1
Overview

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1.1 Introduction

This book is one of a series on textile fibres that the Textile Institute and Woodhead Publishing Ltd decided to publish because, for most of the fibres, the most recently published books are over fifty years old. Also we believe that not only is some of the information in these books now out of date but that they did not cover, to any great extent if at all, matters which are now considered to be important; for example, marketing, R & D, economics and statistics of various kinds. Several books in this series have now been published and are listed in the Related titles section at the front of this book.

When we began to plan this particular volume we immediately came across the problem of which fibres to include. Of course, to a certain extent the words 'bast' and 'leaf' themselves select the fibres for us, but as readers will see from the list of plant fibres that appears in the last section of the book, some further choices had to be made. We therefore decided to limit ourselves to those fibres that have an annual production in the region of fifty thousand tonnes or more and are traded internationally. We decided to include some abridged information about other fibres, nettles and pineapple are two examples which, for various reasons, arouse a certain amount of interest. We have also included coir although it is neither a bast nor a leaf fibre but a seed fibre. We took this decision because coir is accepted by the market and the textile industry as falling into the category of 'hard fibre' such as sisal, henequen and other similar leaf fibres and is a fibre of international importance.

From the point of view of annual production the only bast or leaf fibre that can be called a major fibre is jute, with an annual production of around two million tonnes per year. Nonetheless, those other fibres to which we have devoted a whole chapter hold definite niches in the overall textile market although, until the advent of the composite fibre market a few years ago, hemp seemed to be in terminal decline. Many of these fibres are also used in the manufacture of paper, but only if their prices are sufficiently low to enable them to attract no more than a modest premium over wood pulp. The consumption of these fibres by this vast industry is therefore limited to their lower qualities. Were it possible, for example, to reduce their prices by developing 'green decorticating' to the degree where it produces clean fibre at a suitable price, many of these bast and leaf fibres could take a worthwhile share of the market and thus replace some of the wood pulp used by more ecologically friendly raw materials.

Most of these fibres are produced in developing countries – flax and hemp being the only exceptions and even in their cases the greater parts of their world production comes from eastern Europe, Russia and China. These developing countries naturally add as much value as they can to their raw material production by spinning, weaving and sometimes making finished consumer products from their fibres. But in nearly all cases the distribution and marketing of both the fibres and the intermediary and some end products are handled by merchants in Hamburg, London, Zürich and other major commercial centres. This extremely well established and traditional method of distribution does have disadvantages; in particular insofar as the development of new products and markets are concerned and in feeding back market information 'up the line' to weavers, spinners and fibre producers.

The major countries producing these fibres, China, India, Bangladesh, for example, do have excellent R & D organisations and make real efforts to develop new products for existing markets and new end-uses for their fibres. Several interesting examples of such developments are described by the authors of Chapter 2 on jute but since there are (at least to the knowledge of this editor) no effective marketing organisations capable of testing markets, promoting the products and arranging appropriate prices and distribution, very little actual new product marketing occurs. In other industrial sectors this is usually done by the market leaders or well financed newcomers to the markets but in the textile manufacturing industry in general there rarely are any market leaders. Even the larger companies are often family businesses and generally too small to be able to ensure financial margins that are sufficient to cover the costs of such market development operations.

The only real solution for these small and medium sized enterprises is to co-operate, establish and collectively fund such market development organisations, perhaps with the help of governments or regional (or global) development banks. This seems obvious but it is, in fact, difficult; especially as most of these fibres are produced in Asian countries which have, at least as far as family companies are concerned, fiercely individualistic cultures. But it is difficult to see any other solution to this problem; but solution there must be if these industries are to progress into the 21st century.

1.2 Fibre prices

The markets of the fibres covered in this book do, to a certain extent, overlap. They are therefore competitors and in an ideal world it could be thought useful, in a book of this kind, to provide comparisons between their prices. In a few cases the authors of the following chapters have provided information on individual fibre prices but from a practical point of view the setting out of tables of comparative prices is likely to be more misleading than useful, because:

- individual fibre prices vary according to supply, demand and currency exchange rates (see Chapter 3 flax, as an example).
- Even when considering the prices of a particular fibre, the prices will vary according to quality. For example, the case of flax (again Chapter 3), the price of line can be, and often is, ten times higher than that of tow.

It is therefore necessary, when wishing to compare prices, to be specific concerning dates, currencies and qualities. The statistics on fibre prices that are available for some of these fibres specify which quality of the fibre is concerned, and often its country of origin. This, although useful, gives only a limited view of the total market.

