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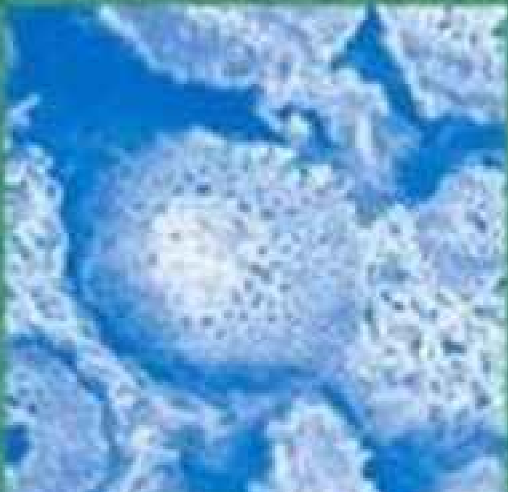

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Edited by Robert R Franck

The Textile Institute

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Edited by
Robert R Franck

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Sándor Cziger was born in 1941, in Dunafóldvár, Hungary. Sándor Cziger studied at the Textile College, the Technical University and the University of Economics, Budapest. He worked at the Hungarian Hemp Trust for many years and was also responsible for R & D at the Textile Research Institute. His last position before retiring was Chief Engineer at the Hird Spinning and Weaving company.

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Doctor Jens Dreyer, born 1966, is a biologist who lives in Hamburg and works as a Post Doctor at the Technical University Hamburg-Harburg in the field of enzyme development and the enzymatic treatment of fibres. His doctorate research at the Institute of Applied Botany at the University of Hamburg examined the biology and agronomy of high fibre *Urtica dioica* L. cultivars, the study of which was first initiated by Prof Dr G. Bredemann in 1927. He started his work on nettles in 1992 and now has a small nettle-fibre company together with two partners.

Gillian Edom works as a field teacher for Chichester Harbour Conservancy, West Sussex. She has been researching the botany of the nettle (*Urtica dioica*) and its uses for over six years and is currently researching for a Master of Philosophy degree in nettle fibre extraction at De Montfort University, Leicester.

Michael Karus obtained his degree in Physics and Mathematics at the University of Cologne and majored in Nuclear Physics and Relativity. After graduating he worked as a teacher at the Universität Tübingen, in the tele-education programme, Ecology, as well as working as a part-time staff scientist at the KATALYSE-Umweltinstitut in Cologne. From 1989 until 1991 he worked as a member of the public relations staff at Flachglas Solartechnik, in Cologne where he focused on solar-thermal power plants. In 1991 he returned to the KATALYSE-Umweltinstitut, where he worked as a staff scientist and department manager, focusing on energy, ecology and electrosmog. He is a founding partner and director of the nova-Institut für politische und ökologische Innovation GmbH, in Hürth, and also manager of their renewable resources, market research and economy departments. Since 2000 he has been the co-ordinator of the European Industrial Hemp Association (EIHA), and since 2002 the Chief Editor of the news portal, www.renewable-resources.de.

Professor Ryszard Kozlowski graduated in Applied Chemistry at the University of Poznan in 1961. He did his Ph.D. in the area of the biochemistry of retting of flax and hemp. He went to work at the Institute of Natural Fibres, where he is now General Director. He was awarded the degree of Professor of Technical Science at Poznan University in 1990.

In addition to his work at INF, Professor Kozlowski is co-ordinator of the FAO/ESCORENA Research Network on Flax and other Bast Plants and a member of several international organisations, including the Society for Sustainable Agriculture and Resource Management (SSARM) and the American Association for the Advancement of Science (AAAS).

Professor Kozlowski has received a number of awards for his research in the field of natural fibre resources, such as the Officer Cross of the Order of Restoration of Poland in 2000. In 2004 he received recognition from the American Chemical Society, Division of Polymer Chemistry for five years involvement and input in advancement of polymer science. He has authored or co-authored numerous books and over 250 papers.

K.B. Krishnan graduated (B.E. Mechanical) in 1961 from Madras University. After serving two years as Design Engineer in M/s Textool company, he joined the Lakshmi Machine company in 1963 and served in different positions including General Manager (Engineering), Technical Director-Development (Textiles), and Vice-President. He is, at present, Management Advisor R & D. He specialised in Textile Machinery design at M/s Rieter Machine Works Ltd, Switzerland in 1963–1965 and has published seven papers in the textile field.

He is the Chairman of the Technical and R & D committee of the Textile Machinery Manufacturers Association and a member of the advisory committees of other research organisations such as SITRA, BTRA, ATIRA, and NITRA and is also a Member of Council of the Textile Institute, Manchester, UK. He is the Chairman of the Spinning Preparatory, Spinning Doubling Machinery Sectional Committee TX of the Bureau of Indian Standards.

P.M. Mathai is a graduate physicist and was awarded the Secured First Rank and Gold Medal of the Coir Technology Course conducted by the Coir Board of India. He was then appointed to the Coir Board as Quality Control Inspector and promoted to Controlling Officer of this department. After years of experience Mr Mathai was appointed Deputy Director and was, in particular, resposible for recommending prices for Coir products to the Indian Government (at that time the government operated a scheme of minimum export prices). He was also responsible for preparing and implementing various schemes concerning the industry and was a visiting faculty member and external examiner of the National Training and Design Centre of the Coir Board of India. He was then promoted to the Joint Directorship and posted as Regional Officer responsible for the activities of the board in twelve states of the Republic of India. A short time ago he took voluntary retirement from his Coir Board activities and is now the General Manager of a major Coir company that is 100% export orientated.

Jörg Müssig obtained his degree in Mechanical Engineering at the Gerhard-Mercator University in Duisburg in 1995 and his doctorate from Bremen University in 2001.

After graduating in 1995 he joined the Faserinstitut Bremen e.V. From 1996 until 1996 he was a member of the 'New materials' working group of the Academy for the study of the consequences of scientific and technical advances at Bad Neuenahr-Ahrweiler GmbH, Germany. From 1998 to 2001 he carried out research in the areas of composites and fibres at the Department of Material Science of Bremen University and in 2001 rejoined the Faserinstitut Bremen as leader of the Bio-based Materials/Sustainability department.

Since 2000 he has been a member of the 'Quality' working group of the German Association of Natural Fibres (DNV) and of the 'Natural fibre composites' working group of the 'Consortium of reinforced plastics – technical federation' (AVK-T). Since 2001 he has been a member of the European co-operative research network on flax and other bast plants (Italy) and since 2002 of the sustainable composites network (GTB).

Since 2004 he has been an appointed member of the Young Academy at the Berlin-Brandenburg Academy of Sciences and Humanities and the German Academy of Natural Scientists Leopoldina.

Jack Salmon-Minotte is General Secretary of the Confederation Européenne du Lin et du Chanvre and Director of 'Masters of Linen' (the promotional organisation of European Linen). He is also a Graduate of the Ecole Superieure des Techniques Industrielles et Textiles (Villeneuve d'Asq, France) also of the Université Dauphine, Paris, in Business Studies.

Jack joined the French Linen Industries Trade Association after working for two years in the apparel sector and six years in a subsidiary of the Empain-Schneider group. He is a member of the Flax and Hemp Group of the European Commission and a Member of the Board of 'Expofil' (the yarn trade exhibition).

Jenó Sponner was born in 1937, in Moson, Hungary, and studied at the University of Economics, Budapest. After graduating he joined the Hungarohemp Magyar Kenderipari Tröszt (Hungarian Hemp Trust). During his 42 years with this organisation, at first as an economic analyst, then as a factory director, he became Deputy General Manager of the Trust. He was then appointed General Manager of Elsó Magyar Kenderfonó in Szeged, the largest Hemp company in Hungary.

László Tóth was born in 1926, in Szeged, Hungary in 1926 and studied at the Textile College, Szeged and the Technical University, Budapest. He then joined the Hungarian Hemp Trust (cotton spinning and weaving), became Director of the weaving factory and subsequently R & D Director. He was then appointed General Manager of the Trust in Szeged, a position he held for 23 years.

Chongwen Yu was born in 1962, Ph.D, Professor and Head of Dept. Textile Engineering, College of Textiles, Donghua University, Shanghai, China. He has a Bachelor's degree in Textile Engineering, China Textile University (1980–1984), and a Master's degree in Textile Engineering (1987), China Textile University (1984-1987). He obtained a Ph.D. in Textile Engineering, China Textile University (1990–1994). He was Visiting Scholar, North Carolina State University, 1997–1998, and Associate Chairman of Bast and Leaf Fiber Processing Committee of China, Associate Chairman of New Spinning Committee and a Member of Standard of Textile Product Committee (Bast and Leaf Product Group) of China. He is a Member of the Fiber Society of the USA.

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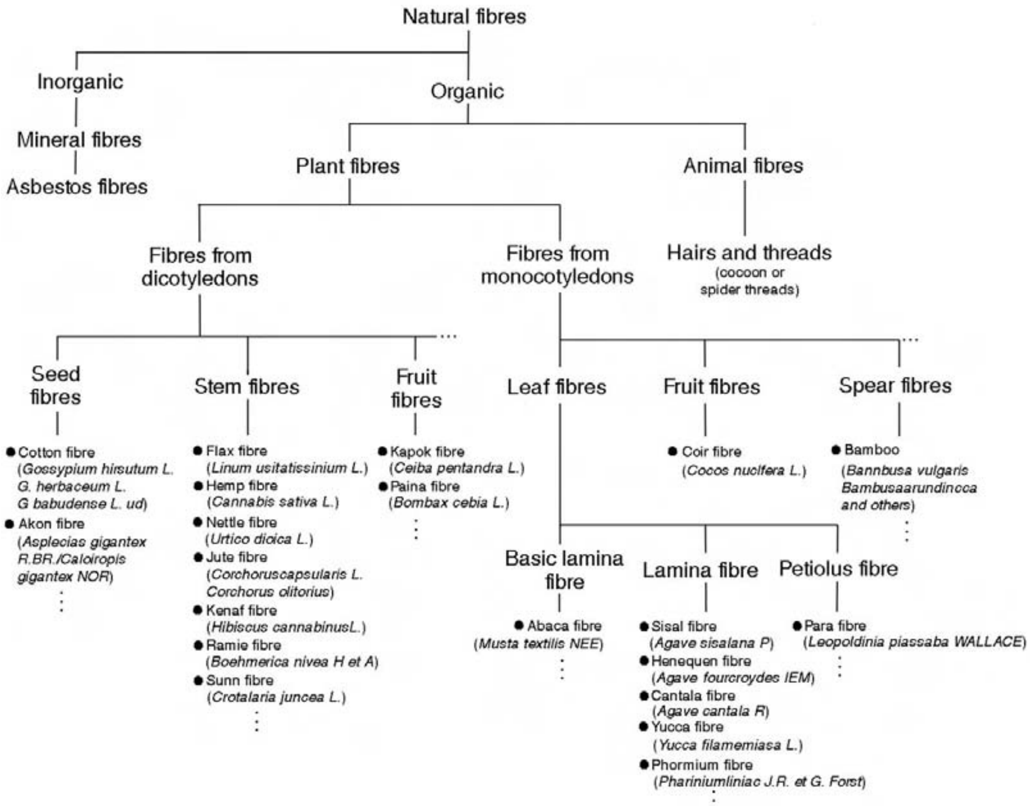

Overview of natural fibres (Müssig, 2001, reproduced with permission).

1
Overview

R R FRANCK

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; protoplasm mostly as folded ribbon, possibly pieces, and protruding	uniformly protoplasm 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 7–24–47 smooth	1.5–2.5 10–24–32 smooth	1–6 14–21–42 smooth; cross-markings rare, but possible	2–6–15 5–14–25 smooth	1–4–7 13–24–40 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 rod-like apparent crystals heavy	mostly rare similar to sisal heavy	frequent similar to sisal heavy	mostly few rarely apparent crystals heavy	rare – 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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2
Jute

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2.1 Introduction

Jute is grown mainly in India, Bangladesh, China, Myanmar, Nepal and Thailand. The total area under cultivation, yield and total production of jute/mesta[1] in these countries are given in Table 2.1 (see also Appendix B on page 82). These figures cover the total production of 'jute and similar' bast fibres, which are: white jute (*Corchorus capsularis*), tossa jute (*C. olitorius*), kenaf (*Hibiscus cannabinus*) and rosella (*H. sibdoriffa*). Abaca (*Musa textilis*) is not included as the fibre is obtained from the leaf sheath of the plant and is therefore not a bast fibre. India and Bangladesh account for more than 93% of the jute fibres produced all over the world.

There are over thirty *Corchorus* species but only two of them are widely known, *Corchorus capsularis* (white jute) and *Corchorus olitorius* (tossa jute) These are commercially grown in Bangladesh, India and Nepal. Kenaf and mesta (rosella or roselle), the other fibres allied to jute, are grown in China and Thailand. Mesta is also grown and is commercially important in India and Thailand. White and tossa jute cannot normally tolerate water-logged conditions but can be grown on high land that is normally subject to flooding.

Jute is mainly used for manufacturing products for the packaging of grains, sugar, cocoa, coffee and other food crops as well as for cement, fertilisers, salt, cotton, etc. These, i.e., hessian (burlap) and sacks, currently account for 80% of

Table 2.1 Area, yield and total production of jute/mesta in major producing countries (season 2001–2002)

	India	Bangladesh	China	Myanmar	Nepal	Thailand
Particulars						
1. Area ('000 hectares)	980.0	519.6	52.0	53.5	11.3	19.2
2. Yield (tons/hectare)	1.93	1.78	2.62	0.95	1.45	1.54
3. Production ('000 tons)	1890.0	924.7	136.0	50.8	16.4	29.5

Source: JMDC – *Indian Jute* Vol. XIII, No. 1, June 2003, Courtesy: FAO Statistics.

jute production. The use of jute fabrics as carpet backing is a later addition in jute products and accounts for about 15% of the world's fibres consumption. Other uses of jute include carpet yarn, cordage, felts and paddings, decorative fabrics and other items for industrial use.

Raw jute production was originally concentrated in eastern Bengal which, after the partition of the Indian Sub-continent in 1947, became East Pakistan and later in 1971 became an independent country, Bangladesh. After partition measures were taken in India to increase the production of raw jute in order to supply raw material to its jute mills. The expansion of Indian jute production together with the growth in kenaf production in China during the 1950s are largely responsible for the fall in the share of Bangladesh's total world production from 80% in 1949/50 to 35% in 1969/70 and to 25% by 1979/80.

Although jute has been an economically[2] important crop in Bangladesh and India it has, to some extent, lost its past importance in the economy of these countries, although it still has a high socio-economic value. As an important cash crop of the region it contributes to the economy of these countries in various ways. In agriculture as well as in industry, in both these countries, jute directly and indirectly supports employment, commerce and other economic activities. There are 76 jute mills in India with installed capacity of 45,012 looms and in Bangladesh there are 72 jute mills with installed capacity of 26,020 looms. In Bangladesh the jute sector provides about 10% of total employment, 12% of gross domestic product (GDP) and around 30–35% of total export earnings. In India, the jute sector provides about 1% of total employment in the organised sector and 0.5% of GDP and 0.5% of export earnings.

However, in Bangladesh and India about four million farm families cultivate jute as an important cash crop. In India, the jute industry provides employment for about 2.5 million workers and marketing and related activities provide employment for another 1.5 million. (This does not include the ten million hand loom weavers mentioned in Sections 5.2 and 5.3.) In Bangladesh about 227,000 workers and 25,000 management and staff are employed in the jute industry. Allied trades, industries and services such as marketing, transportation, etc. provide employment for millions more.

Jute and jute products occupy an important place as a foreign exchange earner, particularly in the case of Bangladesh. Prior to independence jute was the principal source of Pakistan's foreign exchange. After independence jute provided about 84% of Bangladesh's total foreign exchange but although there has been since then a gradual but noticeable decline, jute still provides about 30–35% of the country's foreign exchange earnings. Jute is also a source of revenue for the Governments of India and Bangladesh. The Indian government receives annually more than Rs.640 million (US$13.3 million) by way of taxes and levies while the West Bengal Government's share under sales tax alone amounts to about Rs.120 million ($2.5 million) per year.

Table 2.2 World apparent consumption of jute, kenaf and allied fibres (2000)

Country	Consumption ('000 tonnes)	Country	Consumption ('000 tonnes)
Developing countries			
Africa	51.2	Iran	62.4
Algeria	8.9	Sudan	44.0
Ghana	5.3	Syria	39.2
Kenya	2.7	Turkey	56.8
Morocco	1.6	Bangladesh	148.5
Tanzania	3.2	China	131.2
Zimbabwe	0.9	India	1629.4
Argentina	3.2	Indonesia	7.7
Brazil	22.8	Pakistan	75.2
Mexico	1.8	Myanmar	30.1
Egypt	24.0	Thailand	36.1
Vietnam	8.3		
		Total	2394.5
Developed countries			
United States	74.0	Spain	12.3
Belgium–Luxemburg	72.4	United Kingdom	28.3
France	10.9	Australia	50.6
Germany	13.4	New Zealand	17.3
Holland	14.2	Japan	28.0
South Africa	7.5		
		Total	328.9
Total world: 2723.4			

Source: JMDC – *Indian Jute* Vol. XIII, No. 1, June 2003, Courtesy: FAO Statistics.

World apparent consumption of jute, kenaf and allied fibres[1] is given in Table 2.2. According to the available statistics, world production of jute goods works out to about three million m tonnes (Table 2.3). Of this India accounts for about 50% followed by Bangladesh and China which account for 17% each.[1] [*Editor's note*: further information relating to jute's allied fibres is set out in appendix A.]

The statistics given in Tables 2.1–2.3 are difficult to reconcile and the differences between the totals shown are due to three factors.

1. Some countries, especially India, export fibre as well as jute goods. This shows as a lower figure in the tonnage of their apparent consumption and of jute goods produced in these countries, compared to their production of fibre.
2. Waste is produced in processing from fibre, through yarn to fabric and other jute goods, which will also show as a lower figure of goods manufactured compared to fibre produced.

Table 2.3 World production of jute goods (1995)

Country	Production ('000 tonnes)	Country	Production ('000 tonnes)
Developing countries			
Africa	41.3	Brazil	23.7
Nigeria	1.9	Cuba	10.7
Egypt	21.4	Iran	5.0
Bangladesh	524.4	China	535.0
India	1506.2	Indonesia	10.7
Myanmar	28.7	Nepal	16.0
Pakistan	76.9	Thailand	101.6
		Others	42.4
		Total	**2945.7**
Developed countries			
Greece	2.1	Hungary	1.0
Belgium--Luxemburg	2.1	United Kingdom	10.7
France	3.2	Poland	4.2
Germany	3.2	Japan	10.7
Italy	1.1	Portugal	2.1
		Others	22.7
		Total	**63.1**
Total world: 3008.8			

Source: JMDC – *Indian Jute* Vol. XIII, No. 1, June 2003, Courtesy: FAO Statistics.

3. In the production of jute goods jute fibre is sometimes blended with other fibres such as cotton, polyester, viscose, acrylic, etc. This will appear in the statistics as an increase in the weight of goods manufactured when compared to fibre produced or apparently consumed.

The present situation can be summarised as follows: production of jute fibre, 3027.4 million tonnes; consumption of jute fibre, 2816.8 million tonnes; production of jute goods, 3000.8 million tonnes.

2.2 Fibre production and early processing

2.2.1 Jute and allied fibres

Jute is the common name given to fibres extracted from the stems of plants belonging to the botanical genus *Corchorus*. Although over 40 wild species are known, only two, viz., *C. capsularis* L. and *C. olitorius* L. are cultivated commercially. Within the jute manufacturing industry, *C. capsularis* is known as 'white jute' and *C. olitorius* as 'Tossa' jute.

There are many plants similar to *Corchorus* that grow in the tropics and subtropics, and from which fibres can be extracted from the stem.[3] The plants are all woody-stemmed herbaceous dicotyledons, having the fibre located in the bast, between the epidermis and the woody core. The most important of these from the point of view of textile fibres are two species of the genus *Hibiscus*, viz., *H. cannabinus* L. and *H. sabdariffa* L., both of which are commonly referred to as kenaf, although *H. sabdariffa* L. is, more correctly, rosella.

Hibiscus species are more tolerant of variations in growing conditions than jute, and many countries, especially in Africa and Asia, grow kenaf as a preferred crop, usually for internal use only, the international market for Kenaf being quite small. A third plant of similar type, Urena lobata L., grows well in Africa but the fibre is not often seen on the international market. All fibre-bearing plants have their own distinctive botanical attributes, but the fibres extracted from them are markedly similar to one another in appearance and are not readily distinguishable from jute itself. They are all suitable for converting into yarn on jute spinning systems and in marketing statistics are often grouped together as 'jute and allied fibres'.

'White' jute (*Corchorus capsularis*) which is usually golden yellow, is one of several closely related types in textile use.[4] The cell wall of the fibre varies in thickness. The fibres are coarse, generally 20–25 μm in diameter; the length of the ultimate fibres is only 1–5 mm. Spinnable fibres are composed of ten or more ultimate fibres placed in overlapping fibre bundles joined together by non-cellulosic material, usually lignin. Though jute is a strong fibre, its very low extensibility results in stiff, non-stretchy fabric. In developing countries, jute is much used for woven hessian, sacks, packaging and tarpaulins. Figure 2.1 shows a

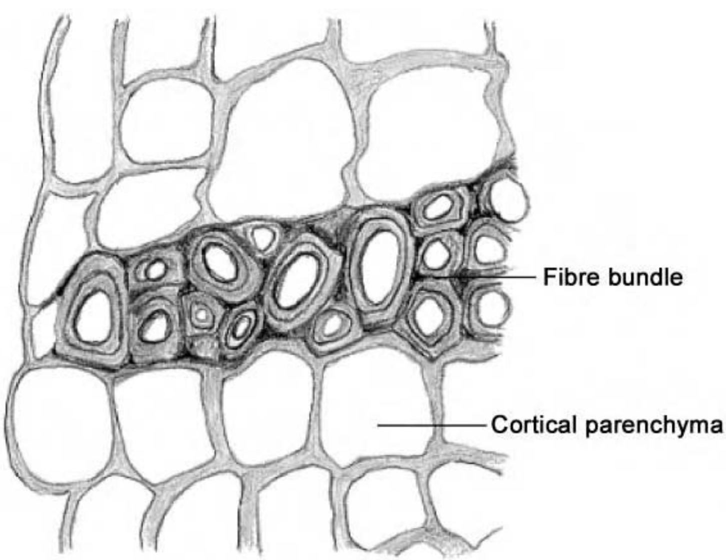

Figure 2.1 Cross-section through jute fibres ($\times$640). Source: Gesamtverband der Deutschen Versicherungswirtschaft. Courtesy: www.tis-gdv.de.

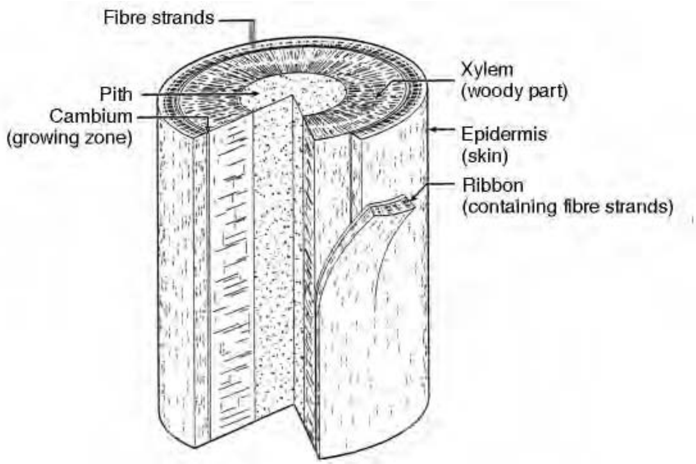

Figure 2.2 Diagram of the anatomy of a jute stem. Source: C. Jarman, *Plant fibre and processing: A handbook*. Courtesy: Intermediate Technology Publications, UK.

line drawing of a cross-section of *C. olitarius* (tossa jute) fibres. Figure 2.2 is a diagrammatic illustration of a jute stem showing the positions of the fibre bundles.

Jute is mainly cultivated in India, Bangladesh, China, Nepal, Thailand, Indonesia and a few other South-East-Asian countries. It can be cultivated under quite a wide variety of conditions but for ideal growth it requires a high level of humidity (40–97%). The ideal temperature lies between 17 and 41 ºC with an amount of precipitation of 1500 to 2000 mm per year. The pure fibre content of the unretted plants lies between 4.5 and 7.5%. About 90 to 120 days after sowing the stems may be harvested and water retted. In the process the stems are carefully sorted according to thickness and the lower, very wooden part of the stalk is cut off. The fibre bundles of this part of the stems are called 'cuttings' and cannot be used for fine yarns due to their coarseness. After retting the stems are decorticated and the fibre bundles are washed and dried.[90]*

2.2.2 Kenaf and roselle (see also Appendix A on page 78)

These two species produce similar fibres and they are processed in the same way as jute. The mean fibre diameter of kenaf is 20 μm (Fig. 2.3 – magnification 640×) with a range from 12–36 μm. Ultimate fibre length may be from 2–6 mm. Kenaf is more lustrous, harder and stronger than jute and is lighter in colour. Kenaf is used to make rope and string, coarse fabrics, mats and carpets.

