>
</tr>
<tr>
<td>Flammable</td>
<td>Store clean items under dry conditions</td>
</tr>
<tr>
<td>Moderate resistance to sunlight</td>
<td>Ignite quickly, burn freely with an afterglow and gray, feathery ash; loosely constructed garments should not be worn near an open flame; interior textiles should meet required codes</td>
</tr>
<tr>
<td></td>
<td>Draperies should be lined</td>
</tr>
</tbody>
</table>

Table 2
Seed Fibers

Seed fibers develop in the seedpod of the plant. In order to use the fiber, it must be separated from the seed. (The seed is used to produce oil and animal feed.) By far the most important seed fiber is cotton. This section discusses cotton and some minor seed fibers.

Cotton

Cotton is an important cash crop in more than 80 countries. Its combination of properties—pleasing appearance, comfort, easy care, moderate cost, and durability—makes cotton ideal for warm-weather apparel, activewear, work clothes, upholstery, draperies, area rugs, towels, and bedding. Even though other fibers have encroached on former cotton markets, the cotton look is maintained. Cotton is also a major component of many blend fabrics.

Cotton cloth was used by the people of ancient China, Egypt, India (where the cotton spinning and weaving industry began), Mexico, and Peru. In the Americas, naturally colored cotton was used extensively.

Cotton was grown in the southern U.S. colonies as soon as they were established. Throughout the 1600s and 1700s, cotton fibers were separated from cotton seeds by hand in a very time-consuming and tedious job. A worker could separate only one pound of cotton fiber from the seeds in a day.

When Eli Whitney mechanized the saw-tooth cotton gin in 1793, things changed. The gin could process 50 pounds of cotton in a day and more cotton could be prepared for spinning. Within the next 20 years, a series of spinning and weaving inventions in England mechanized fabric production. The southern states were able to meet Britain’s greatly increased demand for raw cotton. By 1859, U.S. production was 4.5 million bales of cotton—two-thirds of the world’s production. Cotton was the leading U.S. export. During the time of rapidly expanding cotton production in the south, most U.S. fabrics were spun and woven in New England.

The picture again changed dramatically during the U.S. Civil War. U.S. cotton production decreased to 200,000 bales in 1864, and Britain looked to other countries to fill the deficit. After the war, western states began producing cotton and the southern states built spinning and weaving mills. Between World War I and World War II, most of the New England mills moved south. Factors influencing this move included proximity to cotton producers, less expensive power and nonunion labor, and relocation incentives from state and local governments. By 1950, 80 percent of the mills were in the south. However, during the 1980s and 1990s, most of these mills closed because of increased costs and competition from imports.

Production of Cotton

Cotton grows in any place where the growing season is long and the climate is temperate to hot with adequate rainfall or irrigation. Cellulose will not form if the temperature is below 70°F. In the United States, cotton is grown south of a line from southern Virginia to central California.
The major producers of cotton in the world are China (32.0 percent), India (21.8 percent), the United States (12.2 percent), Pakistan (7.6 percent), and Brazil (5.7 percent). In 2007 the worldwide production of cotton was over 113 million bales (480 pounds per bale). Mechanization and weed control reduce the number of hours required to produce a bale of cotton, thereby increasing productivity.

Factors affecting the U.S. production of cotton include the value of the dollar as compared with other currencies, imports of cotton goods, changes in government incentives for growing cotton, weather conditions, and comparable changes in other countries.

Cotton grows on bushes 3 to 6 feet high. After the blossom drops off, the boll or seedpod begins to grow. Inside the boll are seven to eight seeds with several hundred thousand cotton fibers. Each cotton seed may have as many as 20,000 fibers growing from its surface. When the boll is ripe and about the size of a walnut, the fluffy white fibers expand as they grow and eventually split open the boll (Figure 2).

Cotton is most often picked by machine (Figure 3). This cotton contains many immature fibers—an inescapable result of mechanically stripping the cotton plant. After picking, the cotton is pressed into a brick weighing approximately 22,000 pounds and taken to a gin to separate the fibers and the seeds. In a saw gin, the whirling saws pick up the fiber and carry it to a knife-like comb, which blocks the seeds and permits the fiber to be carried through (Figure 4). The fibers, called lint, are pressed into bales weighing 480 pounds each and sold to spinning mills or exported.