1.3 The Food and Agricultural Organisation's statistics (www//FAOstat)

Throughout this volume we have made copious use of the statistics collected and collated by the FAO and we would wish to acknowledge the very considerable value of the work that is done in this field by them. Nonetheless, these statistics cannot be more accurate than the figures that are supplied to them by the many countries involved and it does seem that from time to time some inaccuracies creep into the system. These could be due to double counting or by the inaccuracy of the input figures but, should any doubt arise, it is advisable to check directly with the FAO and possibly with other independent sources.

1.4 Comparative data on the physical and chemical characteristics of bast and leaf fibres

It is sometimes useful and convenient to be able to compare the characteristics of fibres without having to search for the information by consulting a different source for each fibre; this is the purpose of the tables in the Appendix to this introduction. Also, it will be seen from some of the tables that different sources often give different values for the physical and chemical characteristics of the fibres. The reason behind these seeming differences is that we are dealing with natural, growing, organisms that are not uniform in their compositions or properties. The fibres may have been obtained from different varieties of the same plant species, the tests may have been carried out at different stages of maturity of the plants and by using different methods of analysis or testing, the plants from which the fibres were extracted may, and probably did, grow in different soils and under different meteorological conditions. Therefore it is to be expected that the test results are not likely to be identical. By offering our readers the results obtained from different sources we are able to illustrate the variation that exists in this field.

1.5 Appendix: Comparative physical, chemical and morphological characteristics of certain fibres

1.5.1 Mechanical characteristics

Although glass fibre is not a bast or leaf fibre it is included in Table 1.1 because of its established use in composite products, a market in which several of the natural fibres covered in the table are beginning to compete (see Chapter 8).

Table 1.2 gives certain other physical characteristics of flax, hemp and jute. Note that the cellulosic microfibrils of bast fibres impart enormous tensile strength (at best similar to Kevlar), and the lignin content gives rigidity and a degree of hydrophobia. Lignin also becomes thermoplastic, softening at 90 ºC and flowing at about 170 ºC. The combined effect of the chemical composition is to impart properties which are useful as benefits for industrial fibres:

- high strength – tensile strength and tenacity (50 cN/Tex for jute)
- low extension at about 2%
- high modulus of elasticity (1 M at 250 cN/Tex)
- high coefficient of friction giving anti-slip characteristics
- excellent heat, sound and electrical insulating properties
- biodegradability through fungal/bacterial action.

Table 1.3 gives slightly different but not too dissimilar results to Table 1.2.

Table 1.4, taken from *Vlasberichten* – the Belgian flax producers' trade publication published in Kortrijk (Courtrai). This table gives certain other physical characteristics of several natural fibres compared to certain manufactured high-performance fibres.

In J. T. Marsh's classic textbook on *Textile Science*, first published in 1948, we find the dimensions of ultimate fibres shown in Table 1.5.

Table 1.6 is fairly comprehensive and includes fibres not mentioned in previous tables such as roselle, sun fibre, pineapple and maguey, although not all characteristics are given for each fibre.

Table 1.7 is extracted from a larger table taken from Luniak's *Identification of textile fibres* and includes certain characteristics not found in many other publications.

Table 1.8 gives the lengths and widths of bate and leaf ultimate fibres from several authors in considerable detail.

Table 1.9 compares the Young's modulus of several bast and synthetic fibres and is taken from the same source as Table 1.14.

Table 1.10 is taken from an Indian Government study of the development of natural fibres in composite products.

Table 1.11, from the same source as Table 1.10, includes two characteristics not shown in other tables, volume resistivity and micro-fibrillar angle but, unfortunately, only for a few fibres.

1.5.2 Chemical characteristics

Table 1.12 compares the chemical composition of the major bast and leaf fibres covered in this book.

Table 1.13, from Jarman's *Plant fibre processing* gives similar chemical compositions for these fibres, although there are some differences.

Table 1.14 is taken from a Ministry of Agriculture of Canada report on 'Market opportunities for hemp based products'.

Table 1.15 is taken from the same source as Table 1.14 and gives some strikingly different figures for some of the characteristics than those given in previous tables.

Table 1.16 lists the chemical composition of plant fibres by percentage mass.

1.5.3 Morphological descriptions

Tables 1.17 and 1.18 are taken from Luniak's *Identification of textile fibres*, quoted above.