The potential development of the use of jute and kenaf fibres in composite materials is discussed in Chapter 10.

Even though the kenaf plant is grown and used in many countries, in an inter-

* J. Müssig, private communication, 2004.

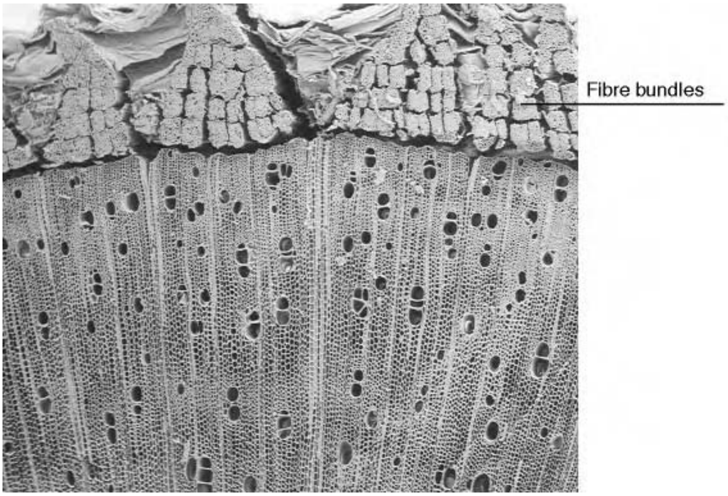

Figure 2.3 Photomicrograph of cross-section of kenaf stem (×20). Courtesy: Roger M. Rowell, Forest Products Laboratory and University of Wisconsin.

national comparison its cultivation is clearly on a smaller scale than that of jute. Kenaf requires less water to grow than jute plants do; it is cultivated in Europe, South America, Mexico, USA, Japan and China. With about the same stalk length of 2.5–3.5 m, kenaf needs many hours of light per day for its vegetative growth and in terms of soil quality and climate it can be cultivated in a broader variety of soils and climates than jute.[91] The fibre content is stated at 15 tons/year/hectare.[92] According to the Rowell and Stout report, the precise time of harvest is of decisive importance for ideal fibre quality. Ideally the kenaf plant should be harvested when about 10% of the buds are in bloom. After harvesting the stalks are retted. This must be done with great care if good quality fibres are to be obtained.[91]*

2.2.3 Retting and fibre extraction (decorticating)

Before fibres such as jute can be extracted from the plants, they need to undergo a process called retting. This is required to eliminate the gummy substances which cement the fibre to the rest of the tissues in the stem, and to each other. In the case of jute and allied fibres this involves steeping the stems in water, where enzymes produced by bacterial action remove the pectin and gummy materials, after which the fibres can be stripped from the woody core. The fibres are then washed and hung out to dry before being taken to the local market for sale to balers and exporters.[6] Retting takes between 10 to 20 days, or more depending on the water and on its temperature. Extraction of the fibres from the retted stalks (decortication) is, in the case of jute and similar fibres, still usually done manually (Fig. 2.4).

* J. Müssig, private communication, 2004.

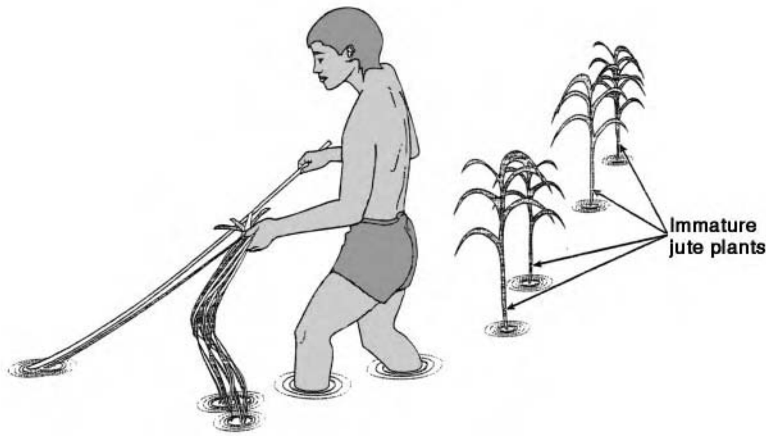

Figure 2.4 Manual stripping of jute fibre from retted stem. Source: C. Jarman, *Plant fibre and processing: A handbook*. Courtesy: Intermediate Technology Publications, UK.

Mechanical decorticators of the kind mentioned in section 2.2.4 are not yet commonly used. In manual decortication the fibres are stripped from the woody core of the stem using knives. In the retting process, the thicker parts of the stem take longer to rett than the thinner parts. Consequently, if the butt end of the stem is correctly retted, the apex will be over-retted and may suffer damage. Retting is therefore terminated when the main part of the stem is adequately retted, and, if necessary, fibre from the butt end, which may still have pieces of bark adhering to it, will be cut off and processed separately from the 'long jute' as 'cuttings'. The various factors affecting retting of jute and mesta are types of water, temperature, pH and macro-nutrients.

Water appears to be the most important of the various factors affecting retting. An abundant supply of clean water is a prerequisite for proper retting. Retting in slow-flowing water produces the best fibre.[7,8] In stagnant water, the products of the fermentation process accumulate near the stems and tend to affect the colour and lustre of the fibre, whilst in slow-flowing water these are removed by the current before they can produce any adverse effects and the fibre appears very bright and glossy. In faster, running water, retting is adversely affected. The inside bundles of the stack of stems, or 'juck', ret faster than the outer stems and this produces fibres of uneven quality.[9] For satisfactory retting, the stem-to-water ratio should be around 1 : 20. Retting is quicker in soft than in hard water and the colour and lustre of the fibre is remarkably improved by immersing the stack under water with bamboo poles and coir ropes. Concrete slabs as weights also give excellent results.

A temperature of 34 ºC with a pH value in the range of 6.0 to 8.0 is the optimum for good retting. Various chemicals, particularly nitrogen and phosphorous compounds, have been tried to boost the retting of jute and nitrogenous compounds and have proved to be the best stimulants. In general, cations such as NH_4, K, Ca and Mg and anions such as SO_4, NO_3 and PO_4 have beneficial effects while chloride ions at high concentrations slow the process down.

Conventional and ribbon retting: advantages and disadvantages

In conventional retting, whole stems are steeped in water, but in ribbon retting only the ribbons of green bark extracted from the stems are immersed in water. These ribbons are removed from the stems after harvesting in the fields. From four to six stems are decorticated manually at the same time. This produces a ribbon-like bundle of long fibres whilst decorticating after the conventional retting process produces fibres of between 15 cm to 25 cm in length. The quantity of water required for ribbon retting is much less than for the conventional method.

Ribboning of an entire jute stem is not possible; some of the bark always remains on the stem, especially at the top of the stalks. Any ageing of harvested stems further aggravates this loss of bark on ribboning because a certain amount of fibre always remains stuck to the bark. During the vegetative growth phase, jute plants may be attacked by insects, apion in particular, and it has been found that apion infected jute stems also entail an additional loss of bark during ribboning. Besides, the amount of labour involved in the whole process of ribboning is really forbidding. About one man day is required to ribbon three bundles of jute stems, which yields only 6.5 kg of raw jute. The disadvantages of the ribbon retting of jute so far observed are: longer retting period indicating poor rettability of jute ribbon;[11] heavy loss of fibre strength; loss of fibre yield (19–30%); downgrading of fibre quality; entanglement of retted fibre during washing and high labour cost.

On the other hand, transport costs are lower for ribbon retted fibre, retting takes less time, fibre quality is improved, pollution is much reduced and less water is required in comparison with conventionally retted fibre. The comparison between stem and ribbon retting is shown in Table 2.4.[12] For a detailed account of recent improvements in retting techniques readers are referred to Appendix C on page 83.

2.2.4 Machinery for jute decorticating

The Jute Agricultural Research Institute, Barrackpure, West Bengal has developed a decorticating machine[15] for the mechanical extraction of jute fibres. The machine is designed to extract and scrape out barky material from the stems of bast fibre crops such as jute, mesta, sunnhemp, urena, etc. The machine breaks down the inner woody cores of the stems into pieces and scrapes the bark, especially at the root ends of the stalks. The production of commercial fibres by

Table 2.4 Comparison between stem retting and ribbon retting process

S. No.	Criteria	Procedure	
		Stem retting	Ribbon retting
1.	Transport	Whole stalks carried to the pond	Ribboning done at the field, only ribbon (40% of stem) to be carried
2.	Retting period	10–20 days or more	7–10 days
3.	Pond volume required	435 m^3/ha of crop: (120 days)	Less than 100 m^3/ha of fibre crop; (120 days)
4.	Retting arrangement	Need stakes, cover & weights, if soil is used, fibre quality is reduced	Very convenient, ribbons submerge by themselves, no weights needed, only a support preventing contact with mud
5.	Fibre extraction	Needs stripping and washing, slow (60–90 man-day/ha)	Only washing required
6.	Fibre quality	Lower quality, barky hard ends requiring 'cuttings'	Superior quality, barky ends minimised
7.	Quality of sticks	Long sticks obtained, easy to handle, structural uses possible	With decorticator use, sticks are broken. Ribboners yield long sticks
8.	Plant nutrient loss	Large qualities removed with stalks	Returned to soil if the cores are incorporated to the soil
9.	Impact on environment	Over 10 tonnes/ha of organic matter released, excessive water pollution	Only 3 tonnes/ha of organic matter released, water pollution minimised

Source: Mitra, B C, *Data book on jute*, January 1999. Courtesy: National Institute of Research on Jute and Allied Fibre Technology (NIRJAFT), Kolkata.

these machines requires only five or six days including retting. The capacity of the machine is about a tonne of green jute plants per hour with a 5 hp prime-mover. Five men are needed to operate the machine, two for feeding stems into the machine and three for arranging, bundling and steeping of the extracted material. If required the capacity of this machine can be increased.

The best stage in the growth of the plant for decortication is at 115 $\pm$ 10 days after germination. Decortication should be done immediately after harvesting and can be continued for two to three days if the stalks are kept under cover. Defoliation is not necessary before feeding the stems into the machine. The plants are fed into the machine butt-end first. Two to eight plants are fed into the machine at a time, depending upon their diameter. It has been found that the optimum diameter for decortication by these machines is around 12 mm.

Improved results are obtained if the stalks are sorted into two groups; one group of 12 mm diameter and below and the other of 12 mm and above.

2.2.5 Fibre sorting for quality

After retting and decorticating,[90] various fibre qualities are used in trade that differ particularly in the properties of colour, fineness, strength, density, root proportion and tendering. Both types are sorted into a total of eight categories in India: 'tossa jute' (TD1 to TD8) and 'white jute' (W1 to W8). In Bangladesh 'white jute' and 'tossa jute' are divided into five classes (A to E). According to Rowell and Stout[91] the classification of fibres still takes place using organoleptic methods but as the classification systems are different in each country international comparison is difficult.*

2.3 Physical and chemical properties

2.3.1 Physical properties

Jute and kenaf are strong fibres, exhibiting brittle fracture, but having only a small extension at break. They have a high initial modulus, but show very little recoverable elasticity. Tenacity measurements recorded in the literature vary widely, and although some of this variation is due to differences in the methods of measurement, a major part arises from variation in linear density of the fibres themselves.†

Taking into account all the available evidence, a tenacity of 70 g/tex is a reasonable middle value for a wide range of jute fibres, based on single fibre test lengths of 10 mm or less and a time to break of 10 sec. This value of tenacity is appropriate to fibres of linear density 1.8 tex, and it is important to state the linear density, for statistically an increase of 0.1 tex reduces the tenacity by about 1.5 g/tex. This inverse dependence of tenacity on linear density is common to most fibres and also to fine metal wires.

The elongation at which a fibre breaks is a more invariant and fundamental property than the load at which it breaks. It is not affected significantly by changes in linear density, nor by changes in the method of loading. Length of test specimens does have an effect, however, as irregularities in diameter prevent all sections of a long fibre from being elongated equally. For test lengths of 10 mm the elongation of the jute fibres is generally between 1 and 2% of the initial length, but is difficult to measure accurately on such short lengths. In one particular case, 500 fibres from a bulk of medium-quality jute had a mean elongation of 1.60% (of the 10 mm test length) with a coefficient of variation

* J. Müssig, private communication, 2004.

† See also the tables in the appendix to Chapter 1 for further published data on the physical characteristics of jute fibre.

(CV) of 25%. The breaking load[16] of the fibres, however, had the much higher CV of 40%. It may be noted that 1.6% elongation corresponds to a spiral angle of 10º12′, which although slightly greater than the Herman's angle reported is still within the uncertainty of the comparison.

The initial Young's modulus of the fibres, calculated from the slope of the load-elongation curve, has a mean value of about 4×10^3 g/tex/100% extension. The value for any particular group of fibres will, of course, be dependent on the linear density, to some extent owing to the dependence of tenacity values on this factor. The bending of jute fibres has been studied by Kabir and Saha, who calculated the Young's modulus from measurements of the force required to deflect the free ends of a fringe of fibres arranged in cantilever fashion.[17] For this calculation it is necessary to know the fibre diameter instead of the linear density and this causes a difficulty because the cross-section of the fibres is irregular in outline and often far from circular. The authors assumed an elliptical configuration and measured minimum and maximum diameters of a number of cross-sections microscopically for insertion in the appropriate formula. Their calculations showed that over a wide range of commercial fibre qualities, Young's modulus decreased from about $2.0 \times 10''$ dynes/cm^2 at 46 μm average diameter, to $0.8 \times 10''$ dynes/cm^2 at 68 m. These values correspond to 3050 and 815 g/tex/100% extension, respectively and again demonstrate the marked effect of variations in fibre dimensions. Extrapolations of Kabir and Saha's data to smaller diameters show that the tensile value for the modulus of 4000 g/tex/100% extension would be reached at a mean diameter of about 40 μm.

Young's modulus may also be calculated from the fundamental frequency of transverse vibration of a single fibre fixed at one end as a cantilever. For a variety of bast fibre types, including jute and kenaf, the modulus lies between 3 and $8 \times 10''$ dynes/cm^2, and for jute fibres appears almost independent of diameter, unlike the tensile values.[18] In making these dynamic measurements, it was found that each fibre had two resonant frequencies corresponding to vibration along the major and minor axes of the cross-section respectively. The extent of the difference between the two frequencies gives an indication of the departure from a circular outline.

Kabir and Saha also examined the effect of delignification on the bending modulus of jute, using the fringe technique, and showed that successive extractions of lignin on the same fibres resulted in increasing flexibility and decreasing Young's modulus.[19] The delignification method used was treatment with sodium chlorite solution followed by extraction with sodium bisulphate; the removal of 10% of lignin reduced the modulus from 1.10 to $0.79 \times 10''$ dynes/cm^2. At the same time, however, the diameter of the fibres was reduced significantly and this may have affected the flexibility. Physical properties of jute fibres are set out in Table 2.5.[20]

When buried in soil, incubation tests have revealed that the jute fibres and similar fibres retain their tensile strength to a much higher degree, at about well

Table 2.5 Physical properties of jute fibres

Sl. No.	Property	White jute	Tossa jute	Roselle
1.	Unit cell length (mm)	0.8–6.0	0.8–6.0	2.0–11.0
2.	Length/breadth ratio	110	110	140
3.	Hermann's Angle of orientation (X-ray)	7°–10°	7°–9°	9°–12°
4.	Specific gravity	1.4–1.45	2.00–5.00	3.50–5.50
5.	Moisture regain (%) at 65% RH	12.5	12.5	13.0
6.	Transverse swelling (%) in water	20.0–22.0	20.0–22.0	20.0–22.0
7.	Tenacity – single fibre (g/tex)	27–36	16–35	16–40
8.	Elongation at break (%)	1–1.5	1.0–2.0	1.0–2.0

Table 2.6 Strength loss in jute due to soil burial

Type of jute	% retention of tensile strength after soil burial for 3 days
White jute	56.3
Tossa jute	68.3
Roselle	86.5

over 50%, when compared to other fibres such as pineapple and sisal. Natural fibres lose strength when buried in the ground due to the growth of micro-organisms. The micro-organisms play a predominant role in the degradation of fibre cellulose by the secretion of enzyme cellulose, the ultimate result of which was the loss in tenacity values (Table 2.6).

The high retention of the tensile strength of the *Hibscus* genus fibre, roselle (mesta) in comparison with the two *Corchorus* genus fibres (white and tossa jute) may be due to the fact that roselle has a higher length to breadth ratio and also that its Herman's angle of orientation by x-rays is higher; roselle's is 9° to 12° whilst that of the jute fibres is around 7° to 9°.

2.3.2 Fine structure

The locations of the three main chemical components of the fibres are reasonably well established. Alpha cellulose forms the bulk of the ultimate cell walls with the molecular chains lying broadly parallel to the direction of the fibre axis. The hemicellulose and lignin, however, are located mainly in the areas between neighbouring cells, where they form the cementing material of the middle lamella, providing strong lateral adhesion between the ultimates. The precise nature of the linkages that exist between the three components and the role played by the middle lamella in determining the fibre properties are incompletely understood. Professor Lewin,[21] some years ago, in an interesting literature survey on the middle lamella of bast fibre, brought together a great deal of relevant information that illuminated many of the problems but a thorough understanding of the intercell structure is still awaited.

X-ray diffraction patterns show the basic cellulose crystal structure but in jute and kenaf, although the crystallite orientation is high, the degree of lateral order is relatively low in comparison with flax. There is also considerable background x-ray scattering arising from the noncellulosic content of the fibre. The cellulosic molecular chains in the secondary walls of ultimate cells lie in a spiral around the fibre axis. The effect of this is to produce double spots in the x-ray diffraction patterns, the centres of the spots being separated by an angular distance of twice the Bragg angle. For large angles, such as occur in coir fibre and some leaf fibres such as Mauritius hemp, the two spots are visibly separated but for the small angles found in jute and kenaf, the spots overlap. In this case the distribution of intensity across the width of the spots, instead of reaching a peak at the centre of each, is spread out into a single flatter, peak. The [002] equatorial reflection shows these effects particularly well and analysis of the intensity distribution allows calculation of the Herman's RMS spiral angle. A wide range of bast and leaf fibres has been examined in this way,[22] with results showing the Herman's angle to range from about 8° for jute and kenaf up to 23° for sisal. Coir fibre, *Cocos nuciferos*, is exceptional in having a Herman's angle of about 45°.

The leaf fibres in this study are particularly interesting because as well as covering a good range of spiral angles, they also cover a wide range of ultimate cell dimensions. The results indicate that among this group of fibres, the spiral structure averages a constant number of turns per unit length of cell, about ten per millimetre, and with this arrangement in the spiral angle then depends solely on the breadth of the cell. Whether this constancy of turns applies to individual cells, or whether as in wood, the longer cells tend to have steeper spirals, was not, however, investigated.

For the secondary bast fibres, the cell dimensions show little variation between plant species, but the number of spiral turns per unit length of cell averages only about four per millimetre, appreciably less than for the leaf fibres. The importance of the spiral angle measurements lies in the control that the spiral structure exercises on the extension which the fibre can withstand before breaking. Regarding the structure as a helical spring, the extension necessary to straighten a spring of initial angle θ, to the axis is $(\sec \theta - 1) \times 100\%$. A 10° spring will thus extend by 1.54%, a 20° spring by 6.4% and a 30° spring by 15.5%.

2.3.3 Chemical properties

Retted fibres such as jute have three principal chemical constituents; alpha-cellulose, hemicellulose and lignin. The lignin can be almost completely removed by chlorination methods in which a soluble chloro-lignin complex is formed and the hemicellulose then dissolved out of the remaining holocellulose by treatment with dilute alkali. The final insoluble residue is the alpha-cellulose constituent, which invariably contains traces of sugar residues other than glucose.

The hemicellulose consists of polysaccharides of comparatively low molecular weight built up from hexoses, pentoses and uronic acid residues. In jute, *capsularis* and *olitorius* have similar analyses, although small differences occur between different fibre samples. For fibre extracted from jute plants grown in Bangladesh, the range of composition has been given as lignin 11.4–12%, alpha-cellulose 58-63% and hemicellulose 21–24%.[23]* In addition, analysis of the hemicellulose isolated from alpha cellulose and lignin gives xylan 8–12.5%, glucoronic acid 3–4%, together with traces of araban and rhamnosan. The insoluble residue of alpha cellulose has the composition glucosan 55–59%, xylan 1.8–3.0%, glucoronic acid 0.8–1.2%, together with traces of galactan, araban, mannan and rahmnosan. All percentages refer to the weight of dry fibre.

As well as the three principal constituents, jute contains minor constituents such as fats and waxes 0.4–0.8%, inorganic matter of 0.6–1.2%, nitrogenous matter 0.8–1.5% and traces of pigments. In total these amount to about 2%. The detailed molecular structure of the hemicellulose component is not known with certainty, although in the isolated material the major part is stated[24] to consist of a straight chain of D-xylose residues, with two side branches of D-xylose residues, whose position and length are uncertain. In addition there are other side branches formed from single residues of 4-0-methyl glucoronic acid, to the extent of one for every seven xylose units.

The third major constituent, lignin, is a long-chain substance of high molecular weight which, like hemicellulose, varies in composition from one type of vegetable material to another. The molecular chains are built up from comparatively simple organic units that may differ from different sources, and also in the way in which they are combined. Most of the studies in lignin have been concerned with wood and the bast fibres have been rather neglected. It seems unlikely, however, any major differences will exist between jute and wood lignin, but in any case many details of the molecular structure still remain unresolved.

2.4 Yarn production

2.4.1 Conventional spinning system and quality of in-process materials and yarn

The most commonly operated jute spinning system consists of two stages of carding, followed by three stages of drawing and finally a spinning stage.[28] The flowchart is shown in Fig. 2.5. In the first carding stage, the long lengths of fibre

* For further published data on the chemical composition of jute fibres see the tables in the appendix to Chapter 1.

Jute reed
|
Softening
|
Breaker card
|
Finisher card
|
Intersecting gill draw frame – I passage
|
Intersecting gill draw frame – II passage
|
Intersecting gill draw frame – III passage
|
Flyer spinning machine

Figure 2.5 Process flowchart for spinning 100% jute yarn. Source: *Indian Jute,* A bulletin published by Jute Manufacturers Development Council, Kolkata, Vol. 12, No. 2, December 2002.

are passed through a breaker card, which breaks the continuous mesh of fibres into separate fragments, conveniently called ‘entities’, which are akin to the single fibres of cotton and wool. In addition to fragmentation, the pins of the breaker card have a cleaning action by removing loosely adhering non-fibrous matter from the fibre proper.

Sliver quality

Sliver from the breaker card is then passed through the second, or finisher card, which causes a little more fibre breakage and provides further opportunity for removal of non-fibrous matter. In addition, the finisher card has an important mixing effect, since a number of slivers are fed to the card in parallel and emerge finally as a single sliver. The quality parameters for the unevenness for carded sliver[29] are given in Table 2.7.

In the three drawing stages, the movement of fibre is controlled by gill pins fixed to faller bars. In modern drawing frames, the faller bars move on spiral screws, although some spinners prefer the push-bar method for the first stage. At all stages, drafting is accompanied by appropriate doubling of the input slivers. The quality parameters for the unevenness of drawn slivers[29] at the drawing stages are shown in Table 2.8. The output sliver from the final drawing stage then passes to the spinning frame, where its linear density is reduced suitably for the yarn being spun, after which the required twist is inserted. Almost universally in the jute industry, the insertion of twist is performed by overhung flyer, with the yarn winding-on to a bobbin rotating on a dead spindle, against a friction drag. Other methods of inserting twist by ring or pot-spinning are available but are little used, and then only for yarns of higher linear density.

