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History of Natural Fibers

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ABSTRACT

Nature, as though aware of the importance of textiles, has long provided an abundance of fibers–plant, animal, and mineral–of different dimensions and properties. Beginning in prehistory, the natural fibers have served man's textile needs for thousands of years. The Swiss Lake Dwellers in 8000 BC cultivated flax and wove linen into fabrics. By 3000 to 2000 BC, the use of fibers was well developed, and the weaving of cotton was well established in India and Pakistan. Improvements in machines for spinning, weaving, etc., beginning in the 1700s, revolutionized the processing of fibers. Eli Whitney's invention of the cotton gin in 1793 helped cotton become king of the fibers. In recent decades the textile industry was revolutionized again by many technological developments, including the creation of synthetic and modification of natural fibers. Today the world and United States fiber markets are dominated by the natural and man-made fibers, respectively. In spite of gains by the man-made fibers, both the world and United States production of cotton increased during the decade of the seventies.

INTRODUCTION

The natural fibers from plants, animals, and minerals enjoy a history that is uniquely long and proud [1-7].

Their history is long because they have been produced for millions of years and used by man for thousands of years.

Their history is proud because they have served man's textile needs unchallenged for thousands of years. In spite of 20th century competition from man-made fibers and plastics, facilitated by temporarily inexpensive petroleum, the natural fibers still have a strong position in the world fiber market (Tables 1 and 2). The data in Table 2 suggest that the production of 1 lb of cotton is accompanied by about 0.8 lb of other natural fibers. On this basis, the total production of natural fibers in 1978 might have been about 52 billion lb or 24 million metric tons.

As indicated by Table 3, the man-made fibers [10] have taken much of the United States textile market from the natural fibers. Nevertheless, both the world and United States production of cotton increased during the decade of the 1970s (Table 4). These production data (Table 4) were used to develop least squares Eq. (1) (world) and Eq. (2) (United States) (M, million bales; Y, year):

$$1970\text{-}1979, \quad M = 22{,}352 + 0.51152(Y - 1900) \tag{1}$$

$$1970\text{-}1979, \quad M = -4.2588 + 0.21515(Y - 1900) \tag{2}$$

The slopes of Eqs. (1) and (2) indicate that world production of cotton in the 1970s increased more rapidly than United States production.

The natural fibers are great in several other respects:

They are annually renewable.
They use carbon dioxide from the air, and not petroleum, as their source of carbon.
They use sunlight to meet much of their energy requirements.
They are versatile and amenable to treatments that confer improved properties, e.g., water repellency, wrinkle resistance, and flame resistance [12, 13].

Cellulose, the principal component of the plant fibers, is an abundant valuable raw material. In 1978, more than 7 billion lb of rayon and acetate were made from cellulose (Table 1). Approximately 50 million tons of cellulose, as wood pulp, is produced annually in the United States [14].

Cotton has been the principal textile fiber (Table 1) for almost 200 years, that is, since Eli Whitney invented the cotton gin in 1793. World production of cotton (Table 4) increased from 60.0 million bales (28.8 billion lb) in 1978 to 65.3 million bales (31.34 billion lb) in 1979 [15].

TABLE 1. World Production of Fibers[a] 1978 [8]

	Rayon plus acetate	Synthetic non-cellulosics	Raw cotton	Raw wool	Raw silk	Total natural
Thousand metric tons	3,315	9,946	13,065	1,470	50	14,585
Billion lb[b]	7.31	21.94	28.80	3.241	0.110	32.15
Percent of total[c]	11.9	35.7	46.9	5.3	0.2	52.4

[a]Only some fibers, e.g., glass and jute not included.
[b]One metric ton = 1000 kg, 4.593 bales, or 2204.6 lb.
[c]Total of all the above-listed fibers, 27,846 thousand metric tons (61.39 billion lb).

TABLE 2. World Production of Natural Fibers [9], Million Metric Tons (MMT)[a]

	Average 1961-1965		Average 1972-1974	
	MMT	%[b]	MMT	%[b]
Cotton	7.98	55.6	8.89	55.6
Wool	1.19	8.3	1.13	7.1
Other	5.17	36.1	5.98	37.4
Total natural fibers	14.34	100.0	16.00	100.1

[a]One metric ton = 1000 kg, 4.593 bales, or 2204.6 lb.
[b]Percent of the natural fibers.

TABLE 3. United States Consumption of Fibers[a] [11]

	1975	1976	1977	1978
Per capita consumption, lb:				
Cotton	14.9	17.2	16.1	16.2
Wool	.7	1.0	1.0	1.1
Man-made	35.1	38.0	41.8	43.2
Total fibers	50.7	56.2	58.7	60.4
Percent of total fiber consumption:				
Cotton	29.3	30.7	27.3	26.8
Wool	1.5	1.7	1.7	1.8
Man-made	69.3	67.7	71.0	71.5

[a]Flax and silk not included.

TABLE 4. World and United States Production of Cotton[a] (million bales) [11, 15]

	Year									
	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
World	53.7	59.7	62.9	63.3	64.3	53.9	57.4	64.1	60.0	65.3
United States	10.2	10.5	13.7	13.0	11.5	8.3	10.6	14.4	10.9	14.6

[a]Bales of 480 lb or 0.2177 metric tons.

Wool was probably the first fiber to be processed into textiles; probably linen was the first vegetable fiber to be used for textile purposes [2].

Some of the natural fibers have important by-products. Cottonseed, for example, is a source of edible oil and protein. The pigment, gossypol, from cottonseed is being tested as a male contraceptive [16]. Sheep provide meat and milk as well as wool.

CLASSIFICATION AND VARITIES

Nature has generously provided many useful fibers having widely different dimensions and properties. Some of them, e.g., cotton and wool, are available as fibers, whereas others are available as conglomerates or composites, e.g., wood and skins. Although natural fibers are usually classified as vegetable, animal, or mineral, chemists generally think of their chemical nature as cellulose, protein, or mineral. The cellulose fibers may be subdivided into seed, bast, leaf, and fruit, and the protein fibers into wool and hair (Table 5).