Table 1.1 Properties of glass and natural fibres

Properties	Fibre								
	E-glass	Flax	Hemp	Jute	Ramie	Coir	Sisal	Abaca	Cotton
Density g/cm^3	2.55	1.4	1.48	1.46	1.5	1.25	1.33	1.5	1.51
Tensile strength* 10E^6 N/m^2	2400	800–1500	550–900	400–800	500	220	600–700	980	400
E-modulus (GPa)	73	60–80	70	10–30	44	6	38		12
Specific (E/density)	29	26–46	47	7–21	29	5	29		8
Elongation at failure (%)	3	1.2–1.6	1.6	1.8	2	15–25	2–3		3–10
Moisture absorption (%)	–	7	8	12	12–17	10	11		8–25

* Tensile strength strongly depends on type of fibre, being a bundle or a single filament
Source: *http://www.fao.org/DOCREP/004/Y1873E/y1873e0a.htm* Courtesy: Food and Agriculture Organization of the United Nations and R. Brouwer.

Table 1.2 Physical characteristics of flax, hemp and jute

Fibre type	Length mm average (range)	Width mm average (range)	Chemical cellulose	Composition hemi-cellulose	Lignin	Pectin
Flax bundles	(250–1200)	(0.04–0.6)	68–85	10–17	3–5	5–10
Flax (single fibres)	33 (9–70)	0.019 (0.005–0.038)				
Hemp (bundles)	(1000–4000)	(0.5–5.0)	68–85	10–17	3–5	5–10
Hemp (single fibres)	25 (5–55)	0.025 (0.01–0.05)				
Jute (fibre strands)	(1500–3600)	–	70–75	12–15	10–15	1
Jute (single fibres)	(2–5)	0.020 (0.010–0.025)				

Source: Eddlestone, E. P., 'The use of natural fibres in non-woven structures for applications as automotive component substrates' Courtesy: *The Textile Consultancy*, Dalgetty, UK 1999.

Table 1.3 Certain physical characteristics of bast fibres

Fibre	Length textile fibre (mm)	Length ultimate fibre (mm)	Diameter (microns) (denier)	Weight per length	Density (g/cm^3)
Flax	300–900	13–60	12–30	1.7–17.8	1.4
Hemp	1000–3000	5–55	16–50	3.20	1.4
Kenaf	900–1800	1.5–11	14–33	50	–
Jute	150–360	0.8–6	5–25	13.27	1.4
Ramie	1500	40–250	16–125	4.6–6.4	1.4
Nettle	19–80	5.5	20–80	–	–
Sisal	600–1000	0.8–8	100–400	9–400	1.2–1.45

Sources: Bisanda 1992, Lewin and Pearce, 1985, Vaughn 1986, in *Vlasberichten* reproduced with permission.

Table 1.4 Mechanical characteristics of certain fibres

Fibre	Tensile strength (GPa)	Specific tensile strength (GPa m^3/kg)	Flexibility modulus (GPa)	Specific flexibity modulus (GPa m^3/kg)	Tensile modulus (GPa)	Elongation at break (%)	Specific tenacity (GPa m^3/kg)	Elasticity modulus GPa
Cotton	0.28–0.84					5.6–7.1		56–112
Flax	0.90	0.60	85	71		1.8–3.3		1.0
Hemp	0.31–0.39					1.7–2.7		
Kenaf	0.18					1.7–2.1		
Ramie	0.29					2.3–4.6		
Jute	0.22–0.53		2.5–13	09.0	13	1.0–2.0	0.37	0.26–0.32
Sisal	0.08–0.839	0.07–0.42	3–98	3.82 (10.3)	15	2.9–6.8	0.44	0.15–0.19
	1.7–3.5	1.35	68–96	28	70	4.8	0.67	
Kevlar	3.90	2.71	131	91				
Carbon	2.4–3.0	1.71	235	134–213	400		1.28	
Steel	1.2			25.5	200	8	0.15	

GPa: 10^9 N/m with N: Newtons
Source: *Vlasberichten* reproduced with permission.

Table 1.5 Dimensions of some ultimate fibres

	Length in mm			Diameter in μ		
Fibre	Minimum	Maximum	Average	Minimum	Maximum	Average
Cotton	10	50	25	14	21	19
Flax	8	69	32	8	31	19
Hemp	5	55	25	13	41	25
Ramie	60	250	120	17	64	40
Jute	0.75	6	2.5	5	25	18
Sisal	0.8	7.5	3	7	47	18

Source: Marsh, J. T., *Textile Science*, Chapman & Hall, London, 1948.

Table 1.6 Mechanical properties of plant fibres

Fibre	Length of commercial fibre (mm)	Length of spinnable fibre (mm) (i.e. staple length)	Linear density (Tex)	Tensile strength (kg/mm^2)	Extension at break (%)
Cotton	15–56	15–56			
Coir		20–150	50	30	37
Jute	750–1500	60	1.4–3.0	105	2.7
Kenaf	750–1500	60	1.9–2.2	87	3.5
Roselle	750–1500	60	2.14–3.02	91	3.5
Flax	700–900	50–150 (wet spun)	0.2–2.0	134 183	4.1 3.2
Ramie	800	100–200		129 112	3.9 4.2
Hemp (true)	2500 (long hemp)	150–1500	0.3–2.2	126	4.2
Sunn fibre	750–1500			73	5.5
Himalayan/ Nilgiri nettle (Allo)		8.5–53.6 Mean 32.4 cm		'very strong'	
Sisai	600–1000		28.6–48.6	78	5.0
Henequen			40.2–53.1		
Maguey		300–900	5.0		
Abaca	1000–2000		4.2–44.4	140 85	8.0 7.8
Pineapple	900–1500		1.5–2.3	101 52	4.9 2.4

Source: Jarman, C., *Plant fibre and processing: A handbook*. Courtesy: ITDG Publishing, UK.

Table 1.7 The range of some mechanical properties and densities of certain textile fibres

	Tenacity gr/den.	Strength wet as % of dry dry	Extension at break: dry	Extension at break: wet	Density gr/cc
Cotton	1.7–6.3	100–110	3–12	6.13	1.52–1.56
Ramie	4.5–8.8	100–110	1.5–5	3–7	1.51–1.55
Flax	2.6–8.0	100–110	1.5–5	3–7	1.48–1.50
Hemp	3.0–7.0	100–105	1.5–5	–	1.48–1.49
Jute	2.0–6.3	90–105	1–2	2–3	1.44–1.49
Glass fibre	3.0–12	80–100	2–5	2–5	2.47–2.57

Adapted from Luniak, B., *The Identification of Textile Fibres*, Sir Isaac Pitman and Sons, London, UK, 1951.

Table 1.8 The lengths and widths of fibre cells reported by previous authors

(a) Width (μm)

Species	von Wiesner (1867, 1927)	Kirby (1963)	Matthews (1931)	Koch (1963)	Hanausek (1907)
Agave sisalana	30–50 mean 20	–	20–32	–	17–28 mostly 22–23
Boehmeria nivea	16–80	25–75	up to 80	40–50	20–80
Cannabis sativa	15–28	16–50	16–50 average 22	16–32	16–50
Corchorus capsularis	10–21	–	20–25	16–23	17–23
Corchorus olitorius	16–32				
Crotalaria juncea	20–42	13–50 mean 25–30	13–50		13–50 mostly 25–30
Hibiscus cannabinus	21–41	12–36 mean 20	–	–	14–16
Hibiscus sabdariffa	–	10–33 mean 19	–	–	–
Linum usitatissimum	12–26	mean 23	12–25	11–31	12–30
Musa textilis	12–46	16–32	16–32	–	12–40 mostly 21–30

Table 1.8 (continued)

(b) Length (mm)

Species	Kirby (1963)	von Wiesner (1867, 1927)	Matthews (1931)	Identification of Textile Materials (1965, 1970)	Koch and Hooper (1963)	Hanausek (1907)
Agave sisalana	2.5	2.4–4.4	1–5	–	–	–
Boehmeria nivea	average 150	up to 260	198–250	mean 150	120–140	150–250 exceptionally up to 580
Cannabis sativa	5–55 average 22	5–55	mean 20	–	15–28	10–50
Corchorus olitorius *Corchorus capsularis*	–	0.8–4.1	1–5	1.5–3.0	2–3	Several
Hibiscus cannabinus	1.5–11 mean 2.4	1.5–2.75 frequently 2–2.2	2–6	–	–	up to 6
Hibiscus sabdariffa	1.2–6.0 mean 3.0	–	–	–	–	–
Linum usitatissimum	mean 27	20–50	11–38	–	20–39	0.004–0.066 usually 0.025–0.030
Musa textilis	2.5–12	2.0–2.7 mostly 2.7!	3–11	–	–	–

Table 1.9 Comparison of the Young's modulus of several bast and synthetic fibres

	Young's modulus (GPa)
Bast fibres	
Flax	100
Hemp	69
Jute	64
Ramie	59
Synthetic fibres	
Rayon carbon fibre	34–55
Glass fibre	70–85
Aramid fibre, Kevlar	60–200
Silicon carbide	190
Polyacrylonintrile carbon fibre	230–490

Source: Chum, H. L., *Polymers from biobased materials*, Noyes Data Corp 1989 and Chawle, K. K., *Fibrous Materials*, Cambridge University Press, UK, 1998. From: *www.gov.mb.ca*. Courtesy: Dr Goodall-George, Triple R CFDC, Canada.