After ginning, the seeds are covered with very short fibers—\( \frac{1}{8} \) inch in length—called linters. The linters are removed from the seeds and are used to a limited extent as raw material in producing rayon and acetate. Linters are used to stuff small decorator pillows and are used in automotive upholstery, mops, candlewicks, blankets, mattresses, twine, rugs, and medical supplies. Linters are also converted into cellophane, photographic film, fingernail polish, and methylcellulose used in makeup and chewing gum. The seeds are crushed to obtain cottonseed oil and meal used in food and livestock feed, pharmaceuticals, and soap stock. The hulls are used in animal feed, fertilizer, garden mulch, and oil drilling mud to plug leaks in oil wells.

Recent advances in plant breeding have produced cottons that are insect-, herbicide-, and stress-tolerant. Cotton breeders have focused their efforts on improving fiber strength and length. These changes have contributed to higher processing speeds, finer and more uniform yarns, and more durable fabrics. Efforts in plant breeding continue to focus on producing cotton varieties with better resistance to insects, disease, herbicides, fungi, and drought and with enhanced properties for ease of processing, higher reactivity for dyes, and improved product performance. Some bioengineered cotton plants have been developed that incorporate a tiny percentage of polyester in the fiber. In addition, some plant breeders are working to improve the performance characteristics and color options of naturally colored cotton.

**Physical Structure of Cotton** Although some naturally colored cotton is produced, most raw cotton is creamy white in color. The cotton fiber is a single cell, which grows from the seed as a hollow tube over one thousand times as long as it is thick.

**Length** Staple length is very important because it affects how the fiber is handled during the spinning process, and it relates to fiber fineness and fiber tensile strength. Longer cotton fibers are finer and make stronger yarns. Length is determined by removing a sample from a bale of cotton, sorting the fibers by length, and calculating the average staple length and the variation of length or uniformity ratio.
Cotton fibers range in length from 1/2 to 2 inches, depending on the genetic variety. Three groups of cotton are commercially important:

1. Upland cottons (Gossypium hirsutum, the predominant type of cotton produced in the United States) are 3/4 to 1 1/2 inches in length and were developed from cottons native to Mexico and Central America. Approximately 97 percent of the U.S. crop is an Upland variety.
2. Long-staple cottons, which are 1 3/4 to 2 inches in length, were developed from Egyptian and South American cottons. Varieties include American Pima, Egyptian, American Egyptian, and Sea Island cottons. Cotton from the Gossypium barbadense variety is grown in the southwestern United States and is about 3 percent of the crop.
3. Short-staple cottons, Gossypium arboreum and Gossypium herbaceum, are less than 3/8 inch in length and are produced primarily in India and eastern Asia.

Long-staple fibers are considered to be of higher quality and are used to produce softer, smoother, stronger, and more lustrous fabrics. Because their perceived value is higher, they are sometimes identified on the label or tag as Pima, Supima, Egyptian, or Sea Island. Or they may be referred to as long-staple or extra-long-staple (ELS) cotton.

Distinctive Parts The cotton fiber is made up of a cuticle, primary wall, secondary wall, and lumen (Figure 5). The fiber grows to almost full length as a hollow tube before the secondary wall begins to form.

The cuticle is a waxlike film covering the primary, or outer, wall. The secondary wall is made up of layers of cellulose (Figure 6).

The layers deposited at night differ in density from those deposited during the day; this causes growth rings, which can be seen in the cross section. The cellulose layers are composed of fibrils—bundles of cellulose chains—arranged in a spiral that sometimes reverses direction. These reverse spirals (Figure 7) contribute to the development of convolutions that affect the fiber's elastic recovery and elongation. They are also 15 to 30 percent weaker than the rest of the secondary cell wall.

Cellulose is deposited daily for 20 to 30 days, until, in the mature fiber, the fiber tube is almost solid. The lumen is the central canal, through which nourishment travels during fiber development. When the fiber matures, dried nutrients in the lumen may result in dark areas that are visible under a microscope.

Convolutions Convolutions are ribbonlike twists that characterize cotton (Figure 8). When the fibers mature and force the boll open, they dry out and the central canal collapses. Reverse spirals in the secondary wall cause the fibers to twist. The twist forms a natural texture that enables the fibers to cling to one another. Thus, despite its short length, yarn spinning is easy with cotton. However, the convolutions may trap soil, requiring vigorous cleaning to remove it. Long-staple cotton has about 300 convolutions per inch; short-staple cotton has less than 200.

Fineness Cotton fibers vary from 16 to 20 micrometers (microns) in diameter. The cross-sectional shape varies with the maturity of the fiber. Immature fibers tend to be U-shaped, with a thin cell wall. Mature fibers are more nearly circular, with a thick cell wall and a very small central canal or lumen. Every cotton boll contains some immature fibers that can create problems in spinning and dyeing. Figure 8 illustrates the variation in size and shape of the fibers.

Color Cotton is available in a range of colors. Naturally creamy white is highly desirable because it can be dyed or printed to meet fashion and consumer needs. These fibers may yellow with age. If it rains just before harvest, cotton becomes grayer.
Naturally colored cotton fibers have been cultivated for thousands of years. As commercial production replaced hand processes, these fibers declined in importance. By the early 20th century, they had become difficult to find. However, with the current interest in minimizing environmental impact and sustainability concerns, interest in naturally colored cottons has resurfaced. Naturally colored cottons produce less fiber per acre, but sell for about twice the price of white cotton. Naturally brown, rust, red, beige, and green colored cottons are commercially available. These colors deepen with age and care, which is contrary to the aging process of most dyed or printed fabrics (Figure 9). Colored cottons are shorter, weaker, less absorbent, and have less uniform properties than do white cotton, but improvements are expected as plant breeders concentrate on enhancing these properties. These cottons also have higher metal content than white cottons, probably because of the natural pigments in the fiber. Naturally colored cottons are produced in Russia, India, South and Central America, Africa, and the United States. Plant breeders continue to work to add blue, lavender, and yellow to the current list of naturally colored cottons. Naturally colored cotton has lower environmental impact, especially in yard and fabric finishing processes.

Picking and ginning affect the appearance of cotton fibers. Carefully picked cotton is cleaner. Well-ginned cotton is more uniform in appearance and color. Poorly ginned cotton contains brown flecks of trash, such as bits of leaf, stem, or dirt, that decrease fiber quality. Fabrics made from such fibers include utility cloth and may be fashionable when a “natural” look is popular.

Classification of Cotton  Grading and classing of cotton is done by hand and by machine-HVI (high-volume instrument) systems. Fiber characteristics, including staple length and color of the cotton from the bale, are compared with standards prepared by the U.S. Department of Agriculture.

Cotton classification describes the quality of cotton in terms of staple length, grade, and character. Fiber-length classifications for cotton include very-short-staple cotton (less than 0.25 inch), short-staple cotton (0.25 to 0.94 inch), medium-staple cotton (0.94 to 1.13 inches), ordinary long-staple cotton (1.13 to 1.38 inches), and extra-long-staple cotton (1.38 inches). Staple length is based on the length of a representative bundle of fibers from a bale of cotton. There are 19 staple lengths, ranging from less than 1/3 inch to 1 1/2 inches and beyond. A sample classified as 1/3 inch is likely to have fibers ranging in length from 1/4 inch to 1/2 inches, as shown in Figure 10.

There are 39 grades of cotton. Grade refers to the color of the fiber and the absence of dirt, leaf matter, seed particles, motes or dead fibers, and tangles of fiber called neps. Motte fibers do not absorb dyes, lower fiber quality, and cause defects in fabrics. The best-quality grade is lustrous, silky, white, and clean. The predominant grade of cotton produced in the United States is strict low-middling cotton. Strict in this case means “better than.”

This grading system is used primarily for the creamy white fibers that dominate the market. Color is described as white, light-spotted, spotted, tinged, or yellow. Color is also described in terms of lightness to darkness: plus, light gray, and gray. This factor is a combination of grayness and the amount of leaf bits present in white cotton grades.

Character includes such fiber aspects as maturity, smoothness and uniformity of fibers within the bale, fiber fineness, strength, and convolutions. Micronaire values, which reflect both fineness and matuarity, are assessed by forcing air through a standard weight plug of cotton fibers compressed to a fixed volume. Lower micronaire results indicate less mature and coarser fibers, while higher values indicate more mature and finer fibers. Character identifies the amount of processing necessary to produce a good white fabric for commercial use. Because of yearly variations in growing conditions and in geographic locations, yarn and fabric producers carefully select and blend cottons so that the cotton fabrics and products are as uniform from year to year as possible.
Cotton is a commodity crop. It is sold by grade and staple length. Strict low-middling cotton is used in mass-produced cotton goods and in cotton/synthetic blends. Better grades of cotton and longer-staple cotton are used in better-quality shirtings and sheets. Extra-long-staple (ELS) American Egyptian cotton usually is identified by the terms Pima and Supima on labels for sweaters, blouses, shirts, underwear, sheets, and towels.

### Chemical Composition and Molecular Arrangement of Cotton
Cotton, when picked, is about 94 percent cellulose; in finished fabrics it is 99 percent cellulose. Like all cellulose fibers, cotton contains reactive hydroxyl groups. Cotton may have as many as 10,000 glucose monomers per molecule connected in long linear chains and arranged in a spiral form within the fiber. Chain length (average number of glucose monomers per molecule) contributes to fiber strength.

Cotton can be altered by using chemical treatments or finishes. Mercerization (treating yarns or fabrics with sodium hydroxide [NaOH]) causes a permanent physical change. The fiber swells and creates a rounder cross section. Mercerization increases absorbency and improves the dyeability of cotton yarns and fabrics. Liquid ammonia is used as an alternative to several preparation finishes, especially mercerization. Fabrics treated with ammonia have good luster and dyeability. When these fabrics are treated to be wrinkle-resistant, they are not as stiff and harsh as mercerized wrinkle-resistant fabrics.

### Properties of Cotton
Cotton is a comfortable fiber. Appropriate for year-round use, it is the fiber most preferred for many interiors and for warm-weather apparel, especially where the climate is hot and humid.

#### Aesthetics
Cotton fabrics certainly have consumer acceptance. Their matte appearance and low luster are the standards that have been retained with many blends used in apparel and interiors.

Long-staple cotton fibers contribute luster to fabrics. Mercerized and ammonia-treated cotton fabrics have a soft, pleasant luster resulting from the finishes; cotton sateen's luster is due to a combination of fabric structure and finishing.

Drape, luster, texture, and hand are affected by choice of yarn size and type, fabric structure, and finish. Cotton fabrics range from soft, sheer batiste to crisp, sheer voile to fine chintz to sturdy denim and corduroy.

#### Durability
Cotton is a medium-strength fiber, with a dry breaking tenacity of 3.5 to 4.0 g/d (grams per denier). It is 30 percent stronger when wet. Long-staple cotton produces stronger yarns because there are more contact points among the fibers when they are twisted together. Because of its higher wet strength, cotton can be handled roughly during laundering and in use.
Abrasions resistance is good; heavy fabrics are more abrasion-resistant than thinner fabrics. Fiber elongation is low (3 percent), with low elasticity.

**Comfort** Cotton makes very comfortable fabrics for skin contact because of its high absorbency, soft hand, and good heat and electrical conductivity. Static buildup is not a problem. It has no surface characteristics that irritate the skin. Cotton has a moisture regain of 7 to 11 percent. When cotton becomes wet, the fibers swell and become more pliant. This property makes it possible to give a smooth, flat finish to cotton fabrics in pressing or finishing and makes high-count woven fabrics water-repellent. However, as cotton fabrics absorb more moisture in cool, damp conditions, they feel wet or clammy and eventually may become uncomfortable.

Still, cotton is good for use in hot and humid weather. The fibers absorb moisture and feel good against the skin in high humidity. The fiber ends in the spun yarn hold the fabric slightly off the skin for greater comfort. Moisture passes freely through the fabric, thus aiding evaporation and cooling.

**Appearance Retention** Overall appearance retention for cotton is moderate. It has very low resiliency. The hydrogen bonds holding the molecular chains together are weak, and when fabrics are bent or crushed, particularly in the presence of moisture, the chains move freely to new positions. When pressure is removed, these weak internal forces cannot pull the chains back to their original positions, so the fabrics stay wrinkled. Creases can be pressed in and wrinkles can be pressed out, but wrinkling during use and care remain a problem. However, cotton fibers can be given a durable-press finish or blended with polyester and given a durable-press finish so they do not wrinkle as easily. Unfortunately, these finishes decrease fiber strength and abrasion resistance.

Cotton's poor resiliency means that it is seldom used in pile rugs or carpets. However, ongoing research is attempting to improve cotton's performance in this significant market.

All-cotton fabrics shrink unless they have been given a durable-press finish or a shrinkage-resistant finish. Untreated cottons shrink less when washed in cool water and drip-dried; they shrink more when washed in hot water and tumble dried in a hot dryer. When they are used again, they may stretch out slightly—think of cotton denim jeans or fitted cotton sheets.

Shrinkage should be low for all-cotton fabrics that have been given a wrinkle-resistant or durable-press finish or that have been treated for shrinkage. However, more effort may be needed with handwoven or short-staple cotton fabrics, unless the label includes specific information about shrinkage.