Cotton, wool, mohair, silk, hemp, jute, flax, sisal, and asbestos represent only a small fraction of the total natural fibers. In 1897, Dodge [17] listed 1018 species in his Descriptive Catalog of Useful Fiber Plants of the World. As reported by Worner and Skau [7], a somewhat similar catalog by Schilling lists 1926 plants. Perdue has given the names, sources, and used of many natural fibers [4]. Production data for some of these are in Table 6.

Fibers of numerous species are used for various purposes in different parts of the world. Many fibers are used because they are the best available locally for specific needs. Some countries use local fibers because they are acceptable substitutes for expensive imports [4].

IMPACT OF NATURAL FIBERS ON HISTORY.

Fibers not only meet man's basic need for clothing but they also have greatly influenced history. Fibers have affected, and have been affected by, economic, political, cultural, military, and even religious history.

Wool was the basis for the prosperity of the most important medieval city-states in Italy and Flanders, for the trading activities of the Hanseatic League, and for the rise of England as a commercial nation. Wool has been important to the Australian economy [5].

Silks have ranked with jewels and spices as the most coveted imports from the East since the days of the Roman Empire. Placing silk manufacture on a firm basis was one of Jean Baptiste Colbert's main achievements in his thoroughgoing reorganization of the French

TABLE 5. Partial List of Natural Fibers [7]

Cellulosic				Protein	
Seed	Bast	Lead	Fruit	Wool hair	Secretion
Cotton	Jute	Abaca	Coir	Sheep's wool	Silk
Kapok	Flax	Sisal		Hair of:	
	Hemp	Henequen		Camel	
	Ramie	Cantala		Alpaca	
	Sunn	Istle		Llama	
	Kenaf	Phormium		Vicuna	
		Palm		Goat	
				Rabbit	
				Horse	
				Cattle	

TABLE 6. World Production of Some Cellulosic Fibers, 1977 [18]

	Tons	Million lb
Sisal	450,000	900
Henequen	150,000	300
Abaca (manila hemp)	64,500	129
Coir	200,000	400
Total	864,500	1,729

economy. The revocation of the Edict of Nantes, in 1685, which drove the Protestant weavers out of France, greatly increased the prosperity of many other European countries. Silk also played an important part in the transformation of Japan from a feudal to a modern nation [5].

Cotton was such an attractive import for England in the 18th century that it contributed to the downfall of the mercantile system. When cotton became inexpensive, pretty dresses and draperies were brought within the reach of the poorer classes, and the gap between them and the wealthy was narrowed. In the southern United States, the replacement of tobacco with cotton as the chief crop helped perpetuate slavery and presumably made the Civil War more likely [5].

Mississippi's David L. Cohn [19] wrote in his The Life and Times of King Cotton:

> Cotton alone, of all the products of our soil or industry, stirs the emotions of whoever contemplates it. Furs, cattle, oil, gold, wheat, corn, railroads–the tale of all these on this continent excites the imagination as one perceives with what courage and adventurousness men have bent the resources of nature to their use. But it is the melancholy distinction of cotton to be the very stuff of high drama and tragedy, of bloody civil war, and the unutterable woe of human slavery.

The first factories were built to make textiles, the first mechanized processes were applied to them, and their production and distribution were the first to be organized on a capitalistic basis. The desire to produce textiles quickly, inexpensively, and in enormous quantities was one of the main causes of the Industrial Revolution. In the 20th century the replacement of natural fibers by synthetics may bring similar deep-seated consequences [5].

Textile fibers continue to be important to the world economy and affairs. World production of one fiber alone, cotton, in 1979 was approximately 65 million bales or 31.2 billion lb. The current economic importance of cotton worldwide has been described by several authors [9, 20, 21].

FIBERS IN PREHISTORY AND EARLY HISTORY

When were fibers and textiles first used by man or by man's ancestors? The responses to this question are conflicting and uncertain. One reason is that vegetable and animal fibers are relatively perishable. Stone and metal artifacts may resist deterioration for millions of years, but fibers do not. The Leakey group, for example, found bone fragments and crude stone tools claimed to be nearly 4 million years old. They did not report finding fibers [22].

Regardless of archaeological discoveries, it might be conjectured that fibers were used relatively early in prehistory. Fibers were available to early man, and he needed them for warmth, protection, and ornamentation [23]. Probably he used skins, furs, hair, vines, and crude fibers in one way or another. Slender vines and stem fibers might have been used as slings for transporting heavy loads. Tying a knot might have been one of the earliest inventions. From this invention, it would be only a short step to making simple fishnets and net bags. Early man probably pounded fibrous barks with stones to make crude textile-like products [4]. Implements and weapons from the Paleolithic Period, which ended about 10,000 years ago, suggest primitive man had twisted or plaited strips or thongs from animal hides into cords, and even coarser vines and fibrous barks into thicker, stronger rope structures [3].

Listed below are additional reports concerned with the prehistory of natural fibers.

200,000-30,000 BC. Scraping tools at Neanderthal sites (Europe, North Africa, Middle East, and Central Asia) suggest the treatment of skins for clothing [24].

35,000 BC. Homo sapiens appeared. Patterns of weaves on clay vessels from the Old Stone Age may be considered evidence that both spinning and weaving were practiced perhaps 35,000 years ago [7]. The spinning of wool was discovered [25].

35,000-8,000 BC. The use of thread was known among the Upper Paleolithic cultures. Many needles made of ivory tusks dating from this period have been found. Other remains include finely pointed flint and bone punches. The presence of needles is considered evidence that furs and skins were sewn with cotton or some kind of thread [26].

30,000 BC. In the Mousterian Period, red ocher pigments were placed on the cranium and breasts of the dead. Possibly pigments were also applied to fibers and skins [26].

30,000-10,000 BC. In the Upper (Later) Paleolithic Period, there were sculptures and cave paintings [27].

23,000 BC. Hunters living on the banks of the Don River in western USSR used bones to make pins, needles, and other tools [28].

20,000 BC. The making of ropes and cords started in the Paleolithic Age (about 20,000 BC). A Mesolithic cave drawing (Spain) shows ropes partway down a cliff to recover honey [28a].

18,000-13,000 BC. The transition from the Old Stone Age to the New Stone Age or Neolithic Period began. The manufacturing industry began in the revolutionary New Stone Age with the development of techniques for grinding corn, baking clay, and spinning and weaving textiles [29].

14,000-8,000 BC. The spinning and plaiting of fibers might have been discovered in the late Paleolithic Period, but the evidence for this is not conclusive [26].

12,000 BC. There is evidence cotton existed in Egypt [30].

10,000 BC. Sometime after 10,000 BC, among widely separated human communities, a series of dramatic technological and social changes occurred that are summed up as the Neolithic Revolution. The manufacture of cloth and pottery began. The cultivation of previously wild plants encouraged the growth of permanent settlements. Animals were domesticated as a work force and food source [24].

10,000 BC. An early indication of fiber use resulted from the discovery of a palm leaf in a Mexican cave that was dated possibly as early as 10,000 BC. Such fragments are known to have been used for weaving coarse fabrics [4].

10,000-7,000 BC. In the Mesolithic transition period, man founded the first permanent colonies and learned to store seed and fruit [26].

9000 BC. Goats and sheep were domesticated in the Zagros Mountains area of the Near East [28].

9000 BC. A net bag excavated from a Utah cave indicated that by about 9000 BC the American Indians had achieved considerable skill in processing plant fibers [4]. Sheep and goats were domesticated [31].

8000 BC. The Swiss Lake Dwellers of the Stone Age cultivated flax and wove it into linen fabric. They also made wool fabrics [4]. The history of the sheep industry began 10,000 years ago in Central Asia. At first man used the sheep's fleece as a tunic [25]. Flax has been cultivated for at least 10,000 years [32].

7000-2000 BC. The Neolithic Period witnessed the first technological revolution. Progress during these several thousand years was greater than that achieved by Paleolithic man in 50,000 years. Neolithic man had a highly developed esthetic sense. He became a farmer instead of a hunter. There is good proof of textile activities in the Neolithic Period, consisting of the remains of sewing, spinning, and weaving equipment as well as several examples of textile products. The preservation of textile materials in the prehistoric lake villages of 3000 or 4000 BC is due to their immersion in muddy water or slime.

A great Neolithic achievement was the invention of the weaving loom. An important specimen was found in the prehistoric lake village at Robenhausen, Switzerland [26].

To satisfy an esthetic sense, the weavers of the prehistoric lake village at Robenhausen, Switzerland, and certain other localities created not only complicated woven materials with fringes and other ornamental effects, but also inserted threads of different colors. The most beautiful example is a splendid piece of multicolored brocade now in the Landesmuseum, Zurich.

The materials used in dyeing included pigments, vegetable dyes, vegetable ashes, urine, lime, charcoal, manganese dioxide, potash, soda, alum, cinnabar, palm oil, castor oil, and beeswax [26].

6000 BC. Hemp, believed by some to be the oldest cultivated fiber plant, originated in Southeast Asia, then spread to China where reports of cultivation date to 6000 BC [6].

5700 BC. There is evidence cotton fabrics were produced in Mexico as early as 5700 BC [33].

5000 BC. The earliest evidence of weaving, closely related to basketry, dates from Neolithic cultures [34].

Wild species of cotton are thought to have been taken from Africa to the Indus River Valley in Pakistan and cultivated for spinnable lint [35].

Cotton was cultivated and used in the Tehuacan Valley of Mexico. With the help of the carbon-14 process, scientists determined fiber and boll fragments from the area to be about 7000 years old [36].

By about 5000 BC, all the plant fibers of current importance were not only recognized but utilized by techniques that differ little in principle from the methods used today [4].

4400 BC. The earliest evidence of the use of the loom is a representation of a horizontal two-bar loom pictured on a pottery dish found at al-Aadari, Egypt [34].

4200 BC. In Tall al-Asmar, Iraq, archaeologists found indication of trade in wool as early as 4200 BC [6].

4000 BC. Wool garments were worn in Babylon (which means "the land of wool") as early as 4000 BC.

3500 BC. Heavy, strong ropes were used to drag heavy objects in Egypt. The ropes were made by twisting strips cut from hides or fibers from papyrus reeds [5].

3400 BC. The art of spinning and weaving linen was well developed in Egypt by 3400 BC., suggesting flax had been cultivated prior to that date [6].

3000 BC. Spinning and weaving of cotton is practiced in Pakistan, evidenced by the discovery of cotton fabrics and string from excavations at Mohenjo-Daro [36].

Writing began in Mesopotania and Egypt, ending prehistory and beginning history [27].

Reports of the spinning of cotton in India and existence of cotton materials in tombs date back to 3000 BC [6].

3000-2000 BC. The use of fibers was well developed by this period. The weaving of cotton was well established in India and Pakistan. Lace was being made in Mexico and Peru. The Chinese were cultivating hemp and producing fine silk fabrics, and the Egyptians were wrapping mummies in linen cloth.

2900 BC. According to tradition, the Chinese Emperor Shen Nung encouraged the growth of hemp [3].

2640 BC. Silk production and spinning date from 2640 BC [6].

2500 BC. Cotton and cotton textiles existed in Peru [36].

2300 BC. Cotton was cultivated in the Indus Valley [28].

2100 BC. The walls of the tomb of Beni Hassan depict figures costumed with fabrics patterned in small conventional motifs in blue, amber, and brown [37].

2000 BC. Bronze Age fabrics were discovered in various locales in Northern Europe, particularly in Denmark, Sweden, and Norway. Most of these fabrics, based on animal fibers, came from burial places where the corpses were in coffins made from oak trunks [26].

1594 BC. A fabric with a red and blue pattern, and finished with loops at the top, was found near Thebes [37].

1400 BC. A Hindu hymn of 1400 BC describes the manufacture of cotton yarns and the weaving of cotton cloth [6].

600 BC. A royal feast at Susa, capital of Persia, was described by the author of the Book of Esther who mentions, "white, green, and blue hangings" of the royal palace. These canopies of Ahasuerus were similar to hangings of blue and white striped cotton seen in the Far East today [36].

500 BC. Only a few centuries after the first written record (about 800 BC) of fiber use, "Carpasian linen" of asbestos fiber was employed for lamp wicks [4].

The Indians and Chinese were known to have printed cloth [37].

Cotton was used in Zuni and Hopi ceremonies in the Southwestern United States [36].

445 BC. Herodotus wrote of trees which grow wild in India, the fruit of which is a wool exceeding in beauty and goodness that of sheep and from which the natives make clothing [36].

327 BC. Alexander the Great invaded India and returned with robes of printed cotton [36].

63 BC. Lentullus Spinther, according to Livy, introduced cotton awnings in the theater at the Appolinarian games [38].

Prehistory conditions still exist in some parts of the globe as illustrated by the small cave-dwellings of the Tasaday tribe found in the Southern Philippines. This tribe, after centuries of isolation, still uses stone implements and lives off the pith of wild palms and tubers. They use a drill to make fire and use leaves as clothes [39]. It is conceivable the materials used today by primitive peoples are an indication of what was used in prehistory. In any event, primitive peoples are reported to have used the following in treating textiles: Various pigments, vegetable dyes, charcoal, manganese dioxide, lime, resin of coniferous trees, alum, clay, tannins, saliva, lemon juice, urine, coconut milk, seal oil, honey, milk, and sodium carbonate [26].

FIBERS PRIOR TO THE INDUSTRIAL REVOLUTION

In 1597 a machine for knitting stockings was invented by William Lee of Woodborough, England [38]. This may be considered unusual because the period before the Industrial Revolution was noted more for expansion of the textile industry and international trade than for major technological advances. Nevertheless, the technology in that period was adequate for the production of beautiful textiles of various types and general expansion of the textile industry.

By the early Middle Ages some Turkish tribes were skilled in the manufacture of carpets, felted clothes, towels, and rugs. The fine muslins produced at Dacca in Bengal were sometimes printed or painted. Richly patterned fabrics were made in Islamic lands. In Sicily, after the Arab conquest in 827, beautiful fabrics were produced in the palace workshops at Palermo. In about 1130, skilled weavers, who came to Palermo from Greece and Turkey, produced elaborate fabrics of silk interlaced with gold [34].

French manufacture of woven silks began in 1480. In 1520 Frances I brought Italian and Flemish weavers to Fontainebleau to produce tapestry under the direction of the King's weaver. Others were brought to weave silk in Lyons, which became the center of European silk manufacture [34].

English textiles of the 13th and 14th centuries were mainly of linen and wool, and the trade was influenced by Flemish finishers and dyers. Silk was woven in London and Norwich in 1455. In 1564 Queen Elizabeth I granted a charter to Dutch and Flemish settlers in Norwich for production of damasks and flowered silks [34].

In 1450 England and Wales had about 8 million sheep, or three sheep per capita [40].

Weaving and dyeing were established in the Americas prior to the arrival of the Europeans. Both the Peruvians and Mexicans had fine woven fabrics. Inca cotton and wool fabrics were brilliantly colored. Fabrics, especially blankets, made by the Navajos of Arizona and New Mexico had exceptionally close texture and brilliant color [34].

English settlers established a cloth mill in Massachusetts in 1638. There Yorkshire weavers produced heavy cotton fustians, cotton-twill jeans, and linsey-woolsey (a coarse, loosely-woven fabric of linen and wool). Fulling mills were operating in Massachusetts by 1654, freeing the community from dependence on England for fine linen and worsted [34].

Paper–a mat of cellulosic fibers felted from aqueous suspension–had its beginnings in China between 200 BC and 100 AD. Europe did not see the beginning of papermaking until about 1100, and the date of the establishment of the first paper mill in the thirteen colonies was 1690. The paper industry in 1955 was an industrial giant that produced almost 30 million tons of diversified product with per capita paper consumption in the United States of more than 400 lb [41, 42].

Further information on early textile events in the United States has been provided by Smith [43]:

1493. Christopher Columbus introduced yearling calves, goats, sheep, pigs, hens, seeds of oranges, limes, melons, and many kinds of vegetables into the New World.

1607. English settlers at Jamestown, Virginia, sowed English grain, which failed. They also planted potatoes, pumpkins, melons, cotton, oranges, and pineapples.

1609. The first sheep to reach the English colonies were brought to Jamestown.

1623. The Virginia Assembly directed that mulberry trees be planted to encourage a silk industry.

1640. Connecticut offered land bounties for the cultivation of wheat and ordered every family to plant hemp.

1643. A small woolen and fulling mill, probably the first American textile factory, was established at Rowley, Massachusetts.

1654. Production of wool was important in New England industry, partly because many early settlers had been in the wool business in England.

1653. The Virginia Assembly offered a bounty to persons who would produce flax fiber of a certain value. Flaxseed was a staple article of export from New York by 1770.

1661. Pressures for cultivation of silk in Virginia increased with the coronation of Charles II in a robe woven of Virginia silk.

1690. The first paper mill in America was established by German settlers of Pennsylvania. Paper was handmade from linen rags pounded into pulp.

1712. England offered a bounty for silk produced in America, which encouraged French settlers to produce it.

1742. Eliza Lucas Pinckney established indigo as a commercial crop in South Carolina.

1748. The British Parliament provided bounty for all indigo imported from the American Colonies.

FIBERS AND THE INDUSTRIAL REVOLUTION

The processing of fibers, although highly developed as a craft, remained essentially a cottage industry until the 18th century. About 1760 the profound changes that began to stir the textile industry erupted into the Industrial Revolution, which is still continuing in the newly emerging nations. The Industrial Revolution began in Britain and extended to the United States, both nations contributing various time- and labor-saving inventions that mechanized spinning, weaving, and other textile processes [44].

Following the invention of the cotton gin in 1793, cotton displaced wool as the world's major textile fiber and became a valuable agricultural crop, a principal form of wealth and international trade, and a most important raw material. In short, cotton became and long remained king of the textile fibers [1].

The development of the United States textile industry, based on natural fibers, has been described as follows by McArthur [45]:

> The American textile industry began in 1789 with the introduction of advanced English yarn-spinning methods into the United States by Samuel Slater.
>
> In the 18th century, England held a textile industry monopoly, resulting from inventions like John Kay's flying shuttle, which more than doubled a weaver's capacity, and James Hargreaves' spinning jenny, which increased production eightfold. Water power replaced hand power with Sir Richard Arkwright's invention of the water frame, a spinning machine. Edmund Cartwright mechanized weaving with his power loom.
>
> Severe English laws prohibited the export of any machines, plans or tools for them, and this included textile mechanics. Slater sharpened his mechanical skills by apprenticing and working in a leading textile mill. There he memorized details for the Arkwright water frame and other machinery. Slater slipped secretly into London, declared himself a "farmer" and sailed for New York in 1789. He traveled to Pawtucket, R.I., where he contracted to build and operate a mill for the Almy Brown textile firm. Slater's tiny spinning mill on the banks of the Blackstone River launched the textile industry and ignited the American Industrial Revolution. Slater, Almy Brown, and others soon built more cotton mills. Mechanics trained by their companies branched out for themselves or joined other firms.
>
> These mills did the spinning, but contracted the weaving of yarn into cloth to individuals or small groups until 1813 when Francis

Cabot Lowell introduced a practical power loom. Lowell's factory in Massachusetts was the first textile mill in America where all operations from cotton bale to finished cloth were not only mechanized, but also performed under one roof. It was the forerunner of today's vertically integrated textile plant.

The newly mechanized mills operated below their capacity because of short supplies of cotton fiber. There was no way to speed the removal of seeds from cotton until Eli Whitney invented the cotton gin in 1793. Whitney's machine could clean as much cotton in one day as could 50 men. The cotton industry began to expand which accelerated textile production. This development increased the number of textile mills as well as the need for textile workers.

By 1847, more people worked in textiles than in any other industry. Another significant development was the invention of a cotton sewing thread. Developed by Samuel Slater's wife, Hannah, in 1873, this thread was stronger and smoother than linen thread.

Other changes included the replacement of water power with steam engines. This change permitted the location of textile mills away from waterways. After the turn of the 19th century, the textile industry began expanding to the South from New England in order to be closer to the source of cotton. This expansion caused population shifts from rural to urban concentrations as well as industrialization of the rural South.

The textile industry's continued growth gave birth to new inventions and spawned other industries. The sewing machines, invented by Walter Hunt and Elias Howe, were followed by Isaac Singer's more sophisticated model. This model, which was mass produced by a technique developed by Eli Whitney, resulted in the establishment of the vast apparel industry.

A chronological reporting of textile events of the Industrial Revolution follows [36]:

1730. The first cotton yarn is spun by machinery in England.

1733. The flying shuttle is invented by John Kay, increasing fourfold the production of cotton looms (England).

1764. The "Spinning Jenny," the first practical spinning frame, is invented by James Hargreaves (England).

1769. Richard Arkwright patents the roller spinning method in England. Called the father of the modern textile industry, Arkwright combined into one unit the most advanced devices for spinning cotton yarn and harnessed them to water power.

1779. The spinning mule–basis of the modern spinning frame–is perfected by Samuel Crompton from Bolton, England.

1785. Edmund Cartwright, Oxford graduate, makes the first power loom.

1790. Samuel Slater establishes a mill in Pawtucket, R.I., reproducing Arkwright's spinning machinery from memory.

1793. Eli Whitney invents the cotton gin, constructing his first model in 10 days and revolutionizing the cotton industry.

1813. The spinning and weaving process is combined under one roof in Waltham, Mass., after Francis Cabot Lowell reproduced the power loom from memory.

1823. Philip Chell, Kensington, England, patents the first long-draft spinning system.

1828. John Thorpe perfects ring spinning (United States).

1846. William Gregg, pioneer textile manufacturer, builds a mill at Graniteville, S.C.

1850. The first patent for a cotton picking device is granted to Samuel Rembert and Jedediah Prescot, Memphis, Tenn.

1894. The automatic loom is invented by James H. Northrup (United States).

Additional major textile events in the United States during the Industrial Revolution and prior to 1900 are described briefly below. This information is from Smith [43] unless otherwise indicated.

1764. Spinning and carding machinery invented by James Davenport of Pennsylvania. On February 14 a patent was granted and Davenport founded the Glove Mills in Philadelphia. In 1796, he installed a plant in Kensington, Pa.

1768. A Dr. Otto of Bethlehem, Pa., presented to the American Philosophical Association the first cottonseed oil made in America. He had obtained 9 pints of oil from a bushel and half of seed.

1775. First joint stock manufacturing company in America established to promote production and distribution of textile products.

1785. Sea Island cotton was reintroduced into Georgia from the Bahama Island.

1787. Pennsylvania Society for the Encouragement of Manufactures and Useful Arts was organized. Society supported protective tariff, inventions, and research. Committee on Manufactures agreed to promote cotton manufacturing, ordered two English carding and spinning machines. New York, Boston, and other cities established similar societies.

1787. First cotton factory in New England established at Beverly, Mass., under management of John Cabot and Joshua Fisher.

1790. Cotton mill of Almy, Brown, and Slater began operations in Pawtucket, R.I., using British methods. Samuel Slater had come to America familiar with new machinery invented in Britain by Arkwright, Crompton, and Hargreaves. Slater was the first American industrialist to break down the production process into simple component parts, thus enabling his child laborers to outproduce most skilled artisans [46].

1791. Beginning of Philadelphia carpet industry with the manufacture of Turkish and Axminster carpets by William Peter Sprague [46].

1793. Eli Whitney invented the cotton gin, which he patented on March 14, 1794. The machine led to cotton's becoming the chief cash crop of the South and to slavery's becoming more profitable [47].

1793. The first Merino sheep were imported.

1795. Hemp production, subsidized by the Spanish Government, began in California. The subsidy was withdrawn in 1811.

1803. George Washington Parke Custis inaugurated yearly competition in sheep shearing and sheep and wool exhibitions at his Arlington, Virginia, estate.

1803. Glove manufacturing began in Gloversville, N.Y., by Ezekial Case [46].

1807. Seth Adams brought the first Merino sheep west of the Alleghenies to Muskingum County in Ohio.

1809. William Jarvin introduced Merino sheep into New England.

1810. Cotton began to take the place of tobacco as the chief cash crop of the South.

1811. "The Merino Society of the Middle States of North America" was organized in the area of Delaware to protect and encourage wool growers and woolen manufacture.

1814. First factory in world to manufacture cotton cloth by power machinery enclosed in one building was constructed in Waltham, Mass. [46].

1817. Thomas Gilpin produced machine-made paper near Wilmington, Del. For the first time custom-made paper was available [46].

1828. The "Tariff of Abominations" was enacted. This was an extremely high protective tariff sponsored by the Jacksonians as a political move and by the woolen interests.

1830. Robert McCormick, father of Cyrus, invented a power hemp break.

1831. Timothy Bailey of Cohoes, N.Y., improved the powered knitting machine, used the following year in a factory operated by Bailey and Egbert Egberts [46].

1843. Henry W. Vick developed a hybrid cotton seed known as the "Hundred Seed" which resulted in developing other improved varieties.

1846. Erastus Brigham Bigelow founded the first gingham factory at Clinton, Mass. [46].

1848. The power loom to weave Brussels and tapestry carpets was invented by Erastus Brigham Bigelow [46].

1849. James B. Davis introduced Angora goats from Turkey into the United States.

1850. S. S. Rembert and J. Prescott of Memphis, Tenn., were issued a patent on a mechanical cotton picking machine.

1851. A patent for a practical sewing machine was granted to Isaac Merrit Singer, who quickly organized the I. M. Singer & Co. Unique feature of the machine was its stitching feature. Elias Howe won a $15,000 royalty suit against Singer because the Singer machine was based in part on the Howe machine [46].

1853. Noah B. Cloud began the publication of his journal, The American Cotton Planter, in Montgomery, Ala.

1855. The phrase, "Cotton is King," became prominent. The phrase was taken from a book, Cotton is King, or the Economical Relations of Slavery, by David Christy. At this time cotton exports

amounted to one-half the total United States exports. Its value was more than $100 million annually [46].

1857. James E. A. Gibbs of Mill Point, Va., a farmer, perfected the single-thread loop-stitch sewing machine. Improvements were made by James Wilcox. The machine became known as the Wilcox and Gibbs machine [46].

1860. The South, with 42% of the improved land in the United States, produced 43% of the corn, 26% of the wheat, 36% of the dairy cattle, 54% of the hogs, 27% of the sheep, and 43% of the horses and mules–besides all the cotton, rice, and sugar, and nearly all the tobacco.

1863. The U.S. Congress appropriated $3000 to purchase and distribute cotton and tobacco seed in the Northern States.

1870. The New York Cotton Exchange opened, followed by one in New Orleans a year later.

1871. A patent for a cotton stripper, also known in the early forms as a cotton sled or "sledder," was granted to John Hughes of New Berne, S.C.

1878. A twine-knotter for use in binding grain was patented by John F. Appleby.

1880. Thomas A. Edison received a patent for his incandescent lamp which was made with a carbonized cotton thread as the filament [46].

1889. The Singer Manufacturing Co. of Elizabethport, N.J., produced and marketed the first electric sewing machine known in the United States [46].

1891. The zipper was patented by Whitcomb L. Judson [46].

1892. The boll weevil, of Mexican or Central American origin, was first seen in Texas. The pest spread widely and caused as much as $200 million damage to United States cotton crops in some years [46].

1895. A patent was granted on a spindle-type cottonpicker to August Campbell. The principle on which it worked was developed by the International Harvester Co. in the 1920s and introduced in the early 1940s.

Smith and Edelstein [48, 49] have described early chemical developments:

About 1750. Starch sizes were used in weaving and as thickener in block printing.

In the 1800s. Fulling combined soaking in soapy water with mechanical beating to improve woolen cloth. Carbonization removed vegetable matter from raw wool. Water-repellent finishes were based on aluminum soaps; waterproof fabrics produced by coating with rubber latex or linseed oil had been known even earlier. Somewhat later, chlorination of wool was introduced by John Mercer. Glazed and embossed cotton fabrics were made (effect not durable to washing).

The following additional early chemical developments have been listed [38, 50]:

1844. Mercerization of cotton by treatment with caustic soda by John Mercer, England.
1845. Guncotton (nitrocotton or nitrocellulose) developed as a high explosive by Schonbein.
1856. Aniline dyes discovered by Sir William H. Perkins [51].
1868. Hyatt produced celluloid, a plastic, from nitrocellulose and camphor.
1884. The man-made fiber (nitrocellulose) introduced by Chardonnet.
1890. Cuprammonium process for making fibers described by Despeisses.
1892. Viscose and cellulose acetate fibers developed.

NATURAL FIBERS IN THE 20TH CENTURY

History and prehistory are usually measured in terms of time. On this basis, any discussion of the history of natural fibers would give scant attention to the 20th century. If history were measured in terms of significant events and advances, however, a review of natural fibers would be concerned primarily with recent decades. Many living persons have witnessed most of the history of the natural fibers in terms of significant events.

The 20th century is the century in which research and development expenditures exploded in the United States from a few thousand dollars annually to $160 million in 1929, $350 million in 1940, and more than $50 billion in 1979. Vast research and development programs in the United States and in other countries brought many revolutionary changes. The impact of 20th century research on the natural and man-made fibers was dramatic and deep-seated. For the first time in all history the supremacy of the natural fibers was challenged.

A modest amount of research in the 20th century was aimed at benefiting the natural fibers, but more of it was done to develop competing fibers, plastics, etc. Much of the research to benefit the natural fibers was performed or funded by state and federal organizations, particularly the U.S. Department of Agriculture. Most of the vast sums invested in synthetic fibers and plastics research came from several large corporations.

Twentieth century research, massive and sophisticated, soon produced serious competition for the natural fibers in the form of new or improved man-made fibers, plastics, paper, and metal products. Alarmed by this successful competition, the supporters of the natural fibers, principally cotton and wool, took defensive action. Effort on the behalf of the natural fibers was expanded and new organizations were formed:

1938. The National Cotton Council, embracing producers, ginners, oilseed millers, warehousemen, and cotton merchants, was organized.

1941. The Southern Regional Research Laboratory, New Orleans, of the U.S. Department of Agriculture began cotton processing and utilization research.

USDA's Western Regional Research Laboratory, Berkeley, Calif., initiated processing and utilization research on wool and mohair.

The Texas State Legislature created the Cotton Research Committee of Texas.

1948. The International Cotton Advisory Committee was formed.

1962. The National Cotton Council organized the Cotton Producers Institute among cotton growers, who voluntarily contributed $1.00 per bale for cotton research and promotion.

1966. Congress passed the Cotton Research and Promotion Act, permitting the collection of $1.00 per bale from growers for research and promotion.

1967. The International Institute for Cotton was created.

1970. The Cotton Producers Institute became Cotton Incorporated.

Among the additional organizations that promote and benefit the natural fibers are: Natural Fibers Information Center and Natural Fibers Economic Research, the University of Texas at Austin, and the American Wool Council, a Division of the American Sheep Producers Council, Inc.

For about the first third of the 20th century, research by the state and federal groups was aimed primarily at producing natural fibers of better quality at lower cost. Investigations by public and private institutions to improve the production of natural fibers were successful. The success in production research might have pointed to the need for processing, utilization, and marketing research [52].

The need for additional types of research was more fully recognized in 1941 when the U.S. Department of Agriculture's Southern Regional Research Laboratory in New Orleans and the Western Regional Research Laboratory in Berkeley, Calif., were established to investigate cotton and wool, respectively, with emphasis on processing, chemical and physical properties, and the development of new or improved machines and textile products. The Southern, Northern, and Eastern Regional Research Laboratories investigated regenerated protein fibers made from peanuts, soybeans, and milk. Partly because the research was coordinated and the results were published, the investigations of these USDA Regional Laboratories (now Regional Centers) and other publicly supported organizations were highly beneficial to the natural fibers [53, 54].

Many of the research achievements in the area of textile machinery were described by Mayer Mayer, Jr. of the Southern Regional Research Laboratory when he received the prestigious Edward R. Schwartz Award [55]. Several reviews of the research by USDA's Regional Research Centers on cotton, wool, and mohair have been published [13, 56-65].

Chemical research to develop new or improved textile products from natural fibers may be divided into two major types:

1. The cellulosic fibers, usually wood pulp or cotton linters, are brought into solution. The solutions are extruded to obtain new fibers. Proteins also have been dissolved and the resulting solutions extruded to give new fibers.
2. The cellulose or protein fibers are altered chemically without loss of the fibrous form.

Both of these approaches have been used successfully. The first approach was employed to develop the first man-made fibers to achieve commercial success. Rayon, a regenerated cellulose, was made commercially in Europe in 1891 and in the United States in 1910. Cellulose acetate (80% acetylated) became commercial in Europe shortly after World War I and in the United States in 1924. Cellulose triacetate, with 97% of its hydroxyl groups acetylated, was commercialized in the United States in 1954. In the early 1970s, acetate fiber ranked fourth in production of all man-made fibers in the United States, being surpassed only by rayon, polyester, and nylon [50]. Although rayon is classified as a man-made fiber, it may be considered a natural fiber in origin and composition.

The second approach, in which the fibrous form is retained, employs chemical treatments to facilitate processing [65] or to alter properties [56-61].

Early in the 20th century, dye resist yarns were made by acetylating and nitrating cotton yarns. Three dye resist products were made from cotton in the 1920s: the benzoate (reserve cotton), toluenesulfonate (immunized cotton), and acetate (passive cotton). Cotton textile products having amine groups and enhanced dyeability were made by causing the fibrous toluenesulfonate of cotton to react with ammonia or amines. The manufacture of acetylated cotton (Cotopa 30) began in England in 1928 and lasted for several decades. Patents issued to Tootal Broadhurst Lee, England, in 1928 described treatments of cotton and rayon with urea-formaldehyde to impart wrinkle-resistance. Soluble cotton gauze, made by oxidation with nitrogen dioxide, has been used as a surgical dressing. Nitrated cotton yarns, which become soluble in alkaline solutions, have been manufactured. High-style cottons have been made by parchmentizing, embossing, pleating, and applying high polymers. Hydroxyethylated cotton, studied intensively in 1940, has a crisp hand and enhanced reactivity and dyeability. Water-repellent cottons have been made by treating cotton with stearamidomethylpyridinium chloride, octadecylethyleneurea, or other chemicals. The manufacture of wrinkle-resistant, wash-wear cottons was initiated in about 1953. These and other chemically modified cottons, including fully acetylated cotton (Cotopa 60), carboxymethyl cotton, aminized cotton, cyanoethylated cotton, flame-resistant cottons, and weather resistant cotton shade cloth, have been reviewed [12, 56-61]. Treatments for wool and

TABLE 7. World Production of Jute and Hard Fibers, 1000 Metric Tons [28a]

	1963	1970	1976
Jute	2421	2051	2034
Abaca	119	93	67
Sisal-Henequen	826	763	628
Total, 1000 metric tons	3366	2907	2729
Total, billion lb	7.421	6.409	6.016

TABLE 8. Silk and Vegetable Fibers (except cotton): Imports for Consumption, United States, 1978 [70][a] (metric tons)

Flax	Hemp	Jute and butts	Abaca or manila	Sisal and henequen	Istle or tampico	Kapok	Other fibers
454	149	16,999	22,085	10,642	4,027	6,280	23,543

[a]In 1978, 671,000 lb of raw silk and 1,299,000 lb of silk waste were imported [70]. Total vegetable fibers listed above: 84,179 metric tons or 185.6 million lb.

and mohair have been reviewed by Lundgren [66] and O'Connell and Ward [63].

Is cotton still king of the textile fibers? The answer depends on what statistics and situations are considered. In some of the most populated regions of the world, including India and China, cotton continues to represent nearly 90% of total fiber consumption [20]. Cotton's share of the market ranges from about 25% in the United States to 36% in East Europe, 50% in the Soviet Union, and 88% in the Peoples Republic of China [20]. From these figures and Tables 1-4, it is evident cotton is important in all parts of the world and king in some.

FUTURE OF THE NATURAL FIBERS

The future of the natural fibers appears discouraging in terms of percent of the total textile market but heartening in terms of quantities [20, 67]. Most efforts to anticipate the future of the natural fibers have been concerned with cotton. It is worth noting, however, that substantial quantities of other natural fibers (perhaps as much as

TABLE 9. Projected United States Textile Fiber Production and Use [20]

			1985			1990		
	1974	1979	High	Medium	Low	High	Medium	Low
Cotton production[a]	11.54	14.6	12.44	11.27	10.11	13.10	11.57	10.05
Total fiber use[a]	23.50	12.66[b]	33.93	32.97	32.00	38.69	37.10	35.52
Total fiber use, per capita[c]	24.14	26.04	31.40	30.51	29.61	34.24	32.80	31.40
Cotton textile use[a]	7.12	6.5	8.14	7.91	7.68	8.51	8.16	7.81
Cotton textile use, per capita[c]	7.32	6.35	7.54	7.33	7.11	7.52	7.22	6.91
Cotton textile use, per capita[d]	16.14	14.0	16.62	16.15	15.67	16.58	15.91	15.23
Cotton's share, %	30	24	24	24	24	22	22	22

[a]Million bales.
[b]Billion lb.
[c]Kilograms; 1 kg = 2.205 lb.
[d]Pounds; 1 lb. = 0.4536 kg.

TABLE 10. Projected United States Cotton Production and Consumption [67]

		Projected, medium	
	1972	1985[a]	2000[b]
Per capita cotton demand, lb	18	16	17.5
Population, millions	209	235	264
United States demand, million bales[c]	7.8	7.85	9.64
Exports, million bales[c]	5.3	4.0	5.0
Total United States demand, million bales[c]	13.1	11.85	14.64
Production, million bales[c]	13.7	11.85	14.64
Cost per lb, cents	32	50	75

[a]High and low projections for 1985: 883 and 6.86 bales.
[b]High and low projections for 2000: 11.02 and 8.26 bales.
[c]Bales, 480 lb.

0.8 lb per lb of cotton) may be produced (Table 2). The precise effect of high petroleum and energy prices on interfiber competition is not known, but it is claimed the high prices will penalize the man-made fibers more than the natural fibers [68, 69].

Information on the present position of the natural fibers is given in Tables 1-4, 6-8, and Eqs. (1) and (2).

According to the projections of Collins and co-workers [20], cotton's share of the United States textile market will drop from 27% in 1977 to 24% in 1985 and to 22% in 1990. Their high projections of United States cotton production in 1985 and 1990 are 12.4 and 13.1 million bales, respectively. The corresponding low estimates are 10.1 and 10.0 million bales (Table 9). These figures may be compared with the average production of cotton in the United States of 11.77 million bales over the 10-year period of 1970-1979.

Projections of the National Research Council [67] are optimistic about cotton's future (Table 10). According to their projections, the per capita use and total use in the United states in the year 2,000 will be 17.5 lbs and 14.64 million bales, respectively.

Dudley [71] has projected the following per capita use data (in lb) for 1985: cotton, 14-18, wool, 1; and cellulosic, 7-8. These per capita data may be compared with those in Tables 9 and 10.

Collins, Evans, and Barry [20] estimate optimistically the world production of cotton in 1985 and 1990 may increase substantially,

TABLE 11. Projected World Textile Fiber Production and Use [20]

		1985			1990		
	1974	High	Medium	Low	High	Medium	Low
Cotton production[a]	61.06	75.60	72.77	69.94	83.56	79.38	75.20
Total fiber use[a]	120.46	169.15	163.0	156.83	195.90	186.36	176.82
Total fiber use, per capita[b]	6.7	7.6	7.35	7.1	8.0	7.65	7.3
Cotton textile use[a]	60.71	75.60	72.77	69.94	83.56	79.38	75.20
Cotton textile use, per capita[b]	3.4	3.4	3.3	3.2	3.4	3.25	3.1
Cotton's share, %	50.4	44.7	44.65	44.6	42.7	42.6	42.5

[a]Million bales.
[b]Kilograms; 1 kg = 2.205 lb.

TABLE 12. United States per Capita Consumption of Wool[a]

	Year				
	1975	1976	1977	1978	1985
Lbs.	0.74	0.96	0.97	1.06	1.0

[a]The 1985 projection is from Dudley [71]; the other data are from Schubkegel [11].

i.e., from 61.1 million bales in 1976-77 to 75.6 million bales in 1985 and 83.6 million bales in 1990. Their corresponding low projections are 69.9 and 75.2 million bales. Even the low projections represent a substantial increase in world cotton production (Table 11).

Collins, Evans, and Barry [20] think that the erosion of cotton's share of the world fiber market will proceed at a slightly declining rate, from 50% of the market in 1974 to slightly less than 45% in 1985, and less than 43% in 1990. This is compatible with the view of Roberts [72] that the synthetic fibers will continue to grow but at rates lower than those of the 1950s and 1960s.

Favorable factors for the future of wool include excellent fiber properties, the production of by-product meat, the use of land unsuitable for conventional agricultural purposes, the availability of new technology, and low energy requirements. Potentially, wool production could be increased 20-fold in the United States alone, using only grazing land unsuitable for field cropping. In the 48 contiguous states, half the land mass of more than 1 billion acres is suitable only for grazing [63].

World consumption of wool rose from the 1974 low of 2.8 billion lb to a high of 3.2 billion in 1976. In 1978, world consumption totaled 3.1 billion lb [15]. If the projection (Table 12) by Dudley [71] is correct, the United States consumption of wool may be expected to increase with population increases.

As indicated by Table 13 and least squares Eq. (3), the world production of silk increased over the period 1968-1977. It could be argued these data justify at least some optimism for the future of silk.

There may be cheer for both the natural and man-made fibers. Population, per capita consumption, and textile markets are increasing. Perhaps there will be room for both types.

TABLE 13. World Production of Silk [73][a]

	Year											
	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1985	1990
Million lb	82	86	90	90	93	97	99	106	108	108	-	-
Eq. (3)	82.3	85.3	88.3	91.4	94.4	97.4	100.4	103.5	106.5	109.5	133.7	148.8

[a] $M = 5869.4 + 3.0242Y$ (3)

where Y = year and the correlation coefficient = 0.986781.

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