Table 1.10 A comparison of various properties of E-glass and jute

Property	E-glass	Jute
Specific gravity	2.5	1.3
Tensile strength (MN/m^2)	3400	442
Young's modulus (MN/m^2)	72	55.5
Specific strength (MN/m^2)	1360	340
Specific modulus (GN/m^2)	28.8	42.7

The natural fibre imparts lower durability and lower strength compared to glass fibres. However, low specific gravity results in a higher specific strength and stiffness than glass. This is a benefit especially in parts designed for bending stiffness. In addition, the natural fibres offer good thermal and acoustic insulation properties along with ease in processing technique without wearing of tools.

Source: Development of Natural Fibre Composites in India, S. Biswas, G. Srikanth and S. Nangia, *Proceedings of the Annual Convention and Trade Show of the Composite Fabricators' Association (CFA)* Tampa, Florida, USA, October 03-06-2001. Courtesy: *http://www.tifac.org.in/news/efa.htm* reproduced with permission from S. Biswas.

Table 1.11 Properties of selected natural fibres

Property	Jute	Banana	Sisal	Pineapple	Coir (coconut fibre)
Width or diameter (mm)	–	80–250	50–200	20–80	100–450
Density (g/cc)	1.3	1.35	1.45	1.44	1.15
Volume resistivity at 100 volts (W cm $\times 10^5$)	–	6.5–7	0.4–0.5	0.7–0.8	9–14
Micro-fibrillar angle ( )	8.1	11	10–22	14–18	30–49
Cellulose/lignin content (%)	61/12	65/5	67/12	81/12	43/45
Elastic modulus (GN/m^2)	–	8–20	9–16	34–82	4–6
Tenacity (MN/m^2)	440-533	529–754	568–640	413–1627	131–175
Elongation (%)	1–1.2	1.0–3.5	3–7	0.8–1.6	15–40

There are many examples of the use of cellulosic fibres in their native condition like sisal, coir, jute, banana, palm, flax, cotton, and paper for reinforcement of different thermoplastic and thermosetting materials like phenol formaldehyde.

Source: Development of Natural Fibre Composites in India, S. Biswas, G. Srikanth and S. Nangia, *Proceedings of the Annual Convention and Trade Show of the Composite Fabricators' Association (CFA)* Tampa, Florida, USA, October 03-06-2001. Courtesy: *http://www.tifac.org.in/news/efa.htm* reproduced with permission from S. Biswas.

Table 1.12 Approximate chemical composition (%) of cellulosic fibres

Fibre	Cellulose	Hemicelluloses	Pectin	Lignin	Fat/wax
Seed hair fibres					
Cotton	92–95	5.7	1.2	0	0.6
Bast fibres					
Flax	62–71	16–18	1.8–2.0	2.0–2.5	1.5
Hemp	67–75	16–18	0.8	2.9–3.3	0.7
Ramie	68–76	13–14	1.9–2.1	0.6–0.7	0.3
Jute	59–71	12–13	0.2–4.4	11.8–12.9	0.5
Leaf fibres					
Sisal	66–73	12–13	0.8	9.9	0.3
Abaca	63–68	19–20	0.5	5.1–5.5	0.2
Nut husk fibres					
Coir	36–43	0.2	3–4	41–45	

Source: Kraessig *et al.*, 1996; Lewin and Pearce, 1998, in Cavaco-Paulo, A. and Gubitz, G. M., *Textile processing with enzymes*, Woodhead Publishing Ltd, UK, 2003.

Table 1.13 Chemical composition (%) of plant fibres

	Cellulose	Hemi-celluloses	Pectin	Lignin	Water solubles	Fat and wax	Moisture
Cotton	82.70	5.70			1.00	0.60	10.00
Jute	64.40	12.00	0.20	11.90	1.10	0.50	10.00
Flax	64.10	16.70	1.80	2.00	3.90	1.50	10.00
Ramie	68.60	13.10	1.90	0.60	5.50	0.30	10.00
Hemp	67.00	16.10	0.80	3.30	2.10	0.70	10.00
Sunn fibre	67.80	16.60	0.30	3.50	1.40	0.40	10.00
Sisal	65.80	12.00	0.80	9.90	1.20	0.30	10.00
Abaca	63.20	19.60	0.50	5.10	1.40	0.20	10.00

Source: Batra/A. J. Turner, 'The structure of textile fibres'. In C. Jarman, *Plant fibre and processing: A handbook*, Intermediate Technology Publications, UK, 1998.

Table 1.14 Comparison of fibre properties of hemp, flax and cotton

Fibre	Hemp	Cotton	Flax
Cellulose (%)	67	83	64
Hemicellulose (%)	16	6	17
Lignin (%)	3	0	2
Fibre fineness (denier)*	3–20	1–3	2–16
Moisture absorption (%)	8	8	7
Strength (g/dtex)**	5–6	3–6	5–6
Extension at break (%)	2–3	3–7	3

* denier = mass (g) of 9000 m of fibre.
** grams force/unit linear density; dtex = mass (g) of 10,000 m of fibre.
Source: Batra, S., 1985, P. M. Lewin and E. M. Pearce, *Fibre Chemistry*, New York: Marcel Dekker. From: *http://www.gov.mb.ca/agriculture/crops/hemp/bko07s02.html* Courtesy: Dr Goodall-George, Triple R CFDC, Canada.

Table 1.15 Comparison of various characteristics of some natural fibres

	Cellulose (%)	Lignin (%)	Mean length of fibre (mm)	Mean width of fibre (mm)	Tensile strength (psi × 1000)	Young's modulus (psi × 1000)
Cotton	85–90	0.7–1.6	25	0.02		
Flax = (seed)	43–47	21–23	30	0.02	157	14,500
Hemp	57–77	9–13	20	0.022	131	10,005
Abaca	56–63	36–45	6	0.024		
Coniferous wood	40–45	26–34	4.1	0.025		
Sisal	47–62	7–9	3.3	0.02		
Kenaf	44–57	15–19	2.6	0.02		
Jute	45–63	21–26	2.5	0.02	123	9,280
Wheat straw	33–39	16–23	1.4	0.015		
Deciduous wood	38–49	23–30	1.2	0.03		
Glass fibre E					246–508	10,200
Glass fibre S					290–653	12,325
Glass fibre C					247–406	10,150
Kevlar fibre					406	7,945 to 21,315
Carbon fibres					270–638	33,350 to 78,300
Ceramic					247–429	14,500 to 60,900
Steel					406	29,000
Boron					508	60,175
Al-alloy					87	10,295
Nylon					145	870

Source: Consultant's consolidation of industry data from *http://www.gov.mb.ca/agriculture/crops/hemp/bko07s02.html* Courtesy: Dr Goodall-George, Triple R CFDC, Canada.

Table 1.16 Chemical composition of plant fibres by percentage mass (%)

	Coir	Ramie	Abaca	Jute	Sisal	Hemp	Flax	Nettle
Cellulose	32.9–43.4	68.6–83.0	70.2	61.0–72.4	65.8–70.0	60.0–72.0	56.5–72.0	53.0–82.6
Hemicellulose	0.15–0.25	13.1–14.5	21.7	12.0–13.3	13.3	11.0–19.0	15.4–16.7	
Pectin	2.7–3.0	1.9–2.1	0.6	0.2	0.9	0.2–2.0	1.8–3.1	0.9–4.8
Lignin	40.5–45.8	0.6–0.7	5.6	11.8–14.2	9.9–12.0	2.3–4.7	2.0–4.1	0.5
Watersoluble substances	5.2–16.0	6.1	1.6	1.2	1.3		3.9–10.5	
Waxes/fats	–	0.3	0.2	0.1–0.6	0.3	1.4	1.3–2.2	

Adapted from Lewin and Pearce 1985, Philippine Coconut Authority 1979, quoted in Dippon 1999, Triolo 1980, Liebscher 1983, Ludtke 1955, Herzog 1930, Bluhm 1999, Dreyer 1999, Mondenschein 1996. Courtesy: J. Müssig, private communication, 2004.

Table 1.17 Morphology of textile fibres

Longitudinal view	Cross-section
Vegetable fibres	
Cotton	
(raw and bleached)	
Ribbon-like with frequent convolutions, sometimes changing direction; distinct but small lumen, containing protoplasm in raw fibre. *Note*: Immature fibres, very thin cell wall and few convolutions.	Kidney and bean-shaped, seldom round or oval; lumen as a line or oval.
(mercerised)	
For the greater part cylindrical and smooth; ribbon-like fibres and fibre regions or less frequent depending on degree of mercerisation; lumen very small or disappeared.	Most fibres round or oval (number depending on degree of mercerisation); very small or no lumen.
Ramie	
(raw, before degumming)	
Fibre bundles with cross-markings, longitudinal and transverse fissures.	Bundles (and possibly some individual fibres).
(degummed, and possibly bleached)	
Isolated individual fibres, very broad and ribbon-like with infrequent twists; cross-markings, longitudinal and transverse fissures.	Elongated polygons, often with curved side-lines, and sometinmes rounded; thick wall, radial fissures; lumen long and narrow or same shape as fibre section.
Flax	
(raw)	
Fibre bundles, cross-markings, nodes, fissures, but otherwise smooth.	Shape and size of the fibre bundles partly depending on preparation; ultimate fibres mainly sharply polygonal with narrow, round or oval lumen; also rounded oblong forms with larger lumen.
(bleached)	
More or less isolated ultimate fibres depending on degree of bleaching; cross-markings, nodes, fissures but otherwise smooth.	
(mercerised)	
Fibres cylindrical, smooth, few cross-markings and nodes visible.	
(crease-resistant – as mercerised)	
(cottonised)	
Mixture of bundles and single fibres	
Hemp	
(raw)	
Similar to flax.	Similar to flax; lumen often as a mere line and indistinct
(bleached)	
Similar to flax.	
(cottonised)	
Similar to flax.	
Jute	
(raw)	
Fibre bundles, very rarely cross-markings, nodes or fissures; ultimate fibres (bleached or macerated) with lumen considerably varying in size along the same fibre	Fibre bundles of varying size; ultimate fibres mainly sharply polygonal, some with rounded corners; lumen round to ovbal with very varying size

Adapted from Luniak, B., *The Identification of Textile Fibres*, Sir Isaac Pitman and Sons, London, UK, 1951.

Table 1.18 Microscopical differentiation of vegetable fibres

	Cotton	Ramie	Flax	Hemp
Length (mm)	10–25–64	60–120–150–600	1–13–40–120	5–15–25–55
Thickness (μ)	12–25	17–40–60–80	4–18–40(–200)	10–15–30–50
Longit. view	ribbon-like, convolutions, mercerised; mostly smooth	cross-markings, longit. fissures; fibres ribbon-like infrequent twists	cross-markings, nodes, fissures, bleached flax; fibres isolated	similar to flax (differentiation flax/hemp)
Fibre ends	rounded tips, torn base	clearly rounded	mostly pointed also rounded	mostly rounded tips
Cross-section				
Bundle	no bundles	shape and size depending on preparation; partly isolated ultimate fibres	shape and size depending on preparation; roundish, elongated, irregular	similar to flax
Ultimate fibre	kidney or bean-shaped, seldom round or oval; merc.: mostly round or oval	elongated polygons, often with curved sidelines; sometimes rounded; thick wall, radial fissures	mainly sharply polygonal; also oblong with rounded corners	similar to flax
Lumen	line or oval; merc.: none or very small	lumen long and narrow, or same shape as fibre section	mainly narrow round, oval; also larger forms	similar to flax; often as a mere line and indistinct
Adhering plant fragments Epidermis	normally no plant fragments (possibly debris from seed leaves)	occasionally fragments of epidermis with scarred hairs	long cells, many stomata, no hairs or resin ducts	short cells; few stomata; short conical, curved hairs, or round scars
Parenchyma cells and crystals	–	occasionally; with crystals (cystoliths)	no crystals	–
Wood cells	–	–	narrow	wide
Ash	–	occasionally apparent crystals		apparent crystals
Lignification of raw fibre	none	very slight	slight	slight
Swelling in cupram. hydroxide	forms balls and barrels between rings and spirals	uniformly; proto-plasm mostly as folded ribbon, possibly pieces, and protruding	uniformly proto-plasm as wavy thread	middle lamella as folded ribbon

Adapted from Luniak, B., *The Identification of Textile Fibres*, Sir Isaac Pitman and Sons, London, UK, 1951.

Table 1.18 (continued)

	Sunn hemp	Jute	Jute substitute*	Manila hemp
Length (mm)	0.5–4.5–7–12	0.8–2–8	1–5–12	2–5–12
Thickness (μ)	13–20–30–50	5–15–25–32	10–20–40	10–25–50
Longit. view	similar to flax	rarely cross-markings, nodes, or fissures; lumen considerably varying in size along the same fibre		smooth cross-markings rare, but possible
Fibre ends	rounded tips	rounded tips; partly pointed	rounded tips	pointed or rounded tips
Cross-section				
Bundle	similar to flax	fibre bundles of varying size; roundish or elongated		1. roundish, slightly indented 2. round to elliptical
Ultimate fibre	polygonal with rounded corners; thick walls; parenchyma cells thin walls often curved	mainly sharply polygonal; also rounded corners and oblong; wall thickness varying	similar to jute; also parenchyma cells – round with relatively thin cell wall	polygonal, slightly rounded corners cell wall medium to thick; some cells with thin, curved walls
Lumen	small, oblong parenchyma cells also large, curved or flat	round to oval; size considerably varying	similar to jute; parenchyma cells large lumen	round, small to medium; some cells large to medium
Adhering plant fragments Epidermis	layer with stomata and strips with small cells; layer with flat cells; numerous hairs, long, pointed, not scarred			epidermis of leaf on upper side few, on lower side many stomata; cells rectangular
Parenchyma cells and crystals	no crystals	rarely parenchyma cells	thin-walled, heavily lignif.; crystals (except Bimlip.)	rarely crystals and nundles of crystal needles
Wood cells	wide			rare
Ash			apparent crystals (except Bimlip.)	stegmata (rarely apparent crystals)
Lignification of raw fibre	slight	heavy	heavy	heavy
Swelling in cupram. hydroxide		slow, mostly uniform, spirals, possibly balls. Possibly also middle lamella as a folded ribbon		slow, mostly uniform, partly between spirals, possibly also balls

* Kenaf, roselle and urena.
Adapted from Luniak, B., *The Identification of Textile Fibres*, Sir Isaac Pitman and Sons, London, UK, 1951.

Sisal henequen	Cantala	Mauritius hemp	New Zealand hemp	Sansevieria
0.8–2.5–4.5–7.5	1.5–2.5	1–6	2–6–15	1–4–7
7–24–47	10–24–32	14–21–42	5–14–25	13–24–40
smooth	smooth	smooth; cross-markings rare, but possible	smooth	smooth
rounded tips (seldom forked) poss. pointed	rounded tips	rounded tips	pointed tips also rounded	rounded tips
1. crescent to horse-shoe, often split 2. few or no hemi-concentrical bundles with cavities 3. round, elliptic	1. mainly hemi-concentric with cavity 2. crescent 3. round to elliptic	1. crescent to horse-shoe, often split 2. round to elliptic	1. like molar-tooth, often split 2. round to elliptic	1. crescent, often with xylem and cavity between fibres and xylem 2. round to elliptic
polygonal, wall thick to medium	similar to sisal	polygonal with rounded corners; wall thin to medium, some curved; clear spaces at corners	rounded or almost round; wall mostly thick	polygonal, possibly with rounded corners wall thick (xylem thin wall)
round, variable from large to very small	similar to sisal; large to medium	polygonal with rounded corners, round, some oblong flat	round to oval; small to medium	round, small to moderately wide
net-like cells; many almost quadratic, deep stomata	similar to sisal	similar to sisal	upper side of leaf strips with stomata and long cells alternating; lower side short, broad cells	–
rod or wedge-like crystals	similar to sisal	similar to sisal	rarely crystals	cells with wavy net-like thickening
mostly rare	mostly rare	frequent	mostly few	rare
rod-like apparent crystals	similar to sisal	similar to sisal	rarely apparent crystals	–
heavy	heavy	heavy	heavy	heavy
similar to manila hemp	similar to manila hemp	similar to manila hemp	similar to manila hemp	similar to manila hemp

Table 1.18 (continued)

	Yucca	Aloe fibre	Pineapple fibre	Coir
Length (mm)	0.5–2–6	1–4	2–6–10	0.3–0.7–1
Thickness (μ)	4–12–26	15–25	3–6–13	12–20
Longit. view	smooth	smooth	smooth	smooth
Fibre ends	pointed, rounded (forked)	rounded (possibly forked or pointed)	pointed	blunt or rounded
Cross-section				
Bundle	1. crescent (partly bi-collateral with xylem) 2. round to elliptic	1. crescent 2. round to elliptic	1. crescent wide open, often split 2. round to elliptic	round, mostly with cavity (hemiconcentrical bundles)
Ultimate fibre	polygonal or slightly rounded corners, thick wall	polygonal or slightly rounded corners, thick wall	polygonal-rounded to oblong-oval; very thick walls (some thin walls)	polygonal to round, also oblong (and curved) wall medium to thin
Lumen	point or line or round to elliptic	polygonal-rounded, modeately wide	point or line (some fibres wide lumen)	polygonal-rounded, round or elliptic large to medium
Adhering plant fragments Epidermis	cells net-like, with large elongated stomata	rectangular cells	cells with curved walls and stegmata	cells with curved walls and stegmata
Parenchyma cells and crystals	crystals, needles and bundles	rarely crystals	–	–
Wood cells	frequent	mostly frequent	mostly frequent	frequent
Ash	apparent crystals of various forms	rarely apparent crystals	stegmata	stegmata
Lignification of raw fibre	heavy	heavy	varying (slight to heavy)	heavy
Swelling in cupram. hydroxide	similar to manila hemp	similar to manila hemp	the slightly lignified fibres swell and dissolve	slightly swelling

Adapted from Luniak, B., *The Identification of Textile Fibres*, Sir Isaac Pitman and Sons, London, UK, 1951.

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