Elastic recovery is moderate. Cotton recovers 75 percent from a 2 to 5 percent stretch. This means that cotton stays stretched out in areas of stress, such as in the elbow or knee areas of garments.

**Care** Cotton can be washed with strong detergents and requires no special care during washing and drying. White cottons can be washed in hot water. Many dyed cottons retain their color better if washed in warm, not hot, water. If items are not heavily soiled, cool water cleans them adequately. Cotton releases most soils readily, but soil-resistant finishes are desirable for some interior and apparel uses. Use of chlorine bleach is inappropriate for spot removal, but should not be used on a regular basis because excessive bleaching weakens cellulosic fibers.

Less wrinkling occurs in the dryer if items are removed immediately after drying. Cotton fabrics respond best to steam pressing or ironing while damp. Fabric blends of cotton and a heat-sensitive fiber need to be ironed at a lower temperature to avoid melting the heat-sensitive fiber. Cotton is not thermostatic; it can be ironed safely at high temperatures. However, cotton burns readily.
natural cellulosic fibers

Table 3  Summary of the Performance of Cotton in Apparel and Interior Textiles

<table>
<thead>
<tr>
<th>Aesthetics</th>
<th>Attractive</th>
<th>Appearance Retention</th>
<th>Moderate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luster</td>
<td>Matte, pleasant</td>
<td>Resiliency</td>
<td>Poor</td>
</tr>
<tr>
<td>Drape</td>
<td>Soft to stiff</td>
<td>Dimensional stability</td>
<td>Moderate</td>
</tr>
<tr>
<td>Texture</td>
<td>Pleasant</td>
<td>Elastic recovery</td>
<td>Moderate</td>
</tr>
<tr>
<td>Hand</td>
<td>Smooth to rough</td>
<td>Recommended Care</td>
<td>Machine-wash and machine-dry (apparel)</td>
</tr>
<tr>
<td>Durability</td>
<td>Good</td>
<td></td>
<td>Steam- or dry-clean with caution (interior textiles)</td>
</tr>
<tr>
<td>Abrasion resistance</td>
<td>Good</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tenacity</td>
<td>Good</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elongation</td>
<td>Poor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comfort</td>
<td>Excellent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Absorbency</td>
<td>Excellent</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal retention</td>
<td>Poor</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Cotton draperies should be dry-cleaned. Cotton upholstery may be steam-cleaned, with caution. If shrinkage occurs, the fabric may split or rupture where it is attached to the frame.

Cottons should be stored clean and dry. In damp or humid conditions, mildew can form. Mildew digests cellulose and may cause holes if enough time elapses. If textiles smell of mildew, they can be laundered or bleached to remove the odor. But if the mildew areas are visible dark or black spots, they indicate permanent and excessive fiber damage.

Cotton is harmed by acids. Fruit and fruit juice stains should be treated promptly with cold water for easy removal. Cotton is not greatly harmed by alkalis. Cotton is resistant to organic solvents, so it can be safely dry-cleaned.

Cotton oxidizes in sunlight, which causes white and pastel cottons to yellow and all cotton to degrade. Some dyes are especially sensitive to sunlight, and when used in window-treatment fabrics the dyed areas disintegrate.

Table 3 summarizes cotton's performance in apparel and interior textiles.

Environmental Concerns and Sustainability of Cotton Since cotton is a natural fiber, many environmentally sensitive consumers believe it is a good choice. However, although cotton is a renewable resource, it cannot be produced without some environmental impact. Mainstream farming methods that produce conventional cotton make extensive use of agricultural chemicals to fertilize the soil, fight insects and disease, control plant growth, and strip the leaves for harvest. Excess rain can create problems with runoff contaminated with these chemicals, many of which are toxic to other plants, insects, animals, and people. While cotton growers in developed countries have modified agricultural practices to reduce use of

Learning Activity 2

Select an item of apparel you or a class partner is wearing that is all cotton. Identify one or more performance aspects of the product related to each of the serviceability concepts (aesthetics, durability, comfort, appearance retention, care). Has the performance of the product been satisfactory? Explain performance satisfaction and performance problems in terms of fiber characteristics.
agricheicals and soil erosion and genetically modified cotton is grown, which significantly can reduce the amount of pesticides used, that is not the case for all parts of the world.

Cotton that is harvested by machine is often treated with defoliant chemicals to remove the leaves. Machine-picked cotton usually also includes impurities such as seeds, dirt, and plant residue, which requires more effort in cleaning. Hand-picked cotton does not include these components, but children are sometimes used as slave labor to pick cotton.

Cotton is a water-intensive crop requiring at least 20 inches of rain per year. Sometimes this cotton is marketed as rain-fed cotton. But in many areas of the world where rainfall is low or irregular, irrigation is used. Excessive irrigation can upset the water table or the water level in the soil. In some geographic regions, irrigation is so extremely inefficient, up to 50 percent of the water is wasted. Irrigation has created problems in some parts of the world for people and environments dependent on rivers and lakes. So much water can be diverted for cotton production that rivers disappear and lakes dry up, destroying ecosystems and forcing communities to move away from their traditional homes to the irrigated areas.

Tilling the soil contributes to soil erosion by water and wind. Efforts to improve the production of cotton are focusing on use of locally adapted varieties that require fewer agricultural chemicals and less irrigation, wide crop rotation to avoid depleting the soil of necessary nutrients, and mechanical and manual weed control as opposed to chemical herbicides.

Genetically modified (GM) cotton is well established because of its resistance to certain insect pests and tolerance of herbicides. There is some concern about large-scale production of GM cotton in terms of its unknown long-term environmental and health effects. Concern about GM crops and their impact on nonpest insects is an issue. Environmentalists also are concerned about the potential of insects developing resistance to GM crops. However, GM cotton does reduce the use of pesticides and is tolerant of herbicides. Benefits of GM cotton include less use of pesticides, yields equal to or higher than conventional cotton, no loss in fiber quality, less soil erosion because of less tilling of the soil, and higher incomes for producers.

Cotton is produced in many parts of the world and is a major cash crop in more than 80 countries. This means that farmers raise cotton to produce income for their families. When cotton prices and production are good, their incomes increase. However, when cotton prices or production falls, incomes suffer a similar decrease. Droughts, decreasing prices for cotton, disease, or insect problems can create significant hardships for cotton farmers—regardless of the size of their farm. In some parts of the world, a significant portion of the labor involved in hand harvesting cotton is performed by forced child labor. Many segments of the global textile complex deplore this practice and refuse to source cotton from areas that violate minimum age laws.

Cotton seeds are processed into food used to prevent malnutrition in part of Central American and Africa.

In an effort to provide consumers and producers with more information at the point of purchase, several terms are used to describe cotton grown under more environmentally friendly conditions. Organic cotton is produced following state fiber-certification standards on land where organic farming practices have been used for at least three years. No synthetic commercial pesticides or fertilizers are used in organic farming. Integrated pest management programs help decrease use of pesticides. The BASIC (biological agricultural systems in cotton) program uses approximately 70 percent fewer pesticides and is an alternative to organic cotton. Transition cotton is produced on land where organic farming is practiced, but the three-year minimum has not been met. Green cotton describes cotton fabric that has been washed with mild natural-based soap but has not been bleached or treated with other chemicals, except possibly natural dyes. The term conventional cotton describes all other cottons.
Organic cotton and linen washcloth. Fibers are grown without the aid of commercial fertilizers, herbicides, or insecticides. No bleaches or dyes were used in producing the fabric.

Some retailers and manufacturers have made a commitment to use only organic cotton in their products (Figure 11). Organic and transition cottons are more expensive than conventional cotton. The additional costs are related to the lower fiber yield per acre, requirements for processing in facilities that are free of hazardous chemicals, and the smaller quantities of fibers that are processed and sold.

Cotton also uses large quantities of water, energy, and chemical compounds to clean the fiber and to finish and dye the fabrics. Soil or trash is removed from the raw cotton fiber before it is processed into yarn. Opening cotton bales can generate significant amount of dust that if not removed from the air can result in lung disorders for people who work in that part of the building.

In order to add color in dyeing and printing, cotton is bleached in a chemical and water solution and rinsed. Dyes, pigments, and finishing chemicals add to the consumer appeal of cotton products. All these steps make extensive use of water, other chemicals, and heat. Although the industry has improved recycling, reduced waste, and cleaned up wastewater, the net environmental effect of processing cotton continues to be a concern.

**Identification of Cotton** Microscopic identification of cotton is relatively easy. Convolutions are easily seen along the fiber. Burn tests will verify cellulose, but a more precise identification is not possible with this procedure. Fiber length helps in determining content, but long fibers can be broken or cut shorter. Cotton is soluble in strong mineral acids, like sulfuric acid.

**Uses of Cotton** Cotton is the single most important apparel fiber in the United States. All-cotton fabrics are used when comfort is of primary importance and appearance retention is less.