Prior to the late 1940s, jute yarn was mainly spun from rove, the output sliver from the third stage of drawing being given a small twist to hold the fibres

Table 2.7 Unevenness for carded sliver (quality parameters)

	Yarn end-use	Product type					
		Hessian		Sacking warp		Sacking weft	
Sliver weight (lb./100 yd)		18**	15**	20*	15*	20*	15*
Weight CV% (test length = 10 yd)	Good Normal	Below 10 10 to 12	Below 4 4 to 6	Below 10 10 to 13	Below 4 4 to 8	Below 12 12 to 18	Below 4 4 to 8
Thickness CV%	Good Normal	Below 15 15 to 18	Below 11 11 to 14	Below 17 17 to 20	Below 12 12 to 15	Below 20 20 to 23	Below 18 18 to 21

Source: Norms for the jute industry – Part 1, *Quality parameters up to spinning*, Bulletin published December 1997, pp. 5–7. Courtesy: IJIRA.
* at 20% Moisture regain (MR)
** at 16% Moisture regain (MR)

Table 2.8 Unevenness of slivers at the drawing stages (quality parameters)

Type of product	Processing stage	Quality parameters				
		Weight (lb/100 yd)	Weight CV% (test length = 10 yd)		Thickness CV%	
			Good	Normal	Good	Normal
Hessian	First drawing	8 (at 16% MR)	Below 3.5	3.5–5.5	Below 10	10–12
	Second drawing	4 (at 16% MR)	Below 3.0	3.0–6.0		
	Finisher drawing	130 (grist at 16% MR)	Below 3.0	3.0–5.0		
Sacking warp	First drawing	8.5 (at 20% MR)	Below 3.5	3.5–5.5	Below 11	11–13
	Second drawing	4.25 (at 20% MR)	Below 4.0	4.0–6.0		
	Finisher drawing	140 (grist at 20% MR)	Below 4.0	4.0–6.0		
Sacking weft	First drawing	5.5 (at 20% MR)	Below 4.0	4.0–6.0	Below 15	15–18
	Finisher drawing	180 (grist at 20% MR)	Below 4.0	4.0–6.0		

Source: Norms for the jute industry – Part 1, *Quality parameters up to spinning*, Bulletin published December 1997, pp. 5–7. Courtesy: IJIRA.
MR: Moisture regain

together for transport to the spinning frame. Production of rove in this way was a slow process, however, and during the 1950s spinning from rove was superseded by spinning directly from third-drawing sliver. To hold the fibres together, the sliver is passed into a crimping box, which gives it a small crimp. This is just as effective as twist but is a much faster process.

Yarn quality

Control of fibres on the spinning frame, when sliver spinning was first introduced, was by one or more weighted rollers – the 'slipdraft' system. More recently, the 'apron-draft' system was introduced, whereby fibre control was effected either by a double-apron arrangement or by a single apron pressing the fibres against a lower fixed metal plate. Specifications for sale yarn quality parameters are shown in Tables 2.9 and 2.10.[30,31]

2.4.2 Flyer spinning systems

Developments in the flyer system have also taken place, the two-legged flyer being replaced by a rigid metal plate. The yarn runs loosely behind the plate instead of being fixed in position as previously, when wrapped round a flyer leg. Compared to the two-legged flyer, the rigid flyer results in reduced yarn tension and also permits the use of larger bobbins. In commercial spinning it is interesting to note that using similar good quality fibre, the spinning limit of a slip-draft frame fitted with two-legged flyers is commonly taken to be about 210 tex, whereas the combination of apron-draft and rigid flyer increase the fineness of the yarn to about 140 tex.

Table 2.9 Specifications for sale yarn quality parameters (8–12 lb. (276–413 tex) yarn)

Quality parameters	Specifications			
	Good		Normal	
Linear density	8–10 lb (276–345 tex)	10–12 lb (345–413 tex)	8–10 lb (276–345 tex)	10–12 lb (345–413 tex)
Count CV%	Below 5	Below 4	5 to 7	4 to 6
Strength CV%	Below 16	Below 14	16 to 18	14 to 17
Quality ratio**	Above 105	Above 110	95 to 105	100 to 110
Hairiness index	Below 10.5	Below 11	10.5 to 11	11 to 12
Total imperfections*/100m	Below 175	Below 150	175 to 200	150 to 180

Source: Norms for the jute industry – Part 1, *Quality parameters up to spinning,* Bulletin published December 1997, pp. 5–7. Courtesy: IJIRA.
* Total imperfections = thin places (−50%) + thick places (+50%) + slubs (+200%)
** See Section 4.4

Table 2.10 Specifications for sale yarn quality parameters (4.8–6 lb. (165–207 tex) yarn)

Parameters	Specifications							
	Good				Normal			
Linear density	4.8 lb (165 tex)		6 lb (207 tex)		4.8 lb (165 tex)		6 lb (207 tex)	
	Single	2-ply	Single	2-ply	Single	2-ply	Single	2-ply
Count CV%	Below 6	Below 5	Below 5	Below 4	6–8	5–6	5–7	6–8
Strength CV%	Below 20	Below 15	Below 18	Below 15	20–22	15–18	18–20	15–18
Quality ratio*	Above 95	Above 105	Above 100	Above 105	90–95	95–105	95–100	100–105
Hairiness index	Below 9	Below 11	Below 10	Below 12	9–10	11–12	10–12	12–13
Total imperfections*/100 m	Below 200	–	Below 180	–	200–250	–	180–220	–

Courtesy: IJIRA.
* See Table 2.8

2.4.3 Modern developments in jute spinning

Developments have also taken place in drawing frames, for, in addition to the fixed-draft frames in common use throughout the industry, a so-called 'autoleveller' is available. This machine automatically adjusts the draft according to the thickness of the output sliver and thereby maintains a more uniform linear density of sliver than is normally obtained with fixed-draft machines. Used as a second-stage drawing frame, the autoleveller can reduce the CV% of linear density between 100 m lengths of yarn from the 4–5% achievable with fixed draft to about 1.5–2%. A similar effect could have been achieved by increasing the doublings on the fixed-draft frames by a factor of six or seven times and because of this, the frame with automatic draft control is more correctly termed an 'auto-doubler'. It is only on long lengths of yarn that levelness is improved, of course, the short-term levelness being virtually unaffected.

Careful preparation of fibre before presentation to the breaker card is necessary if the best results are to be obtained from the spinning system. Application of water, to soften the fibre, and oil, to lubricate it, is essential, except where oil is undesirable for a particular end-use, in which case a non-oily lubricant must be used. The liquids are usually applied in the form of an oil-in-water emulsion, the composition and rate of application being controlled to give the desired add-on of both water and oil.

If the breaker card is to be hand-fed with long jute, the lengths of fibre are first passed through a series of heavy fluted rollers on a jute softener, a machine that is also used for preparing cuttings. If, however, the breaker card is to be fed from rolls of fibre, a jute spreader is used to form the rolls. This is similar to the goods machine used in the hard-fibre industry, and emulsion application takes place through either softener or spreader.

High speed ring-spinning machines for spinning fine jute yarns are manufactured by Lummus Mackie, UK and N. Schlumberger, France. Also SITRA have developed a low-cost spinning machine for fine-count jute yarns but these have not yet been taken up by the industry due to the lack of demand for such yarns.

Spinning of fine jute yarn

The South India Textile Research Association (SITRA) at Coimbatore has developed a ring spinning frame to spin 100% fine jute yarns.[30] Some of the salient features of the SITRA jute ring frame include

- double-sided machine with sliver feeding creel arrangement (200 spindles/ machine)
- optimum spinning geometry with 45° roller stand angle. Angle of yarn pull is 28° and spinning angles are 21° (lappet bottom position) and 25° (lappet top position).

Process of manufacture	Technology used
Raw jute (BTC) Selection Batch Process spreader Breaker card Finisher card 5X card with D/H	Conventional technology and
Intersecting gill drawing Comber Intersecting gill drawing (2/3 passages) Ring spinning	New Imported technology and new process
Precision winder ----- Ring twister (optional) Packing and despatch	Conventional technology and Process

Figure 2.6 Process flowchart for fine jute and jute blended yarns.

- top arm loading with PK 1601 arm and with slip draft
- self-lubricating vertical rings or multi-grooved rings with nylon travellers
- ABC rings for balloon control
- spinnable count: 4 to 8 lb./spindle (with appropriate sliver)
- spindle speeds 6000 to 6500 rpm
- draft range 15 to 30
- twist range 3.0 to 12.0 TPI.

According to development work carried out by IJIRA[32] the spinning of fine jute yarn, i.e., 4 lb. (138 tex) is possible using imported machines. The process flowchart for producing fine jute yarn is given in Fig. 2.6. The quality characteristics of fine jute yarn and jute blended yarns produced by using imported machines are given in Table 2.11.

Spinning of jute blended yarns on the short staple spinning system

In connection with a United Nations Development Programme assignment, SITRA has also developed[33] appropriate technology and machinery to spin jute/cotton blended yarns on short staple ring spinning systems. Special purpose machinery developed by SITRA for spinning jute/cotton blends include

Table 2.11 Quality characteristics of fine jute and jute blended yarns

Material	Mass CV% (Uster – 1 cm)	Imperfections*/ 100 m	Tenacity (Rkm)	Strength CV%
(i) 4 lb. All jute combed yarn	24.16	127	13.16	21.04
(ii) 3 lb. (70/30) jute v. rayon combed yarn	20.93	73	9.44	19.22
(iii) 2 lb. (50/50) jute/ v. rayon combed yarn	25.03	128	8.31	15.25

* Thin place (–50%) + Thick places (+50%) + Slubs (+200+)

- high-production cutting machine (Patent No. 485/MAS/93)
- a sliver-making machine (Patent No. 711/MAS/93)
  a sandwich blending draw frame[34] (Patent No. 1000/MAS/94).

Counts in the range of 8s to 10s Ne were spun from a 50/50 (jute/cotton) blend. These blended yarns were used to manufacture a wide range of sample fabrics including curtain fabrics, blankets, bedspreads, floormats, industrial fabrics, pile fabrics and others. The process flowchart for spinning jute/cotton blended yarns is given in Fig. 2.7. The machinery set up developed by SITRA

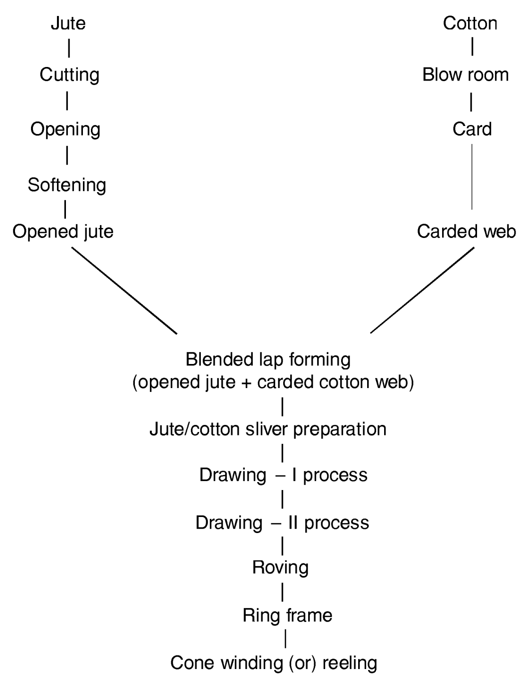

Figure 2.7 Process flow chart for spinning jute/cotton blended yarns.

for jute/cotton blended yarn spinning can also be used for spinning jute/viscose, jute/acrylic and jute/polyester blended yarns.[35]

Home textiles, curtains, furnishings, and upholstery are some of the value-added products that could be manufactured using jute/viscose blends. These products are not only cheaper than 100% viscose fabrics but also have better dimensional stability, which is one of the prime requirements for home furnishings. The fall (drape) of the fabrics made from jute/viscose blends, particularly curtains, would be an improvement on those made from 100% viscose due to the coarseness of the jute fibres.

Due to their warmth-retention property, acrylic fibres are frequently used as a substitute for wool for use in cooler climates. In this context, blending a small proportion of jute with acrylics may have cost advantages without significantly affecting the warmth-retention property of the fabric. Quality norms developed by SITRA[35] for jute/cotton, jute/viscose, jute/acrylic and jute/polyester blends spun in a short staple ring spinning system are given in Tables 2.12–2.15.

Spinning of jute blended yarns on the rotor spinning system

Ahmedabad Textile Industry research[36] has reported spinning jute/cotton blends on rotor spinning systems. In these spinning systems optimum yarn linear density is 100 tex with 30% jute and 70% cotton. Such yarns could be woven on

Table 2.12 Quality norms for jute/cotton blended yarns

Count (Ne)	6^s			8^s			10^s		
Yarn quality attributes	30/70	40/60	50/50	30/70	40/60	50/50	30/70	40/60	50/50
1. Tenacity (g/tex)	9.0	7.5	7.0	8.5	6.5	6.0	9.0	7.5	5.5
2. Elongation (%)	4.5	3.5	3.0	5.0	4.5	4.0	5.0	4.0	3.5
3. Mass irregularity (CV%)	20.5	23.0	23.5	22.0	23.5	24.5	23.0	25.0	26.5
4. Hairs/m	80	85	100	60	65	90	55	55	60

Table 2.13 Quality norms for jute/viscose blended yarns

Count (Ne)	6^s			8^s			10^s		
Yarn quality attributes	30/70	40/60	50/50	30/70	40/60	50/50	30/70	40/60	50/50
1. Tenacity (g/tex)	8.0	7.0	6.5	7.5	7.0	6.5	8.5	7.0	6.5
2. Elongation (%)	4.5	4.0	3.5	5.0	4.0	3.0	5.0	3.5	2.5
3. Mass irregularity (CV%)	19.5	20.0	20.5	20.0	20.5	21.5	22.0	22.5	23.5
4. Hairs/m	65	70	75	50	55	60	40	45	50

Table 2.14 Quality norms for jute/acrylic blended yarns (acrylic 1.5D)

Count (Ne)	6^{s}			8^{s}			10^{s}		
Yarn quality attributes	30/70	40/60	50/50	30/70	40/60	50/50	30/70	40/60	50/50
1. Tenacity (g/tex)	10.0	9.5	7.5	10.5	10.0	8.0	10.0	9.5	7.5
2. Elongation (%)	14.5	13.5	9.0	13.5	12.0	8.0	13.5	12.5	9.0
3. Mass irregularity (CV%)	18.0	18.5	20.5	19.5	19.5	22.5	21.5	22.0	24.5
4. Hairs/m	70	80	95	55	65	80	50	55	65

Table 2.15 Quality norms for jute/polyester blended yarns (polyester 1.4D)

Count (Ne)	6^{s}			8^{s}			10^{s}		
Yarn quality attributes	30/70	40/60	50/50	30/70	40/60	50/50	30/70	40/60	50/50
1. Tenacity (g/tex)	21.0	18.0	15.5	24.5	18.5	14.0	22.5	18.5	16.0
2. Elongation (%)	10.0	9.5	8.5	10.5	9.0	8.0	9.5	8.0	7.5
3. Mass irregularity (CV%)	21.5	24.0	25.5	24.5	25.5	26.0	24.0	27.0	27.5
4. Hairs/m	60	65	75	40	50	65	35	45	50

most types of looms. Some of the products made from such yarns include: denim on shuttle less looms; curtain fabrics and shawls on handlooms; and niwar (a narrow fabric) on tape looms. Lakshmi Machine Works Ltd., Coimbatore have done pioneering work on spinning jute and jute blends on short staple open-end (OE) spinning systems. They have spun counts in the range of 6s to 10s Ne on OE spinning system using 30% to 50% jute in a jute/cotton blend.[37,38]

Spinning of jute blended yarns on friction spinning systems (core yarns)

A report from the Wool Research Association (WRA), Mumbai[39] indicates that friction spinning technology could be used to manufacture core spun yarns with jute yarn as the core and shoddy woollen waste as the sheath. The core jute yarn provides the necessary strength and the sheath of staple fibres provide the necessary comfort and aesthetic appeal for manufacturing products such as blankets, dhurries (a heavy floor covering fabric) and furnishings.[39] Secondary carpet backing yarn was also developed using jute yarns as core and polypropylene fibres as sheath.[40] The yarn mentioned in this section was not on the market at the time this book was written but gives a good indication of the many possibilities for diversifying jute into new markets in the near future.

Upgrading of jute fibres

Many attempts have been made to improve the spinning quality of jute by the action of enzymes and other bio-agents. Enzymes start their bio-chemical reactions in the presence of moisture on the substrates that are specific to the enzyme involved, i.e., cellulose enzyme on cellulose and hemicellulose enzyme on hemicellulose and so on. To soften the hard tissue of bark in the 'pile' of jute stems that are to be treated the concurrent action of both enzymes and bacteria (aerobic and anaerobic) is essential. These enzymes are called hydrolases as they catalyse the hydrolic degradation of specific carbohydrates. These simultaneous actions are the hydrolic degradation of the tissues of the plants (which requires moisture) and the bacterial action, which is accelerated by the easily assimilable reaction products generated by enzymic action. The synergistic effect of the two biological systems results in both softening and upgrading the jute fibres.

Although the average filament strength of enzyme treated jute is more or less the same as that of untreated jute the quality ratio values of the treated yarns are higher than those of the untreated yarns. This is due to the fact that the enzyme and bacteria treated fibres build up to a more compact yarn. Another interesting effect of the enzyme treatment of jute fibres is the increase in equilibrium moisture regain of the treated fibres. A higher moisture retention property ensures improved spinnability of the treated fibres, even under dry atmospheric conditions. From a purely practical point of view these enzyme and bacterial treatments can help to improve spinning and weaving efficiency by about 6%.

Spinning assistants

Jute fibres have a low natural content of fats and waxes and some added lubrication is essential for good yarn regularity. Mineral oil is the commonly used lubricant, applied as an emulsion in water. The amount added ranges between 0.75 and 5% by weight and in particular cases an additional 1 to 1.5% will give the maximum single-thread breaking load. Less than 1% results in a marked falling off in strength, whilst above 2% the yarn breaking load falls steadily, but more slowly.

Mineral oils are absorbed to some extent into the body of the fibre through crevices in the surface and internal holes. Low-viscosity oils are absorbed rapidly and leave the surface relatively oil free, in a state corresponding to boundary-lubrication conditions. High-viscosity oils, on the other hand, are absorbed more slowly into the fibre and mainly remain on the surface, and so produce the appropriate conditions for hydrodynamic lubrication. It has been found that there is an optimum viscosity in the region of 250–300 seconds Redwood which gives the lowest values of percentage mean deviation (PMD), whereas, if the viscosity is increased to 5000 seconds or more the yarn regularity and strength will substantially deteriorate (ref. 28, p. 46).

Friction-increasing additives

If the added mineral oil is scoured from the yarn, which is not, of course, normal commercial practice, the breaking load of the yarn increases by 4 or 5%. This is due to increased friction between the fibres on removal of the oil, which helps to prevent slippage before the fibres break and thus enables them to achieve a higher breaking load. It would be expected that a similar effect would result from the addition of a friction-increasing substance, such as colloidal silica and this is indeed the case. If the silica is added before spinning, the result is a marked increase in irregularity but, if the addition is made on the spinning frame immediately before insertion of twist, the regularity is unchanged because all the drafting was done prior to application but the breaking load is increased by 10% or more, depending on the amount added. As with scouring, the silica prevents fibre slippage and produces more breakage. Moreover, when the fibres do break, rather than slip, the elongation of the yarn increases slightly.

Friction requirements

In a perfect yarn, where the fibres are arranged entirely at random, the PMD value will be inversely proportional to the square root of the number of fibres in the cross-section. Actual PMD values are always greater because the fibres draft not as individuals, but in groups. This results in a succession of thick and thin places along the length of the yarn. There are two opposing factors, the cohesion of the slivers being drafted and the restraint offered by the pressure of the gill pins on the faller bars. If the fibre/fibre friction is low and the fibre/steel friction is high the restraint of the gill pins will be increased, but the cohesion of the sliver will be reduced. The overall effect will be for the groups of fibres to be broken up, which leads to greater regularity. Similar frictional effects have been study by Spencer-Smith and Todd[25] for long staple man-made fibres on flax-spinning systems. These authors concluded that the ratio of the coefficient of static friction between fibres to the corresponding coefficient of static friction of fibres on steel should be as small as possible to spin the most regular yarns. Other factors, such as gill-spacing and fibre-loading on the drawing frames also affect yarn regularity, but in addition to the purely frictional effects.

The need for a low fibre/fibre coefficient of friction for good drafting is the opposite of what is required in the yarn to achieve a maximum breaking load but because of the dominant effect of the PMD in determining breaking load, the choice of lubricant must be made with good drafting in mind, even if this results in some loss of strength in the yarn owing to fibre slippage. Although mineral oils are in common use as inexpensive lubricants many chemical manufacturers supply proprietary additives of an organic chemical nature, which confer particular surface properties on fibres. Such additives are commonly long-chain fatty acids or alcohols, condensed with ethylene oxide molecules. In addition, various wax dispersions are available and although all these non-oily materials are more expensive than mineral oil, the importance of achieving the correct surface properties of fibres by using a proper choice of lubricant is an important factor in spinning the highest quality yarns.

Fine-quality jute – a new development

If the jute manufacturing industry is to have a long-term future, it seems essential that new outlets be found for their products. In textile terms, jute goods are heavy and are being steadily assailed by modern lightweight materials. With the currently available jute yarn counts there is a limit to fabric weight reduction that can be obtained without unacceptable loss of strength. In this respect, the fibre itself is a constraint because of its own higher linear density. New jute fibres are therefore needed, which will permit jute yarns of lower linear density to be spun and woven without significant loss of strength and thus lead naturally to the production of fabrics of lower mass per unit area. To make this a reality the new fibres would need to be much finer those than those presently available. At present commercially available jute fibres have a linear density (after carding) in the range of 15.0 to 30.0 denier.

Using JRC 321 seed variety, The South India Textile Research Association, Coimbatore[26] has developed, by the classical method of plant breeding and selection, a finer fibre with a fineness of 8.0 to 9.0 denier after carding. While using normal jute fibre from JRO seeds, counts finer than 56 lb. are practically not possible. However, 3 lb. and 4 lb. yarns were spun using JRC 321 fibres. These would produce fabrics with weights per square metre that would be suitable for many furnishing fabrics. Quality attributes obtained for yarns spun from JRC 321 are given in Table 2.16.

Table 2.16 Yarn quality attributes from JRC 321 fibres

Quality parameters	Count of yarn	
	3 lb	4 lb
Quality ratio (%)*	86.0	101.0
Strength CV (%)	28.0	20.0
Weight CV (%)	5.0	3.0

2.4.4 Some definitions

$$\text{Quality ratio} = \frac{\text{Single yarn strength in lb.}}{\text{Grist in lb. per spyndle}}$$

$$\text{Count in cotton system, Ne} = \frac{17.14}{\text{lb. per spyndle}}$$

$$\text{Spyndle} = \text{A length of 14,400 yds.}$$

Qualities of 3 lb. and 4 lb. yarns are considered satisfactory for fabrics intended for decorative end uses.[27]

2.5 Fabric production, end-uses and specifications

Jute yarns can be woven on automatic power looms, shuttleless looms or on handlooms. Of the world production of jute goods, which stands at about 3 million tonnes per year,[1] India accounts for about 50% and Bangladesh and China for about 17% each. In India, around 80% of the jute yarns are used for manufacturing sacking, carpet backing and hessian cloth as shown in Fig. 2.8. In Bangladesh, more than 90% of the jute yarns manufactured are utilised for manufacturing sacking, carpet backing and hessian.

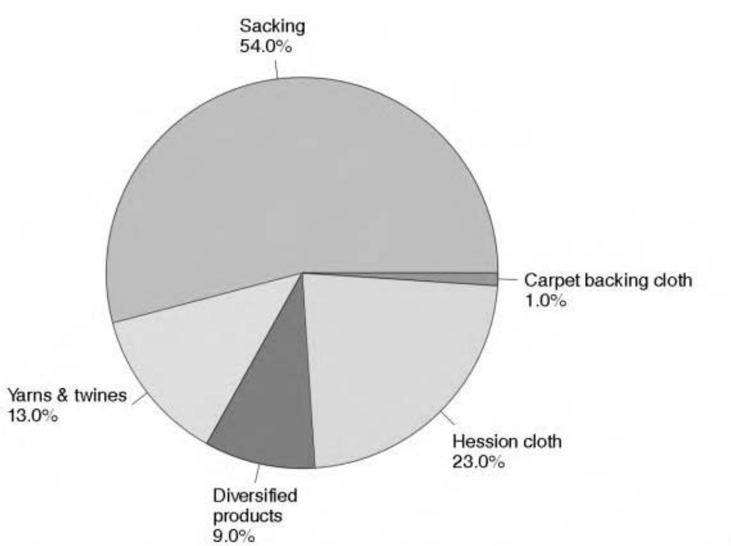

Figure 2.8 Proportions of jute fibres used for manufacturing different products in India (2001–2002). Courtesy: *Indian Jute*, A bulletin published by Jute Manufacturers Development Council, Kolkata, Vol. 12, No. 2, December 2002.

2.5.1 Powerloom weaving

Winding

One of the main purposes of warp yarn winding is to transfer yarn from the spinner's or doubler's package to another which can be used in the creel of a warping machine or for dyeing. Warping requires as much yarn as possible on each package and also a package which has been wound at comparatively high tension, but dyeing requires a soft-wound package so that dye can penetrate; a compromise is therefore sometimes needed in the matter of winding tensions. Winding also enables manufacturers to monitor and improve the quality of the yarns by passing them through yarn clearers whilst they are being wound.

ATIRA and Patwa Kinariwala Electronics[41] have developed an electronic yarn clearer. This is a microcontroller/microprocessor based system for the detection and clearing of objectionable faults such as thick and thin places and slubs in jute and jute blend yarns. The salient features of this system are:

- It is based on opto-electronic principles.
- There are settings for different grists of yarn from 4 to 16 lb. and for clearing different types of faults.
- It displays data such as lot no., spindle-run-time, idle-time, and the yarn grist.
- There is one control module for 60 spindles. Spindles are divided into user defined groups for optimum utilisation.
- A modular design ensures fast and easy serviceability.
- Performance is comparable with imported yarn clearers for jute.
- The 'online' display of different parameters on LCD screens along with central computers enables monitoring and control.
- An optional facility is available for yarn length measurement.
- Clearing efficiency is not affected by changes in winding speeds.

Warping

There are two main types of warping, beam warping and section warping, used to prepare jute and jute blend yarns for weaving. Beam warping is used for long runs of grey (loom-state) fabrics and simple patterns where the proportion of coloured yarn involved is less than about 15% of the total. Section warping is used for pattern weaving and for short runs, especially of yarn dyed fabrics where the content of coloured yarn is greater than about 15% of the total.

Sizing of jute yarn

Jute yarns need to be sized because they are hairy and they have low extensibility under tension. In the Indian jute industry, tamarind kernel powder (TKP) is used exclusively as the only suitable sizing material, the optimum add-on recommended being in the range of 3–3.5% of the weight of the yarn along with a suitable antiseptic (0.025 to 0.03% of the size paste). To achieve further improvements in weaving performance the addition of lubricants, supplementary adhesives and humectants, either as such or in the form of proprietary products, has been tried but the results obtained are not conclusive although some increase in weaving efficiency has been noted in particular cases.

However, it should be stated that in jute weaving warp breakages alone account for about one-third of the total loss of efficiency and so there is clearly scope for reducing them. In this respect it is interesting to note that at all levels of application, polyvinyl acrylate (PVAC) increases the abrasion resistance of warp yarn, for example the ratio of the number of strokes required to break the treated yarn to the number of strokes required to break the unsized yarn increases. Moreover, PVAC reduces fibre shedding during weaving. The quality ratio of warp yarns, in general, also improves on treatment with PVAC. It should also be noted that the BTRA have developed BTRACRYL sizing ingredients for jute yarns.

2.5.2 Weaving of jute yarn

Shuttle looms

The shuttle loom is the oldest kind of power loom; it is effective and versatile but it has certain disadvantages. The shuttles may cause abrasion on the warp yarn as it passes over them and this sometimes causes thread breaks. This, in turn, results in machine stoppages with consequent reduction in weaving efficiencies. They operate at a rate of about 110–220 picks per minute (ppm) which is slower than some new types of loom, and they are also noisier.

Shuttleless looms

Gripper projectile looms and rapier looms can be effectively used to weave jute yarns of any nature. There is only one kind of projectile loom used in the jute industry, air jet looms, which are used for the production of such fabrics as shirtings and denims. Air jet looms are either single nozzle or multiple nozzle types.

There are several kinds of rapier loom. One early model uses one long rapier device that reaches across the entire width of the loom to carry the weft yarn from one side of the loom to the other. Another type utilises a double rapier; one on each side of the loom. The rapier itself can be rigid, flexible or telescopic. In these looms the rapier from one side feeds the weft yarn half way through the shed of warp yarns to the rapier on the other side, which meets it half way across the warp and takes the pick back across the rest of the warp. These rapier looms are efficient and can be used to produce a wide variety of fabrics ranging from muslins to drapery and upholstery materials.

2.5.3 Handloom weaving

With the growing diversification of the use of jute in various non-traditional applications, end-uses such as curtains, upholstery and some heavier furnishing fabrics provided by the hand loom sector require lighter count jute and jute blended yarns of below 4 lb. Technically such lighter yarns could not, up to now, be produced industrially by the mill sector. However, recent developments have led to the design and development of appropriate technology and it is now possible to produce these lighter yarns from 100% jute and jute blends. Some of the specifications for fabrics produced on handlooms are given in Table 2.17.

2.5.4 Diversified products

In the case of handlooms, it was shown that from the jute yarn supplied by jute mills, it would be feasible to produce a number of value added jute/jute blended fabrics for textile applications.[42] In India, around 9% of the jute yarns are used for manufacturing diversified products.[1] The relative share of upholstery and soft luggage, tarpaulins, canvas cloth, webbings and soil savers in the total quantum of jute diversified products is shown in Fig. 2.9.

Canvas cloth contributes the major share of about 50% of all jute diversified products followed by tarpaulins (40%). Upholstery, decorative, wall coverings, soft luggage fabrics and jute soil savers contribute another 10%. But there is considerable scope for the development of these products due to a general awareness concerning the importance of using eco-friendly and biodegradable products if we are to sustain the ecological balance of the world. David Rigby

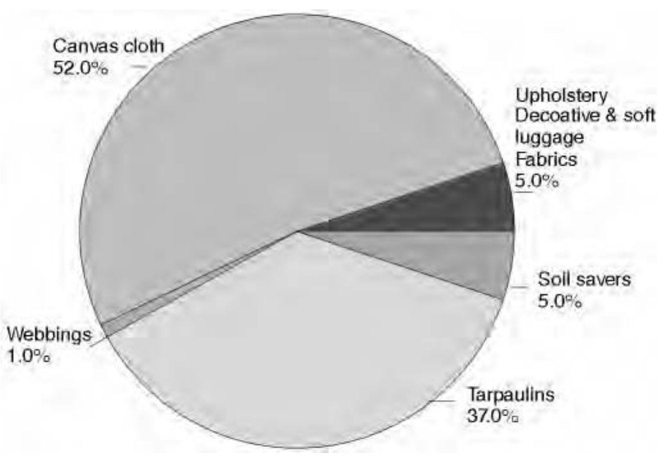

Figure 2.9 Relative share of different diversified jute products. Source: *Indian Jute*, A bulletin published by Jute Manufacturers Development Council, Kolkata, Vol. 12, No. 2, December 2002.

Table 2.17 Specification of handloom woven jute and jute blended fabrics

Characteristics	Type of fabric					
	Jute/cotton	Jute mat	Jacquard furnishing	Jute viscose fabric	Jute curtain	Export carpets
Warp count	Cotton yarn 2/20	9.5 lb. 2 ply	2/17 Cotton	3.2 lb. jute	2/17 cc	3/6 cc
Weft count	Jute & cotton yarn 9.5 single ply, 2/20 cotton	Jute yarn 11 lb., 3 ply	6s Jute	3.8 lb. jute	3.8 lb. jute	Jute 3 ply
Weave	Plain with extra weft	Diamond	Plain & float	N/A	Plain & mockleno	Plain & design
Fabric weight	500 g/m^2	100 g (13 $\times$ 18)	400 g/m^2	250 g/m^2	300 g/m^2	0.120 g/ft^2
Ends x pick /inch	36 $\times$ 36	10 $\times$ 10	40 $\times$ 36	28 $\times$ 30	36 $\times$ 36	8.1 $\times$ 8
Width (inch)	48	13	36	–	48	24

Table 2.18 Application areas for technical textiles and suitable jute products

Sl. No.	Type of application	Application area	Suitable jute products
1.	Agrotech	Agriculture, horticulture, forestry & fishing	Canvas cloth and tarpaulins
2.	Buildtech	Building & construction	Jute laminates
3.	Clothtech	Clothing and footwear	Jute and jute blended fabrics
4.	Geotech	Geotextiles and civil engineering	Soil savers
5.	Hometech	Furniture, interior textiles & floor covering	Curtains made from jute blends, jute wall coverings, dividers, etc.
6.	Indutech	Filtration, belting and abrasives	–
7.	Medtech	Medical and hygiene	–
8.	Mobiltech	Automotive/transportation	Non-wovens made from jute/jute blends for sound & heat insulation
9.	Packtech	Industrial and consumer packaging	Soft luggage fabrics, laminated jute hessian cloth and sackings
10.	Protech	Personal and property protection	Flame proof and mildew proof fabrics made using jute yarn as core and other conventional/high performance fibres as sheath.
11.	Sportech	Sports and leisure equipment	–
12.	Oekotech	Environmental protection	Canvas cloth and tarpaulins made from jute/jute blends

Source: World Technical Industry and its Markets, April 1997. Courtesy: David Rigby Associates, Manchester, UK.

Associates[43] has classified 12 application areas for technical textiles and suitable jute products corresponding to these. These are summarised in Table 2.18.

Jute decoratives and wall coverings

Jute decoratives and wall coverings are becoming fashionable. The Food and Agricultural Organisation of the United Nations (FAO) has summarised the position as follows: 'For various important applications such as curtain materials, upholstery and wall coverings, jute has a special appeal'.[2] Jute as wall coverings had a considerable market in Western Europe but because of technical problems, including colour fastness, jute was displaced by alternative materials. If these defects are quickly overcome and jute items marked at competitive prices there is a chance of regaining these lost markets. Bangladesh and India have initiated measures to promote various types of furnishing fabrics and other articles such as upholstery, curtain materials, blankets, blended jute fabrics and jute felt. There is considerable demand in the domestic sector for these products but in order to meet that demand the production base needs to be strengthened and quality improved.

The production and marketing of these decorative items have a special significance for the traditional handloom industry of India which employs 10 million weavers and produces around 3,500 million metres of cloth per year. A programme for the utilisation of jute yarn to produce 100% jute or blended fabrics has been undertaken at various handloom centres. In order to achieve successful and broad-based programmes it is necessary to ensure the continuous availability of yarn, to arrange proper training, to identify product lines for upholstery, bed linen, cotton material and organise processing and marketing so that the resultant products are priced at competitive levels. In India the National Handloom Development Corporation is the government organisation that co-ordinates the development and financing of the activities of this sector.

Jute wall covering is considered as a fashion product, for which the demand pattern can change frequently and rapidly. Jute was used for wall covering, with a market of about 3 million metres in the 1970s but at present, the market is much smaller at only 400,000 metres in 1988. It is reported that the problem may lie with poor colour fastness (and the presence of lignin).[93] These problems need to be solved if this end-use is to be developed satisfactorily. Also it should be borne in mind that the export of yarn is important from the point of view of the 'image' of the fibre as some of the users in Europe of these yarns are sophisticated designers and producers of wall coverings and sales of specialised yarns to these small weavers depend entirely on quality.

Soft luggage fabrics

Soft luggage fabrics made using jute are already marketable products. The FAO summarises the position as follows: 'A market survey carried out by the Commonwealth Fund for Technical Cooperation (CFTC) identified this product as one of the most promising which needed promotional support.'[43] The main potential for jute lies in high fashion handbags and similar products and also for shopping bags, with some opportunity also for soft travel luggage. According to one estimate the market potential for shopping bags is expected to exceed two million units a year, and for other soft luggage the market is over one million units in France alone. Jute should aim at a share of this market. It is reported that the CIS of the former USSR have shown interest in this area. Jute mills in Bangladesh and India have brought out excellent bags which are being marketed domestically and exported. The specifications of some jute household, soft luggage and decorative fabrics are given in Table 2.19.

Table 2.19 Specifications of jute household, soft luggage and decorative fabrics

Sl No.	Characteristics	Household fabrics			Soft luggage fabrics			Decorative fabrics		
		Interior decoration	Curtain upholstery	Apparel bed linen	Suitcase bags	Handbags	Shopping bags	Made-up articles	Printed fabrics	Matting floor-covering
1.	Weight (g/m^2)	200–300	200–400	100–200	200–400	150–300	150–300	200–500	200–400	300–500
2.	Fibre component jute % blend %	 50–80 20–50	 30–60 40–70	 40–50 50–60	 80–100 0–20	 80–100 0–20	 80–100 0–20	 80–100 0–20	 40–50 50–60	 80–100 0–20
3.	Strength warp × weft (kg) (min) (100 × 200 mm)	60–90	60–112	30–60	76–152	57–114	57–114	76	76	114

Jute canvas

Jute canvas is a closely woven double warp plain weave cloth. It is usually made from better quality jute. Canvas is used for hatch covers, sun blinds, mailbags, tents, soil cloth, etc. Typical specifications[44] of jute canvas cloth (usual range) are given in Table 2.20.

Jute tarpaulins

Lined and laminated jute fabrics are also available to meet special packing needs of the industries to protect the contents from external moisture and also to protect the container itself from corrosion by the contents. Jute tarpaulin cloth is the base cloth for these purposes. The specifications[44] for jute tarpaulin cloth (usual range) are given in Table 2.21. The production of jute tarpaulin cloth[45–47] for the last ten years is given in Table 2.22. Jute tarpaulins are being increasingly replaced by synthetic fibre fabrics.

Jute webbing

Webbings are woven narrow fabrics, the prime function of which is load bearing, generally with multiple plies. The production of jute webbing for the last five years (1996–2001) has been around 3000 m. tonnes.

Table 2.20 Specifications of jute canvas cloth (usual range)

Characteristics	Value
Width (mm)	915–1220
Weight (g/m^2)	540–675
Ends/inch	31–35
Picks/inch	15–18

1 inch = 2.54 cm

Table 2.21 Specifications for jute tarpaulin cloth

Characteristics	Value
Width (mm)	860–1220
Weight (g/m^2) (for 1140 mm width fabric)	400–510
Ends/inch	8–10
Picks/inch	10–13

1 inch = 2.54 cm

Table 2.22 Production of jute tarpaulin cloth

Year	Production (m.ton)
1991–92	111.8
1992–93	111.8
1993–94	87.7
1994–95	86.2
1995–96	58.5
1996–97	53.1
1997–98	65.1
1998–99	37.8
1999–00	21.9
2000–01	10.3

Jute soil savers

Textiles used in the field of civil engineering are known as 'Geotextiles'. Geotextiles are designed for separation, reinforcement, filtration, drainage and protection/erosion control functions. Jute, because it is eco-friendly and biodegradable has gradually replaced synthetic fibres where durability is not a foremost concern, for example, in soil erosion control and slope protection. For other geo-textile applications such as separation, filtration, drainage, road construction, soil stabilisation and river and canal embankments, treated jute geo-textiles treated with chemicals such as copper oxide or bitumen are used so as to provide satisfactory resistance to rotting. There is a current global demand of about 100 million m^2 of jute geo-textile fabrics in North America, Western Europe, Japan and Australia. The construction and properties of some jute soil saver fabrics meant for different applications[48] are given in Tables 2.23–2.26.

Table 2.23 Jute soil saver fabrics for erosion control

Soil composition	Slope angle	Annual rainfall (mm)	Type of geo-textile fabric Wt. (g/m^2)	Aperture (mm)	Width (cm)	Thickness (mm)	Threads (per m)
Debris of soil mixed with boulders and rock pieces	60–85	3000	750	20 × 20	122	7	70 × 70
Sandy silt and clay	45–85	3000	500	25 × 25	122	5	65 × 45
Sand clay and combination	Up to 45	2000	300	10 × 10	122	3	110 × 110

Courtesy: N. Arun, Implementation of Jute in GeoTech, *Man-made textiles in India*, vol. xiii, no. 6, June 2000, p. 262.

Table 2.24 Jute soil saver fabrics for river/canal embankments

Properties	Value
Type of fabric	Woven (twill) treated with rot-resistant chemicals and bitumen
Ends × picks/m	10 × 5
Weight (g/m^2)	700
Width (cm)	102
Thickness (mm)	3
Tensile strength (kN/m)	
Warp direction	25
Weft direction	25
Failure strain (%)	
Warp direction	8
Weft direction	10
Puncture resistance (N/cm^2)	400
Water permeability at 10 cm	
Water head (L/m^2/s)	20

Courtesy: N. Arun, Implementation of Jute in GeoTech, *Man-made textiles in India*, vol. xiii, no. 6, June 2000, p. 262.

Table 2.25 Jute soil saver fabrics for drainage and filtration

Properties	Value
Type of fabric	Non-woven
Thickness (mm)	7–10
Weight (g/m^2)	500–1000
Tensile strength (kN/m)	3–5
Failure strain (%)	25–30
Puncture resistance (N/cm^2)	400
Coefficient of permittivity (m/s)	1/10000–1/1000
Coefficient of transmittivity (m/s)	1/100000–1/10000

Courtesy: N. Arun, Implementation of Jute in GeoTech, *Man-made textiles in India*, vol. xiii, no. 6, June 2000, p. 262.

Jute autocarpet underlay

Driver and passenger comfort is a major concern of present-day car manufacturers, to the extent that even the boots and leg spaces of cars have cushioning layers. This is being achieved by using non-woven jute felts of about 600 g/m^2 in the lining of these spaces.

Seat backing (automobiles)

Again in pursuit of car comfort a layer of non-woven jute felt in the weight range of 300–400 g/m^2 is sandwiched between the leather seat covers with coir

Table 2.26 Jute soil saver fabrics for road construction

Properties	Value
Type of fabrics	Woven (twill) treated with rot-resistant chemicals
Ends × picks/cm	102 × 39
Weight (g/m^2)	760
Width (cm)	76
Thickness (mm)	3
Strength (kN/m)	
Warp direction	20
Weft direction	20
Strain at break (%)	
Warp direction	8
Weft direction	10
Puncture resistance (N/cm^2)	350

Courtesy: N. Arun, Implementation of Jute in GeoTech, *Man-made textiles in India*, vol. xiii, no. 6, June 2000, p. 262.

and spring layers in the backs of car seats. This gives a smooth and comfortable feeling to the seat.

2.5.5 Recent developments in the manufacture of high-performance technical textiles using jute (protective textiles and structural composites)

Protective textiles

Although jute fibres would not normally be thought of for use in apparel, the exclusive combination of certain of its properties make it the ideal fibre for use in protective clothing against fire and heat. These properties are (in some cases after appropriate chemical treatment of the fabrics) high strength, high abrasion resistance, reasonable resistance to heat, durability and washability, and relatively low cost when compared with synthetic fibres. It can be used for protective aprons and gloves for protecting those working in oil installations and refineries, fire brigades, refractor and engineering plants. If required the jute fabric may be given water and oil repellent treatments. In these applications jute partly replaces kevlar. Table 2.27 depicts the performance of jute blended protective garments.[49]

Studies[50] conducted by IJIRA reveal that multi-component jute yarns can be successfully used for the manufacture of technical fabrics such as canvas (for tents and tarpaulins) and fire-retardant (FR) fabrics of international quality standards using friction spinning systems. Since the cost of high-performance fibres used in the manufacture of technical yarns is very high, the use of jute fibre as a blend is cost effective. The quality characteristics of high tenacity multi-component yarns for FR protective fabrics are given in Table 2.28.

Table 2.27 Comparison of the fire protection performance of jute/kevlar blend protective garment and garments made from chemically treated conventional fabrics

Criteria	Protective garments made from jute/kevlar blend	Protective garments made from chemically treated conventional fabrics
Flame retardancy	Permanent	Not permanent, lost on repeated washing in detergents
Emission of toxic gases on ignition	Nil	Emits toxic gases that may endanger life
Cost performance evaluation	Cheaper than 100% kevlar fabrics, performance at par with 100% kevlar fabrics	Inferior

Source: Bardham, M. K., 'Jute eco-friendly fibre for technical application and eco-friendly recycling of non-degradable polyester bottle waste'. *Proceedings of the 24th Technological Conference*, January 2002, p. 100. Courtesy: IJIRA, Kolkata.

Table 2.28 High-tenacity jute blended multi-component yarns for protective fabrics

Parameters	A	B
Yarn count (tex)	59	59
Yarn composition		
A. Sheath fibre used (%)		
(i) Jute	40	30
(ii) F.R. Viscose (1.7 D × 40 mm)	–	35
(iii) Kevlar (1.7 D, S.B)	30	
B. Core (%)	30	35
(i) Kevlar (1.7 D, S.B.)		
Yarn properties		
Tenacity (cN/tex)	36.2	36.7
Quality ratio	277	281
Strength (CV%)	7.0	8.0
Elongation (%)	3.7	3.9
Irregularity (%)	18.0	16.7
Hairiness (3 mm, hair/m)	32.5	45.4

Source: Khauta, D. P., Ray, D. K., Sankar, D., Neogi, S. K. and Bhattacharya, B. K., 'Dref spun jute blended multi-component technical yarns and fabrics'. *Proceedings of Jute India Conference*, New Delhi, October 1997. Courtesy: IJIRA, Kolkata.

Jute fibre for use in composite materials for the automobile industry

Interior trim panels in automobiles, such as door panels, dash boards and head liners are manufactured from composite products which increasingly use bast and leaf textile fibres, including jute, as reinforcement (see Appendix D and Chapter 10). The jute felts are either thermoset with polyester or polypropylene resin or may be reinforced on low-cost plastic sheets. In this case heavier jute felts of 1000 g/m^2 weight are used. The rigid panels are then covered with PVC/polyester cloth and installed with the other interior fittings in the cars. These composites are also used in brake linings replacing asbestos fibre which, as it is carcinogenic, is a health hazard.

Jute-based auto trims have the following advantages:

- lighter weight of the vehicle, leading to fuel savings
- low thermal conductivity of the jute fibre which therefore acts as a good heat barrier
- equivalent performance as compared to composites made with synthetics.

Jayachandran *et al.*[61] evaluated non-woven jute fabrics as seat backings, carpet underlays and fibre reinforced structure punching, where it is environmentally friendly compared to powder phenolic resin which is non-recyclable and non-biodegradable.

Car body panels developed by IJIRA[62] by resin transfer moulding using jute/polyester composites have the following advantages over glass/polyester composites:

- substantially cheaper than glass
- offer real weight savings
- allow easier recycling of moulded parts
- are not as abrasive as glass fibres and therefore give less tool wear.

Thermoplastic composites from jute/polypropylene[63] show better quality characteristics over polypropylene composites (see Table 2.39 in Appendix D, where jute composite materials are further discussed).

2.6 Dyeing and finishing: modern developments in chemical finishing

2.6.1 Dyeing

Patro[69] has described the general techniques employed in the dyeing of jute with basic, acid, direct and sulphur dyestuffs. According to the author, most of the requirements of the jute dyer can be met with dyestuffs of the basic, acid and direct classes, and being a highly lignified fibre, jute shows very good affinity for basic dyes and requires no prior mordanting. However, acid and direct dyes have relatively low affinity for jute.[70] Dye-stuffs with higher tinctorial values on jute generally show poor light fastness but it is possible to select dyes which give better light fastness, together with reasonable tinctorial values. For jute, however, light fast dyeing is difficult to achieve, particularly in pale shades, owing to the yellowing of the substrate fabric itself by the action of light. In order to obtain reasonably fast tinctorial effects the fabric must be subjected to some method of light fast bleaching prior to dyeing.

2.6.2 Bleaching

A process developed in the USA has been described in which jute can be bleached to a good white shade, reversion to its natural colour on exposure to light being inhibited.[72] The jute fabric is first bleached by the conventional hydrogen peroxide method; the bleached fabric is then treated with an aqueous solution of potassium permanganate (8–12% of weight of jute) under mineral acid, which is usually sulphuric acid (8–12% of weight of jute). Subsequently, the reduced permanganate is cleared by rinsing the fabric in an aqueous solution of sodium bi-sulphite or sodium sulphoxylate formaldehyde at pH 3.0 to 3.5.

The development of this process has increased jute's possibilities in decorative and furnishing fabrics. Highly regular and patterned grey fabrics with blended fibres and yarns have also been developed in order to impart special properties and optical effects to the texture of such decorative jute products. Market research conducted in specific areas of the USA has revealed a substantial potential demand for decorative jute fabrics. This process also effectively removes the surface hairs of jute fabrics so as to present a smooth handle.

Another process has been developed in the USA for the production of light-fast jute.[73] The process consists of bleaching the jute fabric at a pH below 3.0 at temperatures in the range 15–43 ºC in an aqueous solution of potassium permanganate and phosphoric acid in amounts such that the ratio of potassium permanganate to phosphoric acid ranges between 1 : 0.7 and 1 : 1.1. The bleached fabric is then scavenged with an aqueous solution of an inorganic reducing agent such as sodium bi-sulphite at a pH below 4.0. After this step, the fabric is scoured with hot water or steam. It is claimed that by means of this process it is possible to produce bleached jute fabric having a colour fastness of not less than 25 Standard Fastness Hours (SFH).

The BTRA[74] has developed a cold bleaching process for jute fabrics using hydrogen peroxide, special polymeric finishes that can be given to jute and jute/cellulosic union fabrics and also eco-friendly dyeing and finishing processes.

2.6.3 Crease resistance

Das[71] has described the results of the treatment of jute fabrics with formaldehyde in order to impart crease resistant properties by means of a pad-dry-cure method. With a 3% formaldehyde solution a dry crease recovery of 186º and a wet crease recovery of 267º was obtained, but this was associated with a loss of tensile strength of about 16%. By treating the jute fabric under partially swollen conditions (i.e., using a controlled water system containing a non-swelling agent) with aqueous formaldehyde containing an acid catalyst, both wet and dry crease recovery were found to increase substantially. Fairly high wet crease recovery in the range of 242–253º can be achieved by treating alkali-swollen jute fabrics with formaldehyde at room temperature. The loss in tensile strength in this case was not very high, being of the order of 21–32%. With increasing formaldehyde concentration both wet crease recovery and loss in strength increased. Similar effects were observed with an increase in the catalyst concentration and period of treatment. However, wet treatment with formaldehyde under room temperature conditions effected an improvement in wet crease recovery only, without any noticeable effect on dry crease recovery.

2.6.4 Rot-proofing

A process has been developed for rot-proofing jute fabrics by means of copper compounds added to the batching emulsion at the preparatory stage before the fibres are spun. The process is equally effective, and at the same time is more economical than the conventional process of proofing finished fabrics by wet treatment. It also requires a lower percentage of copper than the conventional process for effective protection against micro-organisms.

2.6.5 Woollenisation

When jute fibre is treated with strong alkali profound changes occur in its physical structure. Lateral swelling occurs, together with considerable shrinkage in length; the fibres are softened to the touch and develop a high degree of crimp or waviness. The crimp gives a wool-like appearance to the fibre. This process is known as woollenisation. On stretching the fibres break, the crimp is straightened and this increases the extensibility of the fibre.[66] The effect is small at alkali concentrations up to about 10% but the extensibility increases rapidly at concentrations of 15% upwards and may reach 8 or 9%. At the same time, however, the tensile strength of the fibre decreases with increasing alkali concentration. It is interesting to note that the product of extensibility and tensile strength, the breaking energy, appears to pass through a maximum at 15–20% concentration.[67] This has a beneficial effect on spinning because the carded fibre has a longer average length than normal and this results in a more uniform yarn.

The optimum temperature for crimp formation is about 2 ºC and at higher temperatures the crimp parameters are reduced, becoming zero at 40 ºC. An immersion time of at least 30 minutes is necessary for the crimp to be formed. The physical effects of the woollenisation process are different when the jute fabrics are kept under tension. Research[68] has shown that shrinkage is greatly reduced by tension, falling from 11 to 12% when slack to 1.5 to 2.5% under 3 kg tension. The appearance and handling of jute fabrics are greatly improved by the woollenising process, and bleached and dyed fabrics have good commercial possibilities.

2.6.6 Enzyme treatments of fabrics to improve their softness and smoothness

Chattopadhyay *et al.*[75] have found that a temperature of 55 ºC at a pH level of 5, a 1 : 10 material to liquor ratio and 4% enzyme concentration for a duration of 120 min. produces optimum weight loss for enzyme treated jute fabric. Chattopadhyay *et al.*[76] observed a substantial loss in jute fabric weight after enzyme treatment. Due to an increase in pore and consequently an increase in the exposure of lignin surface the crease recovery angle increased by about 25% whereas moisture regain, abrasion resistance and tensile strength decreased after resin treatment.

2.7 Economic and cost considerations

2.7.1 Manufacturing efficiency

In its traditional end-use, packaging, jute is now more costly than some of the competitive synthetic materials that are on the market. This is due to the higher labour intensiveness, and therefore higher labour cost, of jute production and manufacture when compared to synthetic packaging and although the skills involved are moderate, due to socio-economic conditions, the cost of labour is likely to continue to rise. The key to the solution of this problem lies in a rapid increase of labour and machine productivity. It is therefore appropriate to refer to some of the productivity norms that have been developed.[78] Achievable efficiency in the various stages of spinning and of weaving are shown in Tables 2.29–2.32.

Table 2.29 Achievable efficiency at the carding stage

Quality	Hessian/sacking warp		Sacking weft	
Processing stage	Breaker card	Finisher card	Breaker card	Finisher card
Achievable efficiency (%)	84.0	85.0	80.0	82.0

Courtesy: IJIRA, Kolkata.

Table 2.30 Achievable efficiency at the drawing stage

Processing stage	First drawing	Second drawing	Finisher drawing
Achievable efficiency (%)	71.0	72.0	72.0

Courtesy: NIRJAFT, Kolkata.

Table 2.31 Spinning frame efficiencies for different qualities of jute yarns

Quality	Hessian warp		Hessian weft		Sacking warp		Sacking weft
Count range (lb.)	7.0 to 8.5	8.5 to 10.5	7.0 to 8.5	8.5 to 10.5	9.5 to 12.0	Above 12.0	26–32
Achievable efficiency (%)	81.0	81.0	81.0	80.0	78.0	77.0	75.0

Table 2.32 Weaving hessian and sacking efficiencies*

Sl no.	Quality	Machine efficiency (%)
1.	Hessian	65.0
2.	DWT	70.0
3.	B. twill	75.0
4.	A. twill	75.0

* Hessian and DWT fabrics are woven on looms of 46.5″ reed space and A-twill and B-twill fabrics are woven on looms of 37.5″ reed space.
A-twill: around 550 g/m^2 B-twill: around 475 g/m^2

2.7.2 Jute exports

The jute industries grew differently in India and in Bangladesh; in India, the world's largest producer of jute and jute products, production of jute goods averaged about 1.5 million tonnes per year for the last five years. This level is about three times the average production of about 0.5 million tonnes per year in Bangladesh. In India, about 88% of the total jute products are consumed in the domestic market and hence the industry is governed largely by conditions in the domestic markets. On the other hand, 80% of the jute goods produced by countries like Bangladesh are exported and the industry is more exposed to world market conditions, facing competition. Table 2.33 gives details of the exports of the principal countries concerned.[79] [*Editor's note*: Of course, the exports of those countries that do not themselves produce jute fibre export either jute manufactured or semi-manufactured products made from imported fibre, yarn or fabric. In some cases, for example, the UK, Germany and the Netherlands these 're-exports' may well include substantial quantities of fibre as they will include the activities of international merchanting companies based in those countries that trade in textile raw materials.]

About 85% of the jute industry in India is mainly in the private sector, compared to 40% in Bangladesh. The technology used is similar in both countries, although the equipment is much older in India. Despite this the Bangladeshi mills run at lower efficiencies than the Indian mills: 70% compared

Table 2.33 World exports of products of jute, kenaf and allied fabrics

Country	Export in 1000 tonnes	Country	Export in 1000 tonnes
Developing countries		**Developed countries**	
Africa	1.4	USA	2.1
Guatemala	0.2	EC	50.4
Mexico	0.3	Belgium–Lux	26.6
Egypt	0.1	France	3.7
Syria	0.3	Germany	5.4
Turkey	0.3	Netherlands	6.5
Bangladesh	408.5	UK	5.1
China	6.5	Australia	0.2
India	176.5	Japan	0.6
Nepal	10.0		
Thailand	6.9		
Total	**616.1**	**Total**	**65.1**

Source: *http://www.fao.org/es/esc/common/ecg/28807.enBULLJune2003.pdf* Courtesy: Food and Agriculture Organization of the United Nations.

to 80% and incur substantial financial losses whilst the jute mills in India make a reasonable profit, estimated at about 7% of their sales revenue.[2] The poor financial results of the Bangladeshi mills are due not only to their lower productivity but also to the fact that, as stated above, they face greater competition on world markets than do the Indian mills on their home market. In China, the productivity is high and machine maintenance and quality aspects are good. There is great interest in diversifying the jute products that they produce. The existence of excess labour in the jute mill sector, particularly in Bangladesh is a major problem in the jute industry. This effect of excess labour is reflected in the very low labour productivity of the mills. On average, labour productivity in Bangladesh is about half of that in India.[2]

There is a need for 'skills' training both when recruiting new workers and also for the retraining of existing personnel in order to improve labour productivity. The International Jute Organisation (IJO) in Dhaka[2] has suggested essential strategies for the long-term survival of the industry, both in India and in Bangladesh. Their important conclusions are that:

1. There is a need to set up a framework which would enable information and advice to be freely exchanged between companies on such subjects as product diversification, for example.
2. There is a need to reduce costs by
   (a) ensuring stable prices of raw material
   (b) achieving higher manufacturing efficiencies and actively involving workers in improving productivity
   (c) producing lighter weight products

(d) utilising waste
(e) conserving energy
(f) reducing the variety of products manufactured.

3. There is a need to balance, modernise and replace machinery.
4. There is a need for product quality standards and their maintenance by
   (a) adhering to optimal product norms
   (b) quality control
   (c) staff and management training.
5. Developing and implementing appropriate sales and marketing policies is essential.

IJO has also identified the following as thrust areas essential for jute product development in the future.

Traditional jute products

- variety reduction
- improvement in product brightness (lustre)
- improvement in the quality of carding
- reduction of fibre shedding
- odour improvement
- greater use of shuttleless looms for weaving so as to achieve improvements in manufacturing efficiency, product quality and the development of new products.

Diversified (new) jute products

- jute for use in paper pulp
- jute geo-textiles
- carpets
- consumer items – jute and jute blends (luggage, etc.)
- decoratives (furnishing fabrics).

2.8 Market development

Jute used to be regarded as an export-orientated commodity that enjoyed a world-wide monopoly market. However, this was to be challenged by the advent of synthetic fibres in the early 1960s. By the late 1970s high-density polyethylene and polypropylene began to take a share of the packaging market and similarly, synthetic carpet backing cloths attacked that particular market, in which jute was paramount at the time. From the point of view of jute the situation has continued to deteriorate, as is shown by the fact that the international market for jute goods (world exports of jute and allied fibres +

goods made from these fibres) which was of the order of 1.3 million tonnes at the beginning of the 1980s has come down to about 1 million tonnes at present.

In this situation any marketing strategy adopted by Bangladesh, India or China should have the objective of arresting further erosion of these international markets. This would require aiming at new classes of consumer with newer jute products and would entail producing these ranges of new, diversified, jute items. This also implies a transformation in the role and utilisation of jute fibres from packaging to the production of a wider selection of textiles, from geo-textiles to finer fabrics for a variety of end-uses, some of which have been touched on above.

2.8.1 Textile development possibilities of jute fibres

As we have seen in previous sections of this chapter it is now possible to spin fine and regular yarns of up to 4 lb. (or 138 tex). These yarns and fabrics made from them can now be subjected to all types of dyeing, printing and finishes. Jute can be blended with viscose staple fibre, polypropylene, wool, ramie, pineapple fibres, etc. These blends normally have jute as the predominant fibre. Generally 6 denier 100 mm or longer fibres are used to ensure a satisfactory blend. Dyeing is satisfactory and reaches a light fastness of 5+ and washing fastness of 4+. All shades including pastels can be dyed and the fabrics can be shrink-resisted, crease resisted, flame retarded, stiffened, softened, woollenised, etc.

Jute has a number of desirable properties; high breaking and tear strength, good sheen and lustre, inelasticity and dimensional stability, thermal insulation, bulk and a unique texture. It has a raw and natural look, which is appreciated by western consumers. After blending and in union with fabrics some of these properties are further highlighted. It is a common notion that jute is not washable. It is true that the wet strength of jute is lower than its dry strength but in no textile application is jute used when wet and even when being washed and the fibres subjected to pressure and linear and shear stress the strength of the fabric is fully adequate. It should also be noted that jute has superior washability to that of wool or silk.

Union fabrics of jute/cotton with cotton yarn in warp and jute in weft form an important item in the area of jute diversified products. It is also possible to produce union and blend fabrics having cotton in warp and jute/viscose or jute/PP in the weft.

Decorative jute is traditionally used as a wall covering fabric. Correctly finished jute blended fabrics will make excellent furnishing fabrics for use in upholstery and for curtains, screens, etc. For some furnishing end-uses such as upholstery a small proportion of nylon staple fibre (about 5%) is sometimes added to the blend to further increase abrasion resistance. Buckram or interlining fabric is also another recognised end use. Properly finished and printed fabrics can also be used as dress material and for other apparel uses in colder climates.

Jute/pp fabrics can also be converted into attractive blankets after proper finishing and especially raising. Jute fabrics of appropriate construction can also provide an excellent substrate for PVC and other coatings.

Blended yarns of jute/PP after woollenisation have an appearance similar to wool and they have equally good, if not better, thermal insulation properties. They can be made very soft and dyed to fast and attractive colours. It should also be possible to spin these blended yarns to finer counts than 100% jute. Such yarns would be better than 100% wool in many respects, for example, in washability and durability. Also they would be relatively inexpensive. Jute/PP yarns should also have considerable abrasion resistance and even some resilience and as carpet face yarns they could find a substantial outlet. They can also be used for the manufacture of superior quality blankets.[94] Such yarns could also be a good substitute for wool for knitting purposes. They would be better than 100% synthetic products such as acrylic yarns, which have very little weight and natural feel. However, the development of suitable yarns would require a considerable technical effort in order to produce knitting quality knotless yarns suitable for use high production knitting machines so as to allow for mass production, which would be their obvious market as the yarns would be competitive in price with other yarns used in the knitting industry.

Jute/viscose yarns will also enable the production of finer yarns. Viscose is a versatile fibre with good sheen and softness and blending with jute results in a good quality yarn, comparable to raw silk in sheen and look. These yarns can be dyed to fast colours and be subjected to all types of chemical processing such as heat setting, mercerising, fire retardancy, water proofing, etc. These yarns could also be knitted and would produce attractive hand- or machine-woven fabrics which would increase the size of the market open to jute as they would be less expensive than jute-cotton blends because cotton prices in eastern regions of India are increasing. In this respect jute would also have the advantage of being produced locally which would also reduce its total cost to spinners.

Hand and power looms are able to produce jute and jute blended fabrics in a variety of designs and in small lots according to consumers' preferences, which is a major marketing advantage when compared with most other textile producers throughout the world and should provide major export opportunities.

2.8.2 Potential markets for jute products

South America

South American countries are large producers of coffee and other agricultural commodities, a high proportion of which are exported. These need to be protected from damage whilst being transported and close woven, odourless jute bags of the required sizes are well placed to supply this requirement at an economical cost. South America also has a large carpet industry for which there may be some scope for jute carpet backing cloth (CBC).

Decorative jute fabrics and their end products such as wall coverings, shopping bags, wall hangings, etc., should enjoy good demand in these countries. There should also be scope to sell blankets, dhurries, postbags, brattice cloth etc. The substrate for PVC leather cloth, linoleum and other coated products should also form an attractive area for export in these countries.

Africa

Like South America, some countries, Kenya and Uganda for example, are exporters of agricultural commodities and could use considerable quantities of jute sacking. The continent should also offer a substantial market for jute decoratives as furnishing fabrics and also for its end-products such as different types of shopping bag, school bags, etc. There also should be good market for jute and jute blended blankets, dhurries, seed bags, postbags, etc. Bags for packing of industrial products such as cement, sugar and certain chemicals should also create a demand from the industrial units in some of the countries in the region.

Middle East – Iran, Egypt, Sudan, Pakistan, etc.

These countries have a large and increasing requirement for jute bags and other products for packing agricultural and industrial products. Special bags made from laminated jute fabrics, lighter bags, and union bags should also help to increase the size of this market.

Japan and Eastern Asia

Japan is a big user of jute goods and has an increasing demand for a number of jute products. It imports large quantities of rice bags manufactured to its own specifications. It is also one of the biggest buyers of jute yarns. Blended yarns of jute and other bast fibres should offer very good scope in this market. With adequate market development jute decoratives and other end products should meet with considerable success. Wall coverings in particular should quickly become popular with consumers in most of the region and particularly in Korea, Hong Kong, Singapore, Malaysia, and Taiwan, etc. Japan also imports large quantities of CBC.

Australia and New Zealand

Australia and New Zealand are already consumers of jute. Decorative products, jute yarns and CBC in particular are well established but there is, however, still a good deal of scope to increase the usage of jute goods in these countries by offering better designed products for specific end uses. Australia could also be a good market for jute soil savers, mattings, decoratives and their end products such as shopping bags, wall coverings and also for brattice cloths and substrates for PVC and other coatings.

Europe and the USA

Europe and the USA offer tremendous scope for value added products in the areas of decoratives, wall coverings, small finished products (shopping bags, luggage, etc.). Blended fabrics and yarns could be another potential product base in these countries, particularly as carpet face yarn and in the manufacture of furnishing fabrics. The use of jute yarn as carpet weft, fuse yarn, cable yarn and for the weaving of decorative fabrics also has a large potential. Linoleum backing, substrates for PVC leather cloth webbing and mattings, etc., are also markets capable of being developed. Soil savers are already attracting extensive enquiries. Final products made from blended yarns and fabrics could also open up a large market for value added merchandise. All these items require a good deal of promotional effort and a sound product base.

The will and determination of jute and textile entrepreneurs to bring out the advantages of fine jute yarns, blended yarns, speciality jute fabrics, and the many other final and intermediate products mentioned above in areas hitherto not tested by many consumers from all over the world could make jute a real international fibre and an integral part of the world's textile industry. Jute should be projected[64] as a genuine member of the textile family as it has now become finer and is available in blends capable of meeting the exacting requirements of the global textile industry's consumers.

2.8.3 Market promotion

In India, an organisation known as the Jute Manufacturers Development Council (JMDC) assists in the marketing of jute products. Some of their important activities include

- the participation in and organisation of specialised trade fairs, buyer-seller meetings, workshops and seminars
- sponsoring delegations and commissioning market surveys and commodity studies
- providing commercial information and market intelligence surveys to the jute industry and trade
- the identification of new and diverse uses of jute and the encouragement of their manufacture and sale
- the implementation of internal market assistance and external market assistance schemes
- running the jute show rooms.

Another agency, the National Centre for Jute Diversification (NCJD) acts as the nodal agency for entrepreneurship and development in the Indian jute sectors. One of its main objectives is to develop need-based programmes for the popularisation and adoption of jute diversified products. The NCJD also encourages weavers and craft workers living in rural areas and who work in the unorganised sectors to adopt diversified jute products.

An important scheme operated by the NCJD, the Jute Entrepreneurs Assistance Scheme (JEAS) aims at exploring new application areas for jute products and spreading the production base of jute diversified products.[80] According to available information,[81] in India there are about 90 manufacturing units involved in jute diversification projects assisted by the NCJD. This organisation's financial contribution to these projects totals nearly Rs.190 million ($US4 million), which has, in its turn, generated capital investment of over Rs.1,000 million ($20.8 million). The range of the jute diversified products manufactured in these assisted units include

- jute fine yarns
- jute decorative fabrics
- laminated particle board for knock-down furniture
- jute composite board for automobiles and industrial clutches and brake linings
- shopping bags and laminated teabags
- jute non-woven fabrics
- jute cotton blended dhurries
- jute stick particle board
- jute composites and roof ceiling
- jute yarn based moulded items
- hand made paper and allied products
- jute thermoplastic composite board
- soft luggage and briefcases
- fashion garments and accessories.

Another scheme, the Technology Upgradation Fund Scheme (TUFS), is operated by the Ministry of Textiles (Jute) and its aims are to assist the introduction of state-of-the-art[82] or near state-of-the-art technology into the jute mill sector.

2.9 Environmental considerations

Jute, as a biodegradable natural product, is environmentally friendly. It does not pollute the environment either during agricultural cultivation, conversion to jute goods in the industry, transport and usage of jute products or in their ultimate disposal after use. Jute bags and sacks are reusable which not only makes them environmentally friendly but also cheaper than disposable packaging. Jute consumes less energy both during cultivation and conversion to final products than many other textiles, and particularly cotton and synthetics. Jute is annually replaceable. Jute geo-textiles have also proved to be superior in soil erosion control.[83]

Jute geo-textiles also have potential for newer applications other than soil erosion and in some cases are already being used for these purposes, for example, as

- reinforcement in temporary hull (unpaved) roads, rural roads, landscaping, etc.
- reinforcement fabric during the construction of highways
- vertical wick drains to accelerate drainage of water in soils.

The Motz Group[84] has developed a combined synthetic/jute natural turf for athletics fields. The jute in the fabric backing retains moisture and promotes the growth of natural grass, and decomposes over a known period. Geo-jute materials[85] retain moisture up to five times their own weight and are used for soil protection under conditions of heavy rainfall. United Bonded Fabric Pvt. Ltd. of Australia[86] have developed and patented jute geo-textiles to promote soil stabilisation and protection from rainfall erosion by infiltration of water into the soil beneath the fabric.

A joint study conducted by IJIRA and the Dept of Forestry, Govt of West Bengal[87] revealed that open mesh jute woven fabric (geo-textile) could be used for the protection of forests in coastal areas where sand erosion occurs due to high winds and rain.

2.10 Health and safety considerations

Jute fibres are pre-treated with hydrocarbon-based Jute Batching Oil (JBO) to improve spinning performance. The migration of these hydrocarbons from JBO processed jute sack fabrics into the contents of the sacks contaminate them. A study has been made by Mustafizur Rahman,[88] that in a 1 kg jute sack made from fibre pre-treated with 5% JBO, 3.7 g of the JBO residue is transferred to its contents in constant contact with the sack surface. If the mass of the contents is 50 kg then the level of the contamination would be 74 ppm.

The International Jute Organisation (IJO) has adopted a standard for the manufacture of jute bags used in the transport of certain food materials (cocoa beans, coffee beans and shelled nuts). This standard, IJO standard 98/01[95] came into effect from October 1999 and provides a universally acceptable specification. Rice Bran Oil (RBO) technology developed by IJIRA[89] is an eco-friendly cost-effective process for the production of jute sacks suitable for packing foodstuffs. RBO-treated jute is free from hydrocarbons and complies with international eco standards.

2.11 Acknowledgements

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2.12 Appendices

Appendix A: jute's allied fibres – kenaf (*Hibiscus cannabinus*), roselle (*Hibiscus sabdariffa*) and urena (*Urena lobata*)

General

The fibres from these three plants are taken together because the extraction of their fibres, their textile processing and the articles which are made from them are, to all intents and purposes, the same as jute's – even to the extent that the United Nations Food and Agriculture Organisation (FAO) groups their statistics under one heading: 'Jute-like fibres'. They are all members of the mallow (*Malvaceae*) plant family. These plants have many different names, amongst the most common are in India where kenaf and roselle are also known as mesta or bumli. In different countries of Africa urena is called 'congo-jute' or rama-rama and in Central and South America guaxima, uassima and carillo. Kenaf is also sometimes called guinea hemp.

The three species are tropical crops and when cultivated grow to about three metres. Kenaf and roselle are annuals and whilst urena is a perennial it may also be cultivated as an annual. The principal differences between the three species and between them and jute are that kenaf and roselle are less demanding in their soil and climatic conditions. As long as the soil is well drained kenaf will grow in drier and poorer soils than jute and roselle can survive even drier condition than kenaf. Urena requires more moisture than both and a richer soil.[3,96] The cell structures of roselle and kenaf are almost identical. Some of the physical and chemical properties, and a description of the morphology of these fibres can be found in Tables 1.8a, 1.8b and 1.10 in the appendix to Chapter 1.

Early processing

These three fibres, when produced on smallholdings, are usually decorticated in ways similar to jute, but when cultivated on large estates mechanical ribboners of differing complexity may be used. Two of these are illustrated in Figs 2.10 and 2.11.

Figure 2.10 Hand ribboning kenaf stems using bicycle wheel hub. Source: C. Jarman, *Plant fibre and processing: A handbook*. Courtesy: Intermediate Technology Publications, UK.

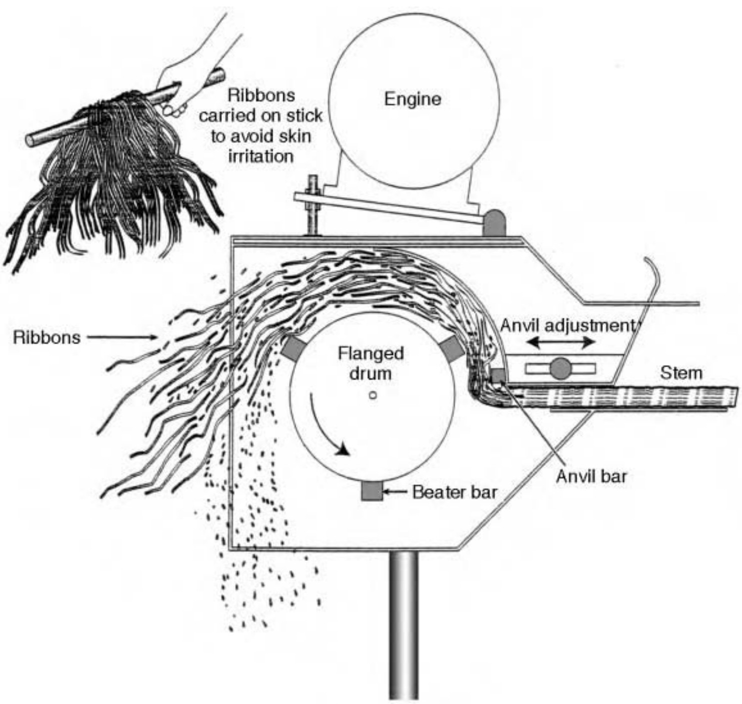

Figure 2.11 Alvan blanch ribboner. Source: C. Jarman, *Plant fibre and processing: A handbook*. Courtesy: Intermediate Technology Publications, UK.

Production statistics

As can be seen from Table 2.34 the production of these three fibres is fairly well spread over the world's tropical countries. As can also be seen from the table the main producing countries are China, India, Thailand and Russia.

Table 2.35 shows that annual production from 1998 to 2002 has been steady at around 400,000 tonnes but that production has decreased by 50% or more since the 1970s and 1980s. If we compare this drop in production with the production of jute over the same period (Table 2.36) we see that the production of jute has remained reasonably constant. It would seem, therefore, that it is the jute-like fibres that have borne the brunt of the competition provided by synthetic fibres, principally polypropylene and polyethylene, that started penetrating many of jute's markets at about that time.

Table 2.34 Production of jute-like fibres by country (2003) (kenaf, roselle and urena)

Jute-like fibres production (tonnes)	2003
Angola	1,000
Bangladesh	1,000
Brazil	9,349
Central African Republic	88
Chile	10,000
China	75,000
Congo, Demoractic Republic of	5,866
Cuba	10,000
El Salvador	3,000
Ethiopia	750
Guatemala	400
India	196,470
Indonesia	7,500
Madagascar	600
Mali	1,300
Mozambique	3,300
Myanmar	30
Nigeria	900
Pakistan	2,200
Russian Federation	48,000
South Africa	1,100
Spain	0
Thailand	57,000
World	434,853

Source: FAOstat.
Courtesy: Food and Agriculture Organization of the United Nations.

Table 2.35 World production of jute, kenaf and allied fibres 1998–2002 ('000 tonnes)

	1998/99	1999/2000	2000/01	2001/02
Jute fibre				
World	**2,212.4**	**2,105.0**	**2,185.0**	**2,501.0**
Developing countries	**2,212.4**	**2,105.0**	**2,185.0**	**2,501.0**
Far East	2,212.4	2,105.0	2,185.0	2,501.0
Bangladesh	851.9	731.5	820.0	876.6
India	1,311.8	1,331.8	1,422.0	1,580.0
Myanmar	33.5	26.5	27.8	28.0
Nepal	15.2	15.2	15.2	16.4
Kenaf and allied fibres				
World	**553.6**	**459.8**	**420.0**	**450.3**
Developing countries	**546.3**	**452.8**	**413.0**	**443.3**
Far East	501.2	410.0	371.7	403.5
China	248.0	164.0	126.0	136.0
India	182.2	198.2	198.0	220.0
Cambodia	2.0	2.0	2.0	2.0
Indonesia	7.2	7.0	7.0	7.0
Thailand	47.2	29.7	29.6	29.5
Vietnam	14.6	9.1	9.1	9.0
Latin America	27.1	25.4	25.7	25.0
Brazil	8.6	7.9	8.2	8.0
Cuba	10.0	10.0	10.0	10.0
Africa	13.8	13.7	12.0	11.5
Near East	4.2	3.7	3.6	3.3
Developed countries	7.3	7.0	7.0	7.0
Total jute, kenaf and allied fibres				
World	**2,766.0**	**2,564.8**	**2,604.9**	**2,950.7**
Developing countries	**2,758.7**	**2,557.8**	**2,597.9**	**2,943.7**
Far East	2,713.6	2,515.0	2,556.6	2,903.9
Bangladesh	851.9	731.5	720.0	876.6
China	248.0	164.0	126.0	136.0
India	1,494.0	1,530.0	1,620.0	1,800.0
Cambodia	2.0	2.0	2.0	2.0
Indonesia	7.2	7.0	7.0	7.0
Myanmar	33.5	26.5	27.8	28.0
Nepal	15.2	15.2	15.2	16.4
Thailand	47.2	29.7	29.6	29.5
Vietnam	14.6	9.1	9.1	9.0
Latin America	27.1	25.4	25.7	25.0
Africa	13.8	13.7	12.0	11.5
Near East	4.2	3.7	3.6	3.3
Developed countries	**7.3**	**7.0**	**7.0**	**7.0**

Source: FAOstat.
Courtesy: Food and Agriculture Organization of the United Nations.

Table 2.36 World production of jute 1964–2003 (tonnes)

Year	Production	Year	Production
1964	2,281,496	1995	2,414,476
1969	2,608,222	1996	2,985,778
1974	1,900,496	1996	2,201,705
1979	2,681,216	1997	2,201,705
1984	2,610,283	1998	2,634,317
1989	2,597,949	1999	2,592,293
1994	2,696,826	2000	2.657,000
		2001	2,923,740
		2002	2,784,740

Source: *www.fao.org* Courtesy: Food and Agriculture Organization of the United Nations.

It is not possible, from the available FAO data, to determine the actual production of each of these three fibres, kenaf, roselle and urena. However, by assuming that the African and American countries produce mainly urena and the Asian countries kenaf or roselle we can establish that the annual world production of arena is approximately 40.000 tonnes, leaving, again approximately, 400,000 tonnes for the other two fibres.

Appendix B: jute world fibre production

Table 2.37 Production of jute by country (2003)

Jute production (m.t)	2003
Bangladesh	800,000
Bhutan	350
Brazil	1,567
Cambodia	650
Cameroon	100
China	90,000
Egypt	2,200
India	1,789,000
Iran, Islamic Republic of	0
Japan	0
Myanmar	41,887
Nepal	17,500
Pakistan	22
Peru	200
Sudan	3,350
Thailand	5,000
Uzbekistan	20,000
Vietnam	21,000
World	2,792,826

Source: *www.fao.org* Courtesy: Food and Agriculture Organization of the United Nations.

[*Editor's note*: Compared to many of the other fibres covered in this book jute has kept up its production reasonably well over the past 40 years, although with a few years with below 'normal' quantities (1974, 1996 and 1997). But this is not the full story because the production of the 'allied fibres' (kenaf, roselle and urena) decreased considerably and they are part of this particular part of the textile market. It would seem that the reason why jute did not suffer from the overall decrease in the market for these fibres was that India is not only, by far, the largest producer (see Table 2.37) but that most of India's production is consumed within the country which was, at least to some extent and during this period, a sheltered economy. This, perhaps, sheltered Indian jute from the competitive factors affecting other countries, such as Bangladesh. These export a greater part of their production to 'developed' markets where they would have had to face severe price competition, not only from jute producers in other countries, but also from synthetic fibres such as polypropylene, polyethylene and to some extent, nylon.]

Appendix C: Recent developments in retting methods

The Central Research Institute for Jute and Allied Fibres (CRIJAF), the Jute Technological Research Laboratory (JTRL), known at present as the National Institute for Research on Jute & Allied Fibre Technology (NIRJAFT)[12,15] and the Indian Jute Industries' Research Association (IJIRA)[7,14] have developed various methods whose objectives are to improve the quality of fibres obtained by biological (bacterial) retting.

The CRIJAF[16] technique

This depends on retting the machine decorticated jute ribbons in normal water, with the object of attaining complete retting of the stalks in a limited supply of water. But because of the damage done to the fibre during decortication and the high cost of decortication by machine the process is not considered to be viable in its present state of development.

The JTRL technique

Scientists at JTRL have sought to improve fibre quality by applying separate treatments at both pre- and post-retting stages. The pre-retting treatment of stems, which has undergone several years of field trials, consists of preparing an inoculum of bacteria which is claimed to accelerate retting. A dilute suspension of this bacterial culture, to which a solution of urea has been added, is then sprayed over the whole body of the green stems.

The process is as follows: the inoculum culture is prepared in the field where the jute bundles are stacked after harvesting. Small cut pieces of green stems are placed in a large receptacle into which a solution of nutrients in water has previously been poured. These nutrients could be sulphides and nitrides of potassium, calcium and magnesium. The inoculum, previously prepared in the laboratory, is mixed with the jute stem nutrient mixture in the receptacle and allowed to multiply for some days, utilising the jute stems as a carbon source. A dilute solution (4–5%) of urea in water is prepared and mixed with the bacterial suspension obtained from the green stem culture in the field. The dilute culture-urea mixture is then applied by garden spray to the bundles of jute stems spread in thin layers on the field. The mixture is applied more profusely to the butt ends of the stems. The bundles are then steeped in water for normal retting. This process produces a marginal improvement in the quality of treated fibres compared to control fibres also retted in the same tank. No tangible reduction of under-retted barky root ends is possible by this JTRL method.

A post-retting treatment has also been developed at this Institute to upgrade lower qualities of jute fibre produced by the ribbon retting route and freshly extracted from the retting tank. The wet fibres are spread on the ground and sprayed with a dilute solution of urea and ammonium dihydrogen phosphate. This is followed by spraying with a fungal culture powder. In actual practice the fungal culture mixed with kaolin is distributed among the farmers in 500 g polyethylene packets. After treatment, the fibre stack is covered with a big plastic sheet to prevent the loss of water by evaporation for a couple of days or thereabouts to complete the retting process. The fibre is washed again in 'clean' water to remove the barks, etc., and dried. This fungal treatment of fibre at the post-retting stage followed by stacking for a further duration and rewashing in clear water is claimed to be effective in improving the quality of the fibre treated. However, considering the cost and overall effort involved in this treatment, the extra costs of labour for washing the fibre for the second time and of the chemicals and fungal spores (excluding the attendant cost of a culture plant for producing the spores), the unavoidable lengthening of the overall period of retting and the possibility of pilferage of fibre stacked on the ground, the process cannot be considered applicable on a large scale in the field.

The Ministry of Agriculture suggestion

To facilitate the process of retting the insertion of three or four sticks of leguminous plants such as 'sun hemp' or 'Dhaincha' in each jute bundle is suggested by the Directorate of Jute Development, Ministry of Agriculture, and the Government of India.[16] Also, to attain uniform retting, it is suggested that the two to three feet basal portion of the bundles be kept under water for two to three days, prior to conventional retting. While the presence of stems of leguminous plants certainly exerts a benign influence on the retting of jute stems, the effort of giving extra retting to the root ends of stems by standing them for two to three days in knee-deep water is not always effective. Mud sticking to the root portions is often found to destroy the lustre and colour of the retted fibre. Also water of the required depth is not always available.

The IJIRA technique

IJIRA's improved retting technique is based on mildly crushing the basal portion of stems to produce a little cracking of the bark and then steeping the root portion only in a 4–5% solution of urea. This not only ensures complete elimination of any under-retted barky roots but improves the quality of the resultant fibre by one to two grades, especially in areas where water is scarce. This also reduces the total period of retting by three to four days in the case of jute and five to six days in the case of mesta.

The rationale of the method is that biological retting of jute involves a complex array of micro-organisms that occur abundantly in the retting ponds and that creation of conditions which facilitate their entry into the stems and particularly into their roots will naturally lead to uniform retting and consequent improvement in the quality of the fibre. Since biological retting, in nature, is not the handiwork of any single species of bacteria the effect of adding an inoculum of any single micro-organism is not likely to be felt amongst the multitude of adventitious bacteria already present. On the other hand, the growth-stimulating influence of urea added in the process is felt not only at the root end of the stem, but also through its entire length as the exposed xylem tissue of the roots will ensure that the chemical is carried up the stem during the steeping of the root-malleted plants in its solution. In this way a very small quantity of urea simply applied to the root side of stems is an effective method of increasing the rate and uniformity of retting and therefore of improving the quality of the fibre.

IJIRA's pre-retting process[7] is simple. The green stems of jute plants are mildly thrashed with wooden hand mallets at their root end so that only the outer bark is crushed at several points, whilst the central woody core remains intact. Several stems are seized by the worker in his left hand with the root ends held over a hard object such as a piece of log or brick. Some 25–30 cm of the bottom portions of the stems are beaten in three to four places by a wooden or bamboo mallet wielded by the right hand of the worker. The stems are then turned over by a twist of the left hand for malleting their undersurface as before. It is preferable to carry out this mild crushing of the stems by using a hand-driven mechanical device, such as those that are available from the various Indian jute institutes as the operation then take less time and costs less. After crushing, the stems are tied into bundles as usual, these are then held vertically for 3–4 minutes in a large drum containing a 4–5% solution of commercial grade urea at ambient temperature so that the crushed portions of the stems are completely immersed in the urea solution. They are then stacked on the field for transportation to the retting tanks.

The urea acts in two ways: first, as a swelling agent to the barky tissues which develop numerous tiny fissures after swelling, thus further improving the access of the retting bacteria to the cambium layer of the stalk, and secondly, as a nutrient to the retting microbes, which are thus stimulated to bring the whole process of retting to completion in a shorter time than would otherwise be the case. IJIRA[14] have also established that jute ribbons can be retted by using proprietary enzyme preparations rich in pectinase for 48 hours. Pectinex Ultra Spl and Flaxzyme from Novo Industry A/S, containing predominantly high pectinolytic activity, were used in this study. Fibres obtained from enzyme retted ribbons have higher strength than those produced by conventional or ribbon retting. In the presence of a citrate phosphate buffer or ethylene diamine tetra acetic acid (Na-salt) enzyme mediated retting is improved This enzyme based retting process, however, is only of academic interest and cannot be a practical proposition because of the prohibitively high cost of the enzymes.

In conclusion, it is the authors' view that conventional biological retting of jute and mesta in abundant, clean water preceded by the IJIRA's malleting/urea treatment of the root portion of stems is the best available method for improving the quality of jute fibres. If the farmers are given a proper price for the higher quality grades of fibre obtained by following this simple technique the extra cost involved would be fully covered as it amounts to only 25% of the potential price gain.

Appendix D: non-textile uses of jute

Jute-based paper pulp

Jute has been identified as a useful raw material for paper manufacture. However, the prices at which jute is available in major jute-growing countries in comparison with the prices of other raw materials such as bamboo, straw, baggage, wood pulp, etc., are a stumbling block for the paper industry in adopting jute as a raw material. Although there are advantages, from the point of view of quality, of using jute for the manufacture of paper this improvement is not at present accepted by the industry as sufficient to justify the use of jute on a substantial scale.

Jute sticks are used for the manufacture of paper pulp. However, there is a need to devise cost-effective ways[2] of collecting, handling, transporting and storing the sticks as well as of establishing a regular distribution network of the resultant product. The use of jute/mesta stalks (whole plant) for papermaking has been experimented with in India by the paper industry and present production is around 18,000 tonnes, or about 1.3% of the average annual raw jute production of 1.3 million tonnes. Bangladesh has set up a jute-based paper plant and is also taking further steps to establish further jute-based pulp and paper production.

The technology for jute-based paper is available but, apparently, the economy lies in captive plantations of jute to provide assured and adequate quantities of raw material for large-scale paper plants. With deforestation being discouraged as an environment-protection measure the prospects for jute-based paper are at least feasible in the long term but specific market-orientated products are yet to make a commercial breakthrough. In the manufacture of certain speciality tissue papers and in the manufacture of newsprint, jute-based paper pulp has been successfully used in blends with normal paper pulp and perhaps such blends would be a necessary intermediate step, paving the way for the eventual use of 100% jute pulp.

Use of jute in pulp and paper

For making pulp,[65] jute and allied fibres are used in several forms, for example as:

- a whole jute plant
- jute sticks
- bast fibre
- mill wastes having virgin fibres (yarn waste, gunny cuttings, caddies, etc.)
- recycled fibres such as old gunny wastes, etc.

Jute is an excellent long fibred raw material[12] for the paper industry. It has certain advantages:

- It is an annual renewable resource whereas the cycle is much longer for hard wood or bamboo.
- It is biodegradable and eco-friendly.
- Unlike bamboo or wood, it does not need a chipping operation (but may need a breaking operation).
- Jute has less lignin content compared to bamboo or wood and is easier to cook.
- The yield of jute is higher at 60–62% compared to 40–45% for bamboo, 42–45% for wood, 28–30% for straw or 13–15% for bagasse.
- It is less bulky to handle and store.
- Jute has long fibres and therefore gives better machine runnability.

Jute structural composites

Composite materials are increasingly replacing metals and wood (as they may be lighter and less expensive). Although plastics on their own are also used for these purposes, they are not very effective in performance. Asbestos is carcinogenic. Generally among composites, glass fibre/resin composite is popular but expensive, though it is very effective in performance. The physical properties of laminated and non-laminated jute stick particle board are given in

Table 2.38 Physical properties of paper from jute pulp

Weight (g/m^2)	Average tensile strength (kg)	Tensile index (Nm/g)	Average burst strength (kg/cm)	Burst index ($kPam^2/g$)	Density (g/cc)
134.89	4.5	21.82	3.33	2.42	0.29
144.78	6.25	28.23	3.73	2.52	0.31
168.22	5.5	21.38	3.47	2.02	0.35
168.44	5.65	21.93	3.73	2.17	0.33
174.33	5.4	20.26	3.4	1.91	0.26
251.67	9.33	24.24	4.5	1.75	0.61
275.89	11.47	27.19	6.0	2.13	0.64
277.78	8.47	19.94	4.13	1.45	0.65
287.22	13.6	30.96	7.0	2.38	0.59
303.11	10.23	22.07	4.9	1.58	0.72

Source: Mitra, B. C., *Data book on jute*, January 1999. Courtesy: National Institute of Research on Jute and Allied Fibre Technology (NIRJAFT), Kolkata.

Table 2.39. Particle boards produced from jute sticks have excellent sound-absorption properties. The composites can absorb about 80% of sound at a frequency of 4000 Hz. The properties of jute composites (Table 2.40) developed by IJIRA[13] are comparable to those of medium density fibre boards.

Substantial amounts of research have been reported in the field of jute composites.[51–59] These cover the use different resins and manufacturing techniques and the quality characteristics of the resulting composites. The potential market for jute-reinforced plastics[60] is based on the specific properties of jute. These are high strength, high modulus and low cost. Jute in the form of fibre, sliver, twine or non-woven fabric is mixed with a binder system (epoxy resins, polyesters or polypropylene) to form the composites for various uses as listed below:

- Architecture: for false ceilings, panelling, partitions, doors and windows, furniture and pre-fabricated shelters.

Table 2.39 Physical properties of laminated and non-laminated jute stick particle board

Sample	Impact strength (kgf/cm)	Flexural strength (MPa)	Tensile strength (MPa)
(a) Particle board	2.1	11.16	4.8
(b) Laminated (polyester) particle board	10.0	16.2	8.24

Source: Mitra, B. C., *Data book on jute*, January 1999. Courtesy: National Institute of Research on Jute and Allied Fibre Technology (NIRJAFT), Kolkata.

Table 2.40 Comparative properties of jute composites and medium-density fibre boards

Property	MDF Exterior grade	MDF Interior grade	Jute composites
(i) Bulk density (kg/m^3)	500–900	500–900	953
(ii) Moisture content (%)	5–15	5–15	3.04
(iii) Water absorption (%) max.			
(a) 2 h soaking	6	9	5–10
(b) 24 h soaking	12	18	12–33
(iv) Linear expansion (swelling in water %, max.)			
(a) Due to general absorption after 24 h soaking			
1. Thickness	4	7	3–18
2. Length	0.3	0.4	0.26
3. Width	0.3	0.4	0.2
(b) Due to surface absorption	4	5	2–14
(v) Modulus of rupture (min.) (N/mm^2)	28	28	43.66
(vi) Tensile strength perpendicular to surface (min.) (N/mm^2)			
(a) Fresh	0.8	0.7	1.2
(b) After cyclic test	0.4	–	0.99
(c) After accelerated water resistance test	0.25	–	0.26
(vii) Screw withdrawal test (min.)			
(a) Face	1,500	1,500	Not applicable (thickness of sheet is less)
(b) Edge	1,250	1,250	

Courtesy: IJIRA, Kolkata.

Table 2.41 Some quality characteristics of jute/polypropylene and polypropylene composites

Properties	Type of composites: Polypropylene	Jute/polypropylene: With adhesive	Jute/polypropylene: Without adhesive
Density (g/cc)	0.90	1.02–1.17	1.02–1.17
Flexural strength (MPa)	41.00	72.92–112.20	56.48–28.83
Flexural modulus (GPa)	1.40	4.50–9.50	4.50–10.50
Tensile strength (MPa)	33.00	49.55–72.87	36.01–33.65
Izod impact strength (J/m) (notched)	24.00	28.00–33.73	26.90–32.19
Water absorption (%)			
2 h boiling	0.10	0.77–2.22	0.93–3.06
24 h cold soak	0.02	0.44–0.91	0.56–1.86

Source: Private communication. Courtesy: IJIRA, Kolkata.

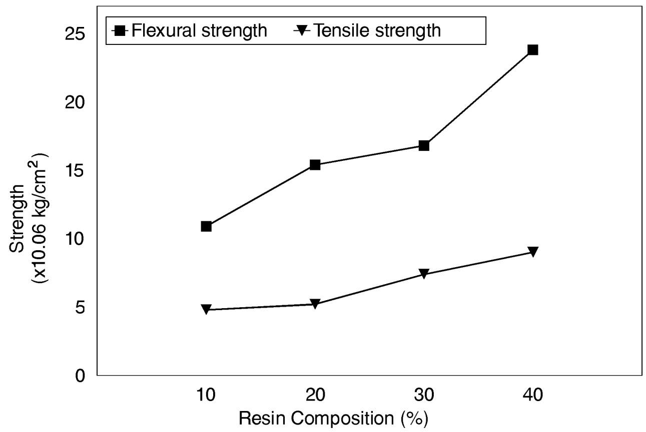

Figure 2.12 Physical properties of jute stick particle board. Source: Mitra, B. C., *Data book on jute*, January 1999. Courtesy: National Institute of Research on Jute and Allied Fibre Technology (NIRJAFT), Kolkata.

- Transport: for bus or railway coaches, auto trims, ship interiors, dashboard panels, etc.
- Engineering components, brake linings, moulding materials, etc.
- Other applications such as packing boxes, signboards, letter boxes, etc.

Jute has also been reported as being used for building materials such as fibre reinforced concrete and roofing tiles, and bituminised runway coverings. Studies by NIRJAFT[12] revealed that flexural strength, tensile strength and impact strength improves with increase of resin component in jute stick particle board (Fig. 2.12) used for interior decoration.

Appendix E: jute testing instruments developed by SITRA

The South India Textile Research Association (SITRA) at Coimbatore has developed several electronic instruments[77] for measuring the compressibility, roughness, dimensional stability and extensibility of jute fabrics.

Testing for handle

Compression

Fabric softness is one of the most frequently used terms in comfort performance by consumers. Fabric compressibility, i.e., the difference in fabric thickness at different loads, gives an objective measurement of the softness or fullness of the fabric. The compression tester developed by SITRA is based on this principle.

Roughness

Fabric roughness is a measure which is generally felt subjectively. The nearest characteristic of a jute fabric to roughness which can be measured objectively is fabric friction. The Fabric Roughness Tester developed by SITRA works on force measurement during the slow movement of fabric against fabric.

Dimensional stability

Low extensibility of fabrics can lead to difficulties in producing over-feed seams; problems in moulding and seam pucker. High extensibility, on the other hand, can lead to a fabric being stretched during laying up, causing the cut panels to shrink when they are removed from the cutting table. Fabrics exhibiting these characteristics are likely to lead to severe problems during the manufacture of sewn articles and to the production of faulty merchandise. SITRA has developed an instrument to measure fabric extension (Fig. 2.15) at 5, 20 and 100 g/cm and bias extension at 5 g/cm.

It is important that the fabric used for a particular purpose retain its dimensions after washing or when subject to other processes. Hence, it is essential to measure properties such as relaxation shrinkage and hygral expansion. Relaxation shrinkage is the irreversible change in the fabric dimension associated with the release of extensional or compressional strains within a fabric that were not permanently set during finishing. Both excessive and insufficient values of relaxation shrinkage can create problems. These dimensional changes occur when the fabric is exposed to high relative humidity, steam or water. Hygral expansion is the reversible change in fabric dimension associated with the absorption or desorption of water. The basic procedure adopted in the Fabric Dimensional Stability Tester developed by SITRA is the measurement of length and width benchmarks before and after a selected finishing process.

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2.14 References

See Appendix II on page 380.

2.15 Glossary of terms

Bark Outer covering of stems.

Brattice cloth A coarse cloth of Jute used for screens, ventilators etc. especially in mines, it is often coated.

Buckram Stiff, coarse linen cloth used in linings and for binding books.

Burlap Coarser cloth of jute.

Count An alternative to 'grist'.

Cuttings The root ends of a reed, with bark adhering to it, that are cut off and processed separately.

Decortication Mechanical extraction of bast fibres.

Dhurries Heavy carpet fabrics.

Entities Jute fibres produced at the first carding stage

Felt A jute fabric characterised by the entangled condition of many or all of its component fibres. The technology used for manufacturing the jute felts is needle punching.

Gunny A strong coarse material made commonly from jute, especially for bagging.

Grist The mass in pounds (lb) of a spyndle of yarn.

Head A large bundle of reeds.

Hessian A plain cloth made from single yarns of approximately the same linear density in warp and weft, usually made from bast fibres, particularly jute.

Juck Stack of harvested jute reeds.

Kutcha bale A loosely packed bale of fibre for local use.

Long jute The length of reed remaining after the removal of cuttings.

Muslin Lightweight plain or leno weave fabric.

Niwar Narrow width fabrics manufactured on tape looms.

Padding Impregnation of a substrate of a liquor or a paste followed by squeezing.

Porter A term originally used as a measure of the spacing of wires in the loom reed. The porter measure of a loom reed is the number of splits (space between wires) in a red length of 37 inches divided by 20. Thus a 10-porter reed contains 200 splits in a length of 37 inches. In jute weaving, each split normally carries more than one thread, and sometimes the spacing of the warp ends in the woven fabric is given in porter measure. To avoid confusion, thread-spacing in fabric should always be expressed as threads per unit length.

Pucca bale A densely packed bale of fibre for export.

Quality ratio The single-thread breaking load of a yarn in pound force (lbf) expressed as a percentage of the grist, or count.

Reed The bundle of fibres extracted from a single plant stem.

Retting Subjection of crop to biological or chemical treatment to make fibre bundles more easily separable from the woody part of the stem.

Sack Coarse fabrics made out of jute yarns for making bags.

Shots The weft threads inserted on the loom.

Spyndle A length of 14,400 yards. Jute system of yarn counts: no. of lengths of 14,400 yds that weigh 1 pound. (1 yard = 19.5 cm, 1 pound (lb) = 454 g)

Stack Arrangement of jute stems in a bundle form.

Twine Twisted threads of jute, hemp, etc., used for package tying.

Ultimate cell The basic plant cell from which the fibres are constructed.

Union Fabric with cotton yarn in the warp and jute yarn in the weft.

3
Flax

J SALMON-MINOTTE and R R FRANCK

3.1 Introduction

3.1.1 Flax and linen

To readers not familiar with the words flax and linen it is perhaps useful to describe their accepted usage. Flax is used in connection with the plant and products that are made directly from it or that are closely associated with it. For example, flax fields, flax cultivation and production, line flax (long fibre flax), flax tow (short fibre flax), flax spinning and flax yarns, and also certain types of flax fabrics, especially those of a heavier industrial kind. The word linen is used with reference to products that are further down the production chain; lighter weight fabrics for household textiles, furnishings and garments and other consumer products made from these fabrics.

3.1.2 History and background

Flax is one of the oldest textile fibres used by mankind and possibly the oldest. Excavations of 8th-century BC stone-age lake-side dwellings found flax seeds, twines and fishing nets[1] and other, but possibly less well documented, sources indicate that flax, or at least very similar fibres, may have been used some three thousand years earlier. Flax was extensively used in Egypt[1] from the 5th century BC for clothing and sails, whilst its cultivation and use were progressively developed throughout Europe, North Africa and Asia. During Grecian and Roman times flax, hemp and wool were the major textile raw materials. Silk was imported from China[2] but its price confined its use to the wealthy. The poorer classes wore leather, hemp and some linen. Flax, wool and hemp continued to be the principal fibres used in Europe until the establishment of the cotton plantations in North America in the 18th century.

Before then some cotton fabrics were imported into Europe from India but from about 1750 onwards large-scale production of cotton in the United States, at economic prices in comparison to flax,[3] led to its replacement by cotton in many of traditional end-uses of flax in Europe and North America.[4] Cotton's competitive advantage over flax at this time was not only based on the price of the fibre. Another important factor was the development of Hargreave's spinning jenny in 1767, a cheaper method of producing cotton yarn than the then traditional hand spinning wheel. Machine spinning of flax was developed only in 1810 by de Girard.[5] Flax's share of the textile market continued to decline as its place was increasingly taken by cotton and in the mid-20th century this trend was accentuated by the arrival of synthetic fibres, and principally by polyester staple fibre. At the end of the 20th century total world flax fibre production was around 400,000 tonnes, compared to a world total textile fibre production of some 50 million tonnes, but these raw figures give a misleading impression of the overall market and several other factors need to be taken into account if we are to have a more 'rounded' view of the situation.

Before 'Perestroika' global annual production of flax was of the order of two million tonnes, of which some 1.75 million was produced by the then Soviet bloc. As is stated in Appendix B the ratio of line flax to tow in these countries was (and, by and large, still is today) 1/3 line flax to 2/3 tow, compared to France, Belgium and Holland where production is 2/3 line to 1/3 tow. This very large quantity of tow had to be utilised and, as under the Soviet 'command economy' economic considerations which are considered as normal in a competitive economic environment did not hold sway, flax was used to produce textile products which in the West had been progressively replaced by articles made from cheaper fibres such as cotton, jute, polyester, and polypropylene. Examples of such products were sacks (for agricultural and other products) ropes, cordages and other heavy textiles. In addition, even in those products which were and still are made from flax, such as household textiles, apparel and furnishings, the end products were generally of indifferent quality and could be distributed only within the Soviet economic area as, despite their cheap prices, their quality was not acceptable in Western markets. However, after 'Perestroika' and the breakdown of the 'command economy' the markets for these products in Russia and adjoining countries decreased very considerably and the area's production of flax fell by some 80% and remains at about this level.

The principal areas in the world where textile (as opposed to oilseed) flax has traditionally been cultivated, and to a large extent still is, are northwest Europe (northern France, Belgium and Holland) eastern Europe, Belorussia and Russia, China and Egypt. Small quantities are grown in other countries, for example Chile and Brazil.

3.2 The flax plant

3.2.1 Description

Flax (*Linum Usitatissimum*) is a dicotyledon of the Linacea family. There are many varieties and cultivars and those most used for the production of fibres are

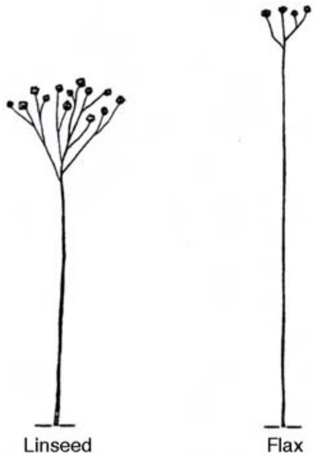


Figure 3.1 Line drawings of linseed and textile flax. Source: J. Turner, *Linseed Law: a handbook for growers and advisors*, BASF, Suffolk, UK. Courtesy: John Turner.

Figure 3.2 Flax seed pods. Source: Dehondt Technologies promotional literature. Courtesy: Guy Dehondt.

listed in Appendix A. The plant is not only used as a source of fibres, principally for textiles, but also for paper and in the manufacture of composite products, and also for linseed oil, which is an important industrial raw material. This is extracted from the seeds and the by-product, or 'cake', is used as animal fodder. When mature, fibre flax varieties are about 80 cm to 120 cm in height, with a diameter of about 3 mm compared to oil varieties heights of 60 to 80 cm, with slightly thicker stems. The stems of fibre flax varieties bear between 80 and 100 sessile leaves and the flowers, usually pale blue are of 'type s'. The seed pods are globular, smooth, flat, usually reddish-brown and end in a slightly curved point. They contain two seeds.

3.2.2 Fibre development

Primary cells in the bast differentiate early in the plant's life into what are called 'primary fibres', to distinguish them from what are generally accepted as flax fibres which are, in effect, amalgamations of primary fibres cemented to each other by pectins. These primary fibres rapidly develop into bundles of several dozen fibres forming a rough interrupted circle in the bast (phloem) of the stalk and which surrounds its woody part. The outermost bundles develop first, with the more central ones developing progressively later. The primary fibres elongate very rapidly until the end of flowering and it is at this point that the plant reaches its maximum potential from the point of view of fibre quality, if not quantity. At maturity fibres represent about 25% of the dry weight of the flax stalks.

Stalks can contain between 20 and 40 fibre bundles and each bundle between 20 and 40 primary fibres. Primary fibre diameters vary from 20 mm to 40 mm and their lengths from 10 mm to 100 mm. As stated above these primary fibres are cemented to each other within the bundles by pectins and the bundles run the entire length of the stalk. Pectins also cement the bundles to adjacent cells in the phloem of the stalks. Each normal primary fibre has a central lumen. Figure 3.5 shows cross-sectional diagrams of flax stalks showing good and poor quality

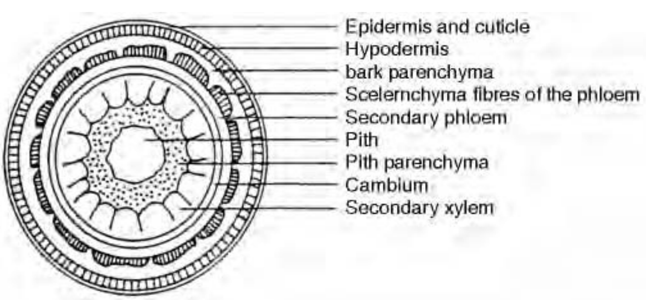


Figure 3.3 Line drawing section of flax stem. Source: Van Cotthem and Fryns-Claessens, 1972 in *The Biology and Processing of Flax*, M. Publications, Belfast, UK. Courtesy: Professor S. Sharma, ed.

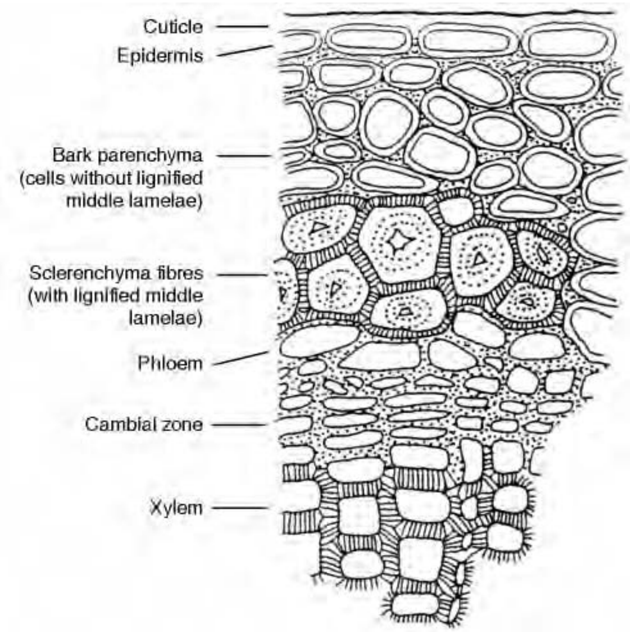


Figure 3.4 Line drawing of transverse section through a flax stem. Source: Dujardin, 1942, in *The Biology and processing of flax*, M. Publications, Belfast, UK. Courtesy: Professor S. Sharma, ed.

fibres. (A more detailed description of the anatomy of the stem can be found in Catlin, D. and Grayson, J., *Identification of Vegetable Fibres*. Archtype Publications, London, 1982.)

Flax varieties and cultivars

Commercialised varieties are registered in national and local catalogues. Some 20 varieties are currently used but the major four represent almost 90% of the areas sown in western Europe. The criteria used by producers when selecting varieties are resistance to disease, fibre yield, fibre quality, resistance to lodging, early flowering and time taken to reach maturity. Table 3.1 shows the sensitivity

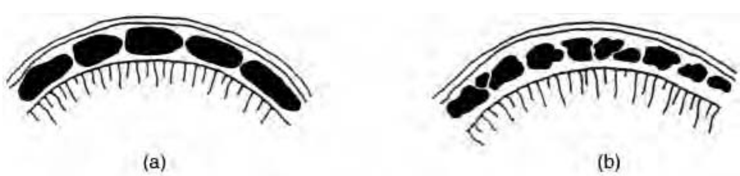


Figure 3.5 Cross-sectional diagrams of flax stalks showing (a) fibre bundles of a high quality flax and (b) fibre bundles of a low quality flax. Source: C.F. Van Sumere and Melliand Textilberichte, GmbH in *The Biology and processing of flax*, M. Publications, Belfast, UK. Courtesy: Professor S. Sharma, ed.

Table 3.1 Some varieties of flax grown in Western Europe[1]

Variety	Year of insc.	Characteristics	Sensitivity to[2]							Productivity	
			Zn	Lo	Fu	SC	Rw	Rr	SB	fibre	seed
Natasja Breeder: Frisje Maatschappy voor Land-bouw Leeuwarden (NL)	1973	Growth: slow Flowering and maturation: very late Flower: blue	8	3	3	7	1	4	8	good	good
Nynke Breeder: Frisje Maatschappy voor Land-bouw Leeuwarden (NL)	1975	Growth: quick Flowering and maturation: early Flower: white	6	5	6	1	7	7	1	medium	good
Ariane Breeder: Coopérative Fontaine-Cany (F)	1978	Growth: slow Flowering and maturation: late Flower: blue	8	3	3	7	1	4	1	very good	low
Regina Breeder: CEBECO Zaden B.V. (NL)	1981	Growth: quick Flowering and maturation: early Flower: white	6	6	8	7	1	7	1	good	good
Belinka Breeder: CEBECO Zaden B.V. (NL)	1982	Growth: quick Flowering and maturation: early Flower: white	6	4	6	3	1	7	1	good	very good

Table 3.1 (continued)

Variety	Year of insc.	Characteristics	Sensitivity to[2]							Productivity	
			Zn	Lo	Fu	SC	Rw	Rr	SB	fibre	seed
Saskia Breeder: Frisje Maatschappy voor Land-bouw Leeuwarden (NL)	1983	Growth: slow Flowering and maturation: half-late Flower: blue	8	4	2	8	1	7	1	good	very good
Opaline Co-breeders: Coopérative Linière du Plessis-Belleville and Agri-Obtentions (F)	1984	Growth: quick Flowering: early Maturation: medium Flower: white	8	2	7	9	1	7	1	very good	low
Viking Co-breeders: Coopérative de Fontaine-Cany and Agriu-Obtentions (F)	1985	Growth: quick Flowering: early Maturation: medium Flower: blue	8	4	2	7	1	1	3	very good	medium
Marina Breeder: CEBECO Zaden B.V. (NL)	1988	Growth: quick Flowering and maturation: half-late Flower: blue	7	4	2	8	–	–	–	good to very good	good
Laura Breeder: CEBECO Zaden B.V. (NL)	1989	Growth: medium Flowering and maturation: half-late Flower: white	7	3	2	2	–	–	–	very good	good

Source: *The Biology and Processing of Flax*, M Publications, Belfast, UK, Courtesy: Dr S. Sharma, ed.

1. Only the varieties whose area is more than 500 ha.
2. Scale: 1 = resistant to, 9 = very sensitive, – = insufficient information.
   Zn: Zinc deficiency; Lo: Lodging sensitivity; Fu: Fusariose (*Fusarium oxysporum lini*); Sc: Scorch (*Pythium megalacantum*, *Chalara elegans*, *Asterocystis radicis*); Rw: Rust Wiera breed (*Melampsora lini*); Rr: Rust Reina breed; SB: Stem break (*Polyspora lini*)

of ten of these varieties to various external influences and some of their other characteristics. China, also a substantial flax producer, imports substantial quantities of west European seeds, the principal varieties being Arianne, Fancy, Argos (France) and Typea (Netherlands) Chinese varieties include Heiya (Nos 10 and 11), Shuangya (Nos 5 and 8) and Mengya (No. 2).[6] Two of the main varieties grown in Russia and Belorussia are Orchanski and Mogiliovski.[7]

The varieties at present included on the authorised list of the European Union's Common Agricultural Policy, and whose cultivation is therefore subsidised, are listed in Appendix A together with details of the subsidisation scheme. Certain east European countries do subsidise flax growing or are considering doing so but not to the same extent as the European Union.

3.3 Physical and chemical characteristics of flax fibres

3.3.1 Chemical characteristics

The principal constituent of flax fibres is cellulose, with smaller amounts of hemicellulose, lignin, pectins and oils and waxes. The cellulose, hemicellulose and pectins are found in the cell walls. Table 3.2 gives the chemical composition of flax fibres as reported by different researchers. These results differ because the detailed composition will vary according to the variety and maturity of the stalks, and the method of analysis. For further details on the constituents of flax fibres see Focher's excellent overview of present knowledge in this field in *The Biology and Processing of Flax* (M Publication, Belfast).

Table 3.2 Chemical composition of flax stems and fibres at maturity

	Couchman		van Overbeke and Mazegue	Dambroth and Seehuber		Sotton and Satta
	Fibre	Stem	Fibre	Stem	Fibre	Fibre
Cellulose	85	49	73	60	71	81
Hemicellulose	9	29	10	7	17	14
Lignin	4	18	15	27	3	3
Pectin	–	3	9	3	3	1
Fats and waxes	–	–	5	–	2	–
Protein	–	–	–	–	3	–
Ash	1	1	4	3	1	1
Total	99	100	116*	100	100	100

Adapted from Sharma and van Sumere, *The biology and processing of flax*, M Publications, Belfast, UK. Courtesy: Dr S. Sharma, ed. and Sotton & Satta data published in *Lin et Cotton*, Industrie Textile, Paris, France, 1988.

3.3.2 Physical characteristics

For detailed discussion of the present state of knowledge concerning the physical characteristics of flax fibres readers are referred to pp. 13 to 30 of *The Biology and Processing of Flax* quoted above. The principal physical characteristics of flax which distinguish it from other fibres are

Figure 3.6 Cross-section of flax stem × 100 showing thickness of fibre walls and lumen. Source: Institut Technique du Lin, Paris.

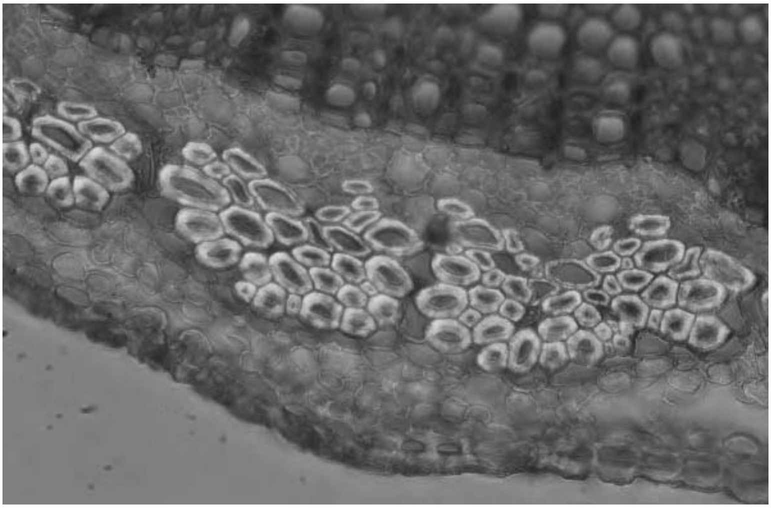


Figure 3.7 Cross-section of flax stem × 40 showing distinct fibre bundles. Source: Institut Technique du Lin, Paris.

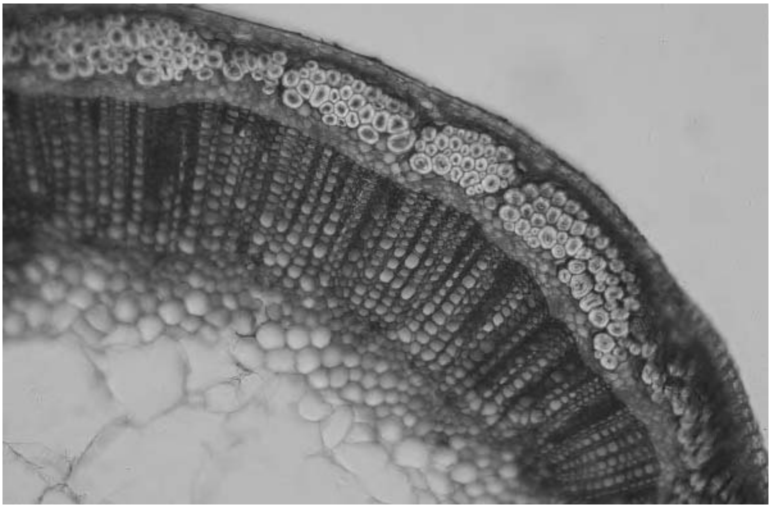


Figure 3.8 Cross-section of flax stem × 10 showing relative position of fibre bundles in the stem. Source: Institut Technique du Lin, Paris.

- rapid absorption and desorbtion of moisture
- high crystallinity of the cellulosic component of the fibre, resulting in
  – high creasability of linen fabrics
  – low extensibility of flax yarns
  – high tenacity of fibres and yarns
  – relatively poor abrasion resistance of linen fabrics
  – high lustre of linen fabrics, especially those produced from wet spun yarns
  – aesthetically attractive drape of linen fabrics.

Values for many of the physical characteristics of flax quoted by several authorities are set out in Table 3.3. These sometimes differ materially from each other and this point is discussed in Chapter 1.

Both the fibres' high crystallinity and ability to absorb and desorb moisture more rapidly that other fibres are important contributions to the cool handling and comfort of flax garments. K. Kernaghan shows comparative stress/strain curves for flax and certain other cellulosic fibres. These illustrate the exceptionally high tensile strength but low extensibility and extension at break of flax, compared to other cellulosic fibres, both wet and dry. He also compares the crease recovery performance of various fabrics in comparison with linen. Table 3.5 (also Kernaghan) illustrates the relatively poor resistance to abrasion of linen fabrics compared to cotton but also shows the extraordinary improvement that can be obtained by blending a small percentage of nylon staple with the flax in the yarn.

Flax does, of course share many of these physical and chemical characteristics set out above with other bast and leaf fibres but the factor which distinguishes flax from most of these is the inability to spin fine count yarns

Table 3.3 Physical characteristics of flax fibres

Source	A	B	C	D	E	F	G	H	J
Density	1.4 g/cm		1.4			1.48–1.50 g/cm	0.2–2.0 tex		
Tensile strenth*	800–1500 (10E N/m^2)			0.90 (Gpa)		2.6–8.0 (gr/den)	134–183 (kg/mm^2)		
E-Modulus (GPa)	60–80			1.0					
Specific density E/density	26–48								
Elongation at break (%)	1.2–1.6			1.8–3.3		Dry 1.5–5 Wet 3–7	3.2–4.1		
Moisture absorption (%)	7								
Length single/fibre (mm)		(i) 9–70 (ii) 33	13–60		min. 8 max. 69 average 32			4–66 usually 25–30	20–39
Length bundles (mm)		(i) 250–1200	300–900				700–900		
Width single fibre (μ)		(i) 5–38 (ii) 19	12–30		min. 14 max. 21 average 19			12–30	11–31
Width bundles (μ)		40–60							
Weight/length (denier)			1.7–17.8						
Specific tensile strength				0.60 (GPa m^3/kg)					
Flexibility modulus (GPa)				85					
Specific flexibility modulus				71 (GPa m^3/kg)					
Wet strength as % dry					100–110				

	K	L	M	N
Length single fibre (mm)	11–38	20–50	Mean 27	range 1.6– mean 7.90
Width single fibre (μ)	12–25	mean 23	12–26	Range 11.68–31.96 Mean19

Created from: A: FAO Rome, B: *The Textile Consultancy*, Dalgetty, Scotland, C: Bisanda 1992, Lewin 1985, Vaughn 1986, in *Vlasberichten*, D: *Vlasberichten*, E: Marsh, J. T., *Textile Science*, Chapman & Hall, London 1948, F: Luniak, B., *The Identification of Textile Fibres*, Sir Isaac Pitman and Sons, London, UK, 1951, G: Jarman, C. in *Plant fibre processing*, Intermediate Technology Publications, UK, 1988: H: Hanausek 1907, J: Koch 1963, K: Matthews 1931, L: Kirby 1963, M: von Wiesner 1867--1927. Quoted in Catlin, D. and Grayson, J., *Identification of textile fibres,* Archetype Publications, London 1992.

*Tensile strength strongly depends on type of fibre, bundle or single filament.

(i) range (ii) average

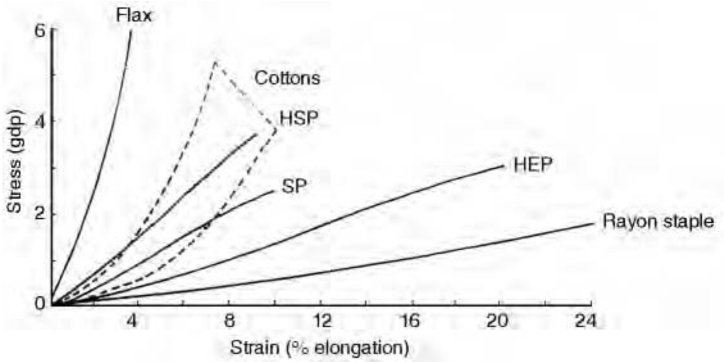


Figure 3.9 Stress-strain relationships for certain cellulosic fibres. Source: Griffiths, 1965, in *The Biology and processing of flax*, M. Publications, Belfast, UK. Courtesy: Professor S. Sharma, ed.

Table 3.4 The crease recovery of fabrics under various conditions

Fabric	R (%)	Crease recovery angle (°) OD	SC	Wet	MP
Wool	14.0	162	157	132	125
Linen	9.0	80	48	100	28
Cotton	7.5	99	95	100	63
Viscose rayon	13.0	150	125	107	50
Polyester	~0.5	125	125	125	125

Source: The biology and processing of flax, M Publications, Belfast, UK. Courtesy: Dr S. Sharma, ed.
R – regain at standard conditions; OD – oven dry; SA – standard conditions (20 °C, 65% RH); MP – minimum performance. Mean of warp and weft measurements (method: Shirley, BS 3086). A perfect crease recovery perfomance is equivalent to 180°.

Table 3.5 Resistance to abrasion of various fabrics

Fabric (warp : weft)	Abrasion resistance[3]
100% Linen[1]	10,000
100% Cotton[2]	25,000
Cotton[2]: 80/20 (flax/nylon)[1]	50,000
80/20 (flax/nylon)[1]	> 150,000

Source: *The biology and processing of flax*, M Publications, Belfast, UK. Courtesy: Dr S. Sharma, ed.
1. 16 lea; 2–6 cc; All ~ 100 tex.
2. Fold yarns.
3. Rubs: 28 oz. Martindale.

from their relatively coarse fibres. The only possible exceptions are ramie and hemp where the production of finer yarns are possible but these fibres suffer from other disadvantages in comparison with flax. Ramie has a higher modulus. When 100% ramie fabrics are worn next to the skin, because of this higher modulus, they tend to feel 'prickly' and hemp is available only in finer count yarns (< 10 s metric) in very limited quantities and at expensive prices.

Tables comparing the physical and chemical characteristics of flax and other fibres are placed in the Appendix to Chapter 1.

3.4 Cultivation and harvesting

3.4.1 Cultivation

The harvesting of flax requires certain skills, operations and the use of agricultural machines that are particular to this crop (and to some extent, to hemp – see Chapter 4). The skills that are required from the farmers, over and above those needed for other crops, apply particularly to the dew retting of the flax straw (as the stalks are called when they have reached maturity and are ready for pulling). They need to be able to judge when the straw is sufficiently retted to 'turn' (see 3.4.3 below) and when to lift it after retting is complete, but before it is over-retted. Flax is not very vulnerable to pests and parasites although certain precautions usually need to be taken (see 3.13 below). However, it does need to be protected against weeds. Preventative measures against zinc deficiency are also essential.

Generally, different varieties are cultivated for seed and fibre production but in some cases the same varieties can be used for both purposes. In these cases

Figure 3.10 Flax seed pod. Source: Masters of Linen.

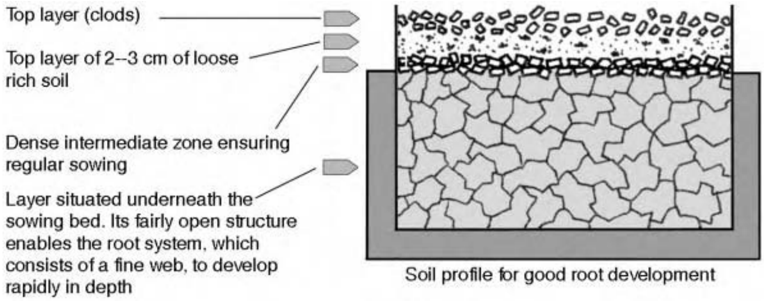


Figure 3.11 Soil profile for good root development. Source: *Linen: Technical aspects of production*, Confederation Internationale du Lin et du Chanvre. Courtesy: Institut Technique du Lin, Paris.

the crop grown for fibre is more densely sown so as to discourage the branching of the stems. Flax is a fast growing plant, reaching maturity within 100 days; it grows best in temperate climates and is a good rotation crop; good practice is not to grow it in the same ground more than once every seven years. Growth takes the plant through five specific stages; flower bud formation, flowering, fruit formation, fibre maturity and seed maturity. The ideal soil profile is shown in Fig. 3.11.

Flax requires little fertilising. Excess fertilising and especially of nitrogen can encourage 'lodging' of the crop. The quantities required are lower than for cotton and many other crops. For example, in kg per hectare flax requires only between 10–45 kg of nitrogen, 60–75 kg of calcium and 100–120 kg of potassium. Weed and pest control chemicals are necessary, but used sparingly; 1.3 kg per ha is normally applied, compared to over 3 kg for wheat, nearly 5 kg for sugar beet and up to 7 kg for potatoes. When sowing both the depth, at about 2 cm, and the distribution, at between 1800 to 2000 seeds per m^2, should be as regular as possible. Normal sowing periods in Europe are from 15 March to 15 April and 'pulling' (see below) from the end of July to the end of August. When growing flax for fibre the sequence of operations is as follows: preparing the ground, planting, anti-weed spraying, pulling, de-seeding (rippling), turning, lifting, drying and stocking. Operations specific to the harvesting of flax are the pulling of the stalks, retting and drying (the latter two are also necessary for hemp). The agricultural machinery required to carry out these operations are pullers and turners.

3.4.2 Pulling

Pulling is carried out when the flax has reached a certain degree of maturity. This is assessed by the colour of the stalks and seed pods, which should be yellow-brown, and their degree of defoliation. Maturity requires approximately 1400 °C day (the sum of the daily average temperatures after

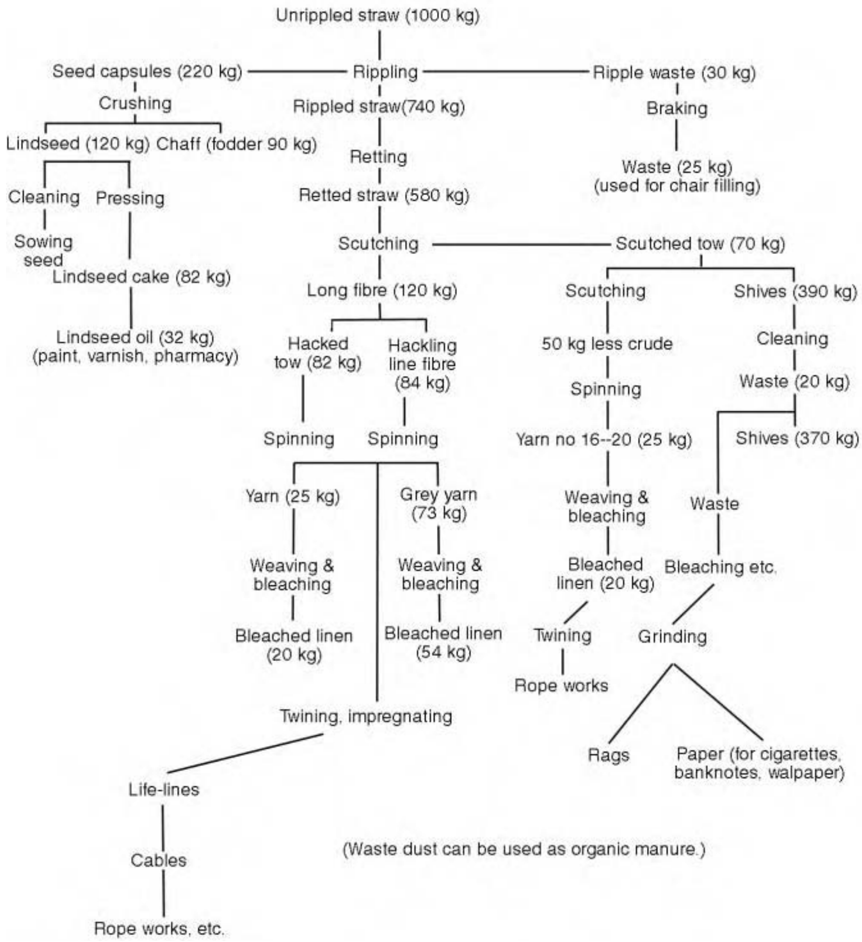


Figure 3.12 West European flax production flowchart. Adapted from G. Demeestere, Dewilde (1987) and Marshall (1989) in *Biology and processing of flax*, M. Publications, Belfast, UK. Courtesy: Professor S. Sharma, ed.

sowing). Flax pulling machines are self-propelled and are either single or double (pulling one row of stalks, or two simultaneously). Their widths vary from 1.0 m to 1.3 m.

During harvesting the puller advances through the standing crop, the stalks are grasped by a pair of endless belts, pulled up from the ground, passed through the machine and laid in swathes on the ground behind it. Flax is pulled rather than reaped, as are many other crops such as cereals. This ensures that the entire length of the fibres, which run from the root to the top of the stalk, is harvested. Reaping would cut the stalks at a height of about 5 cm, thus wasting about 5% of the fibre as the stalks average about 1 m in height.

Figure 3.13 Flax puller in action. Source: Dehondt Technologies promotional literature. Courtesy: Guy Dehondt.

3.4.3 Retting and turning

Retting is a natural process and is the result of enzymes produced by various fungi and bacteria present in the atmosphere and which settle on the swathes of stalks lying on the ground. Under suitable conditions of temperature and humidity these fungi and bacteria colonise the stalks and their enzymes attack preferentially the pectic cements which bind the primary fibres to each other within the fibre bundles and the bundles to the phloem in the stalks (see 3.2.2 above). There are two methods of retting currently in use; dew-retting, also called ground retting, and water retting.

Dew-retting and turning

Dew-retting is by far the most usual method of retting in Europe as it is less labour intensive and does not have the negative environmental consequences of water retting. It does, however increase the risk of damage to the crop due to unsuitable weather during the retting period. For dew-retting the swathes laid on the ground after pulling (Fig. 3.13) are left lying there for a period of up to six weeks. They have a thickness of several centimetres and as the rate of retting is influenced by heat and moisture, obtained from the sun and dew or rain respectively, the straw in the upper layers of the swathes will ret at a faster rate than those nearer the ground. Because retting affects both the quality of the fibres produced and their yield and as it is important that the entire crop rets as uniformly as possible it is necessary to 'turn' the swaithes.

When the stalks of the upper layers are sufficiently retted (this is assessed by rubbing specimens of stalks against themselves and judging the ease with which the unwanted woody matter separates from the fibres), the swathes are turned so that the layers that were nearest to the ground end up facing the sky, and in turn will ret faster than the layers now nearest to the ground. In this way they will reach the same degree of retting as the stalks that were, before turning, on the upper surface of the swathes. The self-propelled machine which carries out this operation is a turner. A crop may be turned one or more times, depending primarily on the meteorological conditions during the retting period. During this period the crop is at risk from the weather because if there is too much rain the straw may partially rot before retting is complete and this will weaken the fibres, thus reducing both quality and yield. On the other hand, if there is not enough moisture during the retting period the straw will not ret sufficiently and the fibres will be damaged during scutching (see 3.5 below). Again this will reduce fibre quality and yield.

Water-retting

In water retting the straw, after pulling, is tied into fairly large bundles and steeped in water, in either slow-running rivers, ponds or tanks. The retting period varies from three days to a week or a little more, depending on the temperature of the water. When retting is complete the bales are removed and the stalks dried by stooking them in fields. Drying time will depend on the weather. When sufficiently dry the straw is collected and stored. The advantage of water over dew-retting is that it is more controllable and avoids the risk of the crop being spoilt by inclement weather during the weeks that it lies on the ground. However it does also have serious disadvantages. As stated above water retting is more labour intensive than dew-retting because none of the processes involved are mechanised. A further disadvantage of water retting is that the water in which the straw has been steeped is highly polluted and, in western Europe, needs to be treated before being discharged as waste water. When eastern European countries become full members of the European Union the same environmental regulations will apply. At present, although small quantities of water retted flax are still produced by family concerns in Belgium, it has almost completely disappeared in western Europe and also in most east European countries but is still fairly widely practised in China and Egypt.

3.4.4 Rippling or de-seeding

Rippling is the name given in flax cultivation to the operation known as de-seeding or threshing when referring to other crops. Rippling takes place at different stages in the harvesting cycle depending on whether the crop has been grown to produce seed for replanting or whether the seed is a by-product of flax grown for fibre.

Rippling for seed production

First the crop is pulled. As opposed to flax that is grown for fibre this is done after the seeds are formed, which is usually some two to three weeks after flowering. As the stalks are pulled they are passed through a comb and the seeds are collected into bags. In countries other than those of western Europe they may then be retted and further processed into fibres. This is not usually the practice in western Europe because lignification of the fibres sets in after flowering and this thickens them and renders them less flexible, thus considerably reducing their quality and therefore their value. This is one of the reasons why flax fibre produced in western Europe is of consistently better quality and fetches higher prices than that produced outside this area. However, developments are taking place in Lithuania and Poland which aim to raise the quality of some of the fibre produced in those countries by following western European practice and harvesting for fibre production at flowering, growing separate crops for seed.

Rippling for fibre production

This is the part of the sequence of operations that are carried out when the straw is scutched and is included in section 3.5.2.

3.4.5 Baling and stocking

When the straw is sufficiently retted the swathes are lifted from the ground usually, in western Europe, by a round bailer and stocked until required for scutching. Every effort is made not to lift the swathes if the straw contains over 15% moisture as this may lead to the development of mildew whilst in storage. Mildew will affect the quality of the fibres by weakening and discolouring them. Again in order to keep the humidity of the straw to under 15% the straw is stocked under cover. In western Europe this is often in 'Dutch barns' but sometimes, if they are available, in walled barns. In eastern Europe and China the straw is often not baled but collected into bundles which may be stored under cover, or may be built into stacks and thatched with bundles of flax straw. Some of these stacks can be very big, measuring for example, some 30 m by 10 m by 10 m.

3.5 Scutching

3.5.1 Introduction

Scutching is the sequence of operations whose principal purpose is to separate the fibres from the rest of the plant. For some other bast and leaf fibres such as sisal and jute this is called decorticating. During scutching certain by-products are produced; these are short fibres, or tow as it is usually called in English, seeds and waste woody matter, called shiv or shive. Scutching also rids the fibre of extraneous and waste matter such as weeds, earth, dust, and small pebbles that are collected as the crop is pulled or lifted after dew retting. The aim of a good scutching operation is to extract the maximum possible amount of fibre from the retted straw with the highest possible ratio of long fibre, usually called line, to tow. This is because the value of line can be ten times or more that of tow.

Efficient scutching depends upon the straw being well and uniformly retted. If the straw is under-retted the pectins which bind the fibres to each other and to the adjacent baste (see section 3.4.3 above) have not been sufficiently removed. The fibres will then suffer undue damage when attempts are made to separate them during scutching because they will still be too firmly cemented together. This will result in a lower than expected overall yield of fibre to straw and a lower proportion of line to tow. Over-retted straw will lead to the same result as the fibre will have been weakened by being attacked directly by enzymatic action, again resulting in excessive fibre breakage during scutching.

3.5.2 The scutching process

This consists of a series of sequential mechanical operations through which the flax straw is processed. These operations are: the preparation and presentation of

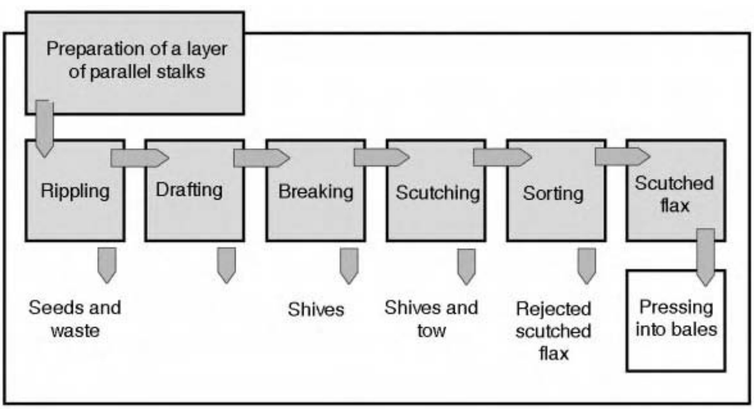


Figure 3.14 Scutching line. Source: *Linen: Technical aspects of production*, Confederation Internationale du Lin et du Chanvre. Courtesy: Institut Technique du Lin, Paris.

the feed layer of straw to the scutching line; rippling; drafting the straw layer; breaking the stems; scutching the stems; grading and baling the line fibre produced. In addition by-products and waste have to be removed. The machines which carry out these operations constitute a scutching line.

A complete modern scutching line can process up to 500 kg of stalks per hour which, in western Europe, produce about 70 kg of line and 30 kg of tow. Older machines and those produced in Russia and still in use in eastern Europe have lower productivity and less gentle action and this a factor in the lower yield of line to tow which prevails in these countries. This is further discussed in Appendix A.

Straw layer preparation

The round bales of retted straw are placed on an unwinding platform. The layer should have a weight of about 2 kg per metre. A greater weight would not be satisfactorily processed and a lighter one would reduce productivity. If the straw is not presented in a round bale the square bales or bundles of straw are placed in a convenient position near the feeding apron and the layer is made up manually.

Rippling

The removal of the seeds is combined with combing and straightening the stalks in the layer so that they can all be efficiently and uniformly processed, which would not be the case if they were in a tangled state when presented to the breaking rollers and the scutching turbines. After being combed out of the straw layer the seeds pods are removed pneumatically from the scutching line and bagged.

Drafting the layer

This machine is usually called a divider. Its purpose is to decrease the linear weight of the straw layer so that each stalk can be efficiently processed during subsequent operations. The drafting is done by five to ten pairs of toothed wheels. The drafting ratio is usually one to five and the linear weight after drafting will be of the order of 250 g to 500 g/m^2.

Breaking

The purpose of this operation is to break up the woody matter in the stalks so that it can be removed as shive by the scutching turbines (see Fig. 3.15). The drafted layer passes through a series of pairs of wide-toothed fluted cylinders set perpendicularly to the direction of movement of the straw. The number of cylinders varies from five to ten pairs, their diameters are about 18 cm and their pitches increase gradually from 18 to 28.

Scutching

Scutching separates the fibres from the woody matter in the retted stalks. It is sometimes referred to as swingling but this is now a rather archaic term. The machine consists of two pairs of parallel counter-rotating turbines bearing ‘beaters’ or blades and over which a pair of endless belts hold and carry the straw. These cylinders are often referred to as scutching turbines. The cylinders of each pair are so arranged that the blades of each cylinder intersect. The pair of belts move the straw through the counter-rotating blades of the cylinders which, by striking the stalks, cause the shiv and tow to be separated from the fibres and fall through the machine. The speed of rotation, depending on the raw material, can vary from 150 to 250 rpm.

As part of each stalk is gripped by the belt their entire length cannot be scutched in one operation. To scutch the untreated half of the stalks the grip is reversed between the two pairs of cylinders and the unscutched half presented to the second pair of cylinders and scutched. After scutching the resulting line flax is transferred to a horizontal bar by the belts. This is then removed manually and twisted into bundles, often called ‘hands’, weighing between 500 g and 1000 g. The tow which is collected after having fallen through the machine is either further processed on the premises (see 3.5.3 below) or pressed into bales of about 100 kg and sold. The shiv, which is removed pneumatically from the

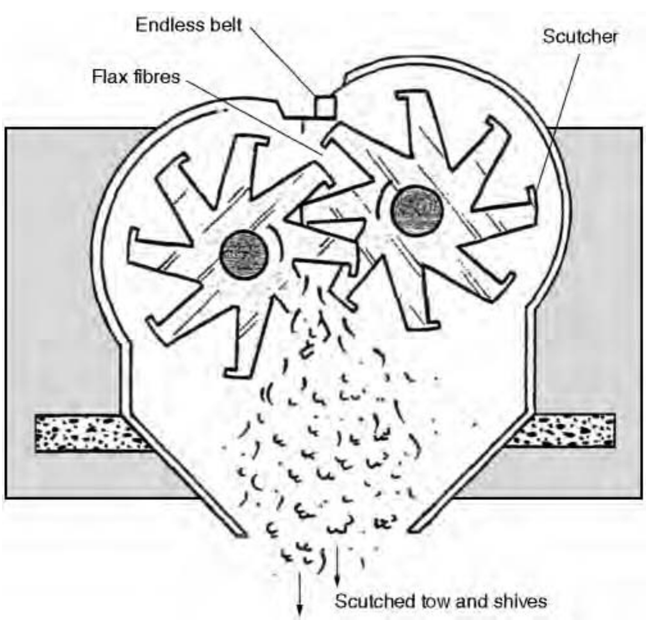


Figure 3.15 Cross-section of scutching turbines. Source: *Linen: Technical aspects of production*, Confederation Internationale du Lin et du Chanvre. Courtesy: Institut Technique du Lin, Paris.

scutching line, is bagged and sold. Waste matter, such as earth, small stones and weeds which may have been collected during turning and harvesting, is disposed of.

Sorting and packing

The 'hands' of line flax are graded according to colour, cleanliness (and possibly other criteria) as they are taken from the bar at the end of the scutching line. They are then packed into bundles of 10 kg to 20 kg, which are pressed into bales of around 100 kg.

3.5.3 Tow processing

The tow produced during scutching is called scutched tow, so as to differentiate it from the tow produced during hackling ('hackled tow', see below), which is a higher quality textile raw material. Scutched tow is marketed in three grades; raw, half-finished or finished and which of these grades is used depends on the envisaged end-use of the yarn. Scutched tow processing machinery usually consists of several shakers which remove dust and other waste and two or three cards of the breaker type to separate, further clean and partly parallelise the fibres. The last card may form a sliver, which will be fed into the preparing frames of the spinning system. Alternatively the carded tow may be press-baled should further processing not require sliver (see flowchart Fig. 3.16).

Several companies in Belgium, France, eastern Europe, and Russia make flax scutching lines and machinery for the further processing of flax tow. The major end-uses for which scutched tow is used are twine, ropes and cordage, carpet backing, certain types of heavy industrial fabrics and composite materials. It may also be used to produce affined flax fibres (see below).

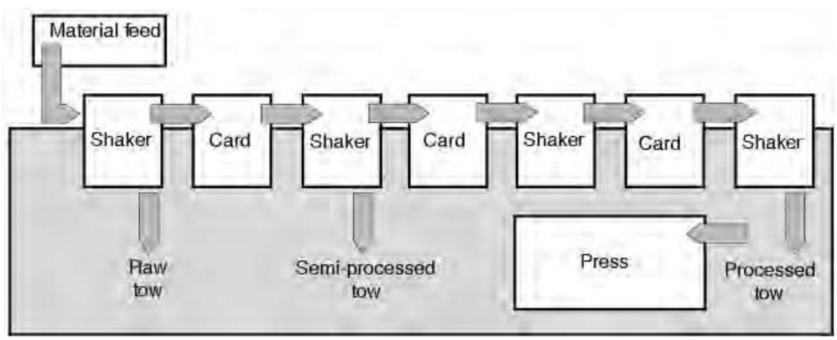


Figure 3.16 Tow processing flowchart. Source: *Linen: Technical aspects of production*, Confederation Internationale du Lin et du Chanvre. Courtesy: Institut Technique du Lin, Paris.

Affined (cottonised) flax

The first attempt to modify flax fibre so that it could be spun on the more productive cotton system date from the mid 18th century and was a multistage chemical process.[5] Further efforts made, particularly in Germany during the Second World War, were primarily aimed at replacing cotton which had to be imported. These developments did produce a fibre that could be blended with cotton and spun on cotton spinning frames but, once cotton again became freely available, these fibres were not able to compete on price or quality with cotton when processed on cotton machinery.

In the 1970s more sophisticated technologies were developed and it became possible to produce flax fibres whose thickness, length and fibre diagram matched more closely those of the fibres with which they were to be blended. This process started being used on an industrial scale in the early 1980s. The process involves cutting the fibres to the length required by the fibre(s) with which they are to blended or according to the spinning system on which they will be spun. This also enables the flax fibres to be moved between the different machines by normal pneumatic conveyors. