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Cotton: Science and technology

Edited by S. Gordon and Y-L. Hsieh

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Introduction

Cotton fiber is the purest source of cellulose and the most significant natural fiber. The economic significance of cotton in the global market is evident by its majority share (over 50%) among fibers for apparel and textile goods. Both the market value and the quality of cotton products are directly related to fiber quality. Competition with other fibers is affected by innovations and commercialization of other fibers including microdenier (polyesters and nylons), elastomeric (spandex), and lyocell fibers, among others. Fundamental understanding of the fibers (structural formation during development, chemistry, physics), significant improvement in fiber quality as well as in process innovation and product differentiation are critical to uphold the inter-fiber competitiveness of cotton fibers and the share of cotton fibers in the global apparel and other textile markets.

Part I of this book focuses on the chemical and physical properties of cotton fibers. The most essential cotton fiber qualities related to mechanical processing, i.e. traditionally yarn spinning, weaving, and knitting, are length, strength, fineness and their distributions. The ranking importance of these fiber qualities varies with the type of yarn spinning method, such as ring, rotor, and air-jet. These fiber qualities also determine the yarn strength, yarn regularity, handle and luster of fabrics. For chemical processing such as scouring, dyeing and finishing, fiber structure related to maturity, or the level of development, plays a major role. This is largely due to the impact of the noncellulosic cell wall components and the cellulose in the secondary cell wall on these chemical processes.

In order to develop effective strategies for fiber quality improvement and for innovative processing and product development, the developmental linkages between these chemical and physical properties and particular fiber qualities need to be identified. The relationship between cell wall development and fiber structure and properties has only gained attention more recently. Findings from some of these systematic studies linking fiber structures and strength with stages of fiber development and genotypes are detailed in Chapter 1. Chemical properties of cotton are discussed in both Chapters 1 and 2. The chemical structures and reactions are detailed in Chapter 1 whereas the effects of moisture, mercerization, swelling and resin-treatments are included in Chapter 2.

The strength of cotton fibers is attributed to the rigidity of the cellulosic chains, the highly fibrillar and crystalline structure, and the extensive intermolecular and intramolecular hydrogen-bonding. Chapter 2 includes detailed discussion of mechanical properties, including tensile strength, fracture and fatigue, and structural mechanics as well as other physical properties such as thermal, electric, friction and optical. The majority of strength data have been based on bundle strength, such as that generated by the Stelometer or high volume instruments (HVI) in recent years.

The understanding of structural origins of fiber properties such as strength and dyeability is fundamental to competitiveness and future development of quality cotton goods. However, significant challenges remain today partly due to the variability of the cotton fibers, a common characteristic of a natural product. Even the complex strength relationships between single fibers and bundles or fibers and yarns are not completely clear. For example, fibers shorter than 12.7 mm make little contribution to yarn strength. Fiber elastic behavior (elongation) and inter-fiber frictional characteristics may also contribute to yarn strength, but their association with strength has not yet been systematically studied.

The fiber properties that determine the market value of cotton are discussed in Chapter 3 along with the test methods used to measure these properties, and caveats associated with each method. Currently around 30% of the world's cotton is objectively tested using HVI[1]. The remaining 70% is largely classed subjectively by humans against physical cotton standards. The USDA Universal Cotton Standards are used in over twenty countries to class and determine the value of cotton for trade and spinning. Other national standards and merchant 'shipper type' standards are also used to ascribe value to traded cotton. International efforts to expand the use of objective testing and to develop fast and accurate test methods for important properties such as fiber fineness and maturity, trash content, neps and stickiness continue. Other important qualities to the spinner and dyers such as the wax layer that envelopes the fiber, moisture uptake and microbial decay are also discussed in Chapter 3.

In Part II, the production (growing of cotton) and processing of cotton fiber and fabric are described. Genetic modification or transformation of cotton plants via molecular genetic approaches has resulted in the introduction of pest-tolerant, and herbicide-resistant traits to cotton. A brief history and introduction to the science behind genetic modification of cotton, including traditional plant breeding is given in Chapter 4. The new traits introduced to cotton via molecular genetic modification have improved crop productivity and significantly reduced the reliance by cotton on some insecticides. Around a third of all cotton grown in the world is now genetically modified. However, despite the potential of genetically modified crops, there remain significant technical hurdles to overcome before many of the promises and claims made for genetically modified cotton are realized. Genetic transformation, that is the artificial insertion of a single foreign gene or a few genes into a plant's genome, requires two fundamental steps: Introduction of the new gene and regeneration of intact plants. Both steps have numerous constraints, and not least is the understanding of the role inherent genes have in their own chromosome set. Future genetic manipulation of cotton is aimed at realizing better fiber quality, increased resistance to pests and diseases, and improving the ability of the cotton plant to grow under adverse water, heat and nutrient conditions.

Like genetically modified cotton, organic cotton generates much debate on its worth to society. There continues to be worldwide interest in organic cotton on the basis that it is an environmentally friendly and cost-effective way to produce cotton. Production of organic cotton has recently increased to about 0.1% or about 110,000 bales of world cotton production, mainly due to increased production in Turkey as well as India, China and some African countries. Based on the facts available, growing organic cotton is more expensive to produce than conventional cotton if the same nutrient and pest management equivalents are used to ensure comparative yield and quality outputs. Viewed from this perspective organic cotton production practices are not necessarily more environmentally friendly or sustainable than current conventional practices. Management of organic cotton, from production through textile processing, is discussed in Chapter 5 and compared with conventional practices. How organic cotton is certified and organized as an industry segment is also discussed, along with the limitations of organic cotton production practice that need to be overcome if organic cotton is to become more than a small niche product.

Harvest and ginning processes are discussed in Chapter 6. These processes, which represent the first steps in the conversion of fiber to fabric, have a significant influence on the quality of the fiber realized from a crop. Enormous differences exist in harvest and ginning processes across the cotton world. Harvest methods range from totally hand-harvested crops in some countries to totally machine-harvested in others with only the United States, Australia and Israel harvest methods being fully mechanized. The principal function of the cotton gin is to separate lint from seed and produce the highest monetary return for the resulting lint (fiber) and seed under the marketing conditions that prevail. Currently the market rewards whiter, cleaner cotton with a certain traditional appearance of the lint known as preparation. Preparation is a relative term describing the amount of cleaning or combing given to cotton so that it matches official (USDA) physical grade standards upon which cotton is valued. However, these properties are more often not as important to the final product as the focus at the gin and across the merchant desk would attest. The majority of spinners prefer fiber that is long, even in length, strong, fine and without high proportions of nep and short fiber. These last two parameters are unfortunate characteristics of cotton harvested and ginned by mechanized means. Whilst not included in existing classification systems for cotton, the presence of nep and short fiber seriously affects the attractiveness of some cotton produced in the USA and Australia, which utilize automated harvesting and ginning systems.

Cotton accounts for the bulk of the raw material used in the very large short-staple spun yarn market, despite rapid incursion of synthetic fibers into the textile market over the last 35 years. The proportion is considerably less in the non-woven market, although the potential for increased use on the basis of cotton's natural attributes is high. Opening and carding, spinning, knitting, weaving and non-woven production processes are described respectively in Chapters 7 to 10 and 16. Whilst the basic mechanics of these processes, which evolved from hand-operated machines and tools, some used over 6000 years ago, have not changed greatly, speed, efficiency and thus productivity have increased dramatically. For example, cotton carding machines processing fiber at 70 kg per hour just over ten years ago now process fiber in excess of 200 kg per hour, and modern yarn spinning technologies, like the Murata Vortex Spinner (MVS) enable yarn to be spun at speeds in excess of 400 m per minute. Likewise the productivity of knitting and weaving machines has increased. Chapters 7 and 8 cover the various processes and technologies involved in the conversion of raw cotton fiber into yarn suitable for subsequent fabric manufacturing. Chapters 9, 10 and 16 cover the major cotton fabric formation processes, which are most commonly knitting and weaving processes, as well as the newer non-woven processes. In the last few decades non-woven fabrics have become more popular, and currently represent the fastest growing sectors of textile materials, particularly in the market for single use, or disposable products.

Coloration of cotton is a well-developed industrial process to add value. Chapter 11 discusses the common classes of dyes and dyeing and printing metholodogy. Dyeing involves the diffusion of dyes into the non-crystalline regions of the highly crystalline cellulose structure in the cotton fibers, thus favoring elongated and coplanar dye structures. Retention or substantivity requires strong secondary forces and/or chemical bonding with the hydroxyl functional groups of cellulose. Improvement of dye affinity to cotton, reduction of chemical effluents from dyeing as well as development of dyes that serve other functions are among some of the current trends.

Survival in today's textile market relies on knowledge of raw material costs, the maintenance of product quality, health and safety issues and recycling (cradle-to-grave) processes associated with the manufacture of cotton products. Part III of this book provides insight into the science and technology that influences and is used in these areas. In the highly competitive global textile market, the survival of a textile company depends greatly upon its ability to meet demanding quality specifications within acceptable price and delivery time frames. Chapter 12 deals largely with the objective or instrument testing of yarn and fabric physical and related properties inasmuch as they relate to their subsequent performance in textile processing and end-use performance. Whilst, generic or general testing of yarns and fabrics is carried out irrespective of their end-use to ensure consistency in production, specific tests are also conducted to determine the performance of fabric or yarn for specific and especially critical end-uses. For example, for fabric to be used in children's nightwear, flammability is of paramount importance, whereas for fabrics used in parachutes, bursting and tear strength, impact resistance and air permeability are critically important.

Chapter 13 covers world cotton and cotton textile production and the influence of technological advances on productivity, and on consumer supply and demand for cotton. Government subsidies have a significant and distorting influence on production and the final price paid for cotton. The distorting effects of these subsidies, which are created in response to local political pressures in each country, are also discussed. World cotton production and consumption are currently trending higher under the influence of new technologies, including the use of genetically modified cotton varieties. World cotton production reached 26 million tons in 2004/05 with the cost of production for most producers falling between 50 and 60 US cents per pound. International cotton prices have declined in real terms over the last six decades because of advances in technology, and this process is continuing. In the 20 to 25 years to the mid-1990s, the average world price of cotton was 70 cents per pound, but the average international price during the current decade is expected to stay between 50 and 60 cents per pound, in line with the costs of production for most producers.

Health and safety are key components of responsible production and processing of cotton and of a responsible management system for cotton operations. Workers handle and process cotton in many work operations from planting the cottonseed, to the finished cotton textile, i.e. from production, harvesting, ginning, yarn and fabric manufacturing, and preparation, through to dyeing and finishing. Each cotton industry sector has its own particular health and safety considerations. Chapter 14 covers the pertinent health and safety issues for each sector of the cotton industry.

Environmental conservation from the perspective of preserving expensive produced cotton, reducing disposed wastes and regenerating new usage from spent cotton goods is of significant concern today. Chapter 15 discusses issues related to the recycling of cotton textiles including reuse, disposal, landfill and incineration. Life cycle analyses of cotton require the examination of the environmental impact of cotton production, energy consumption in processing and disposal. The sources of cotton as well as the processing methods for recycling are detailed in this chapter. The ultimate conversion of cotton cellulose requires chemical processing or dissolution and remains a technological challenge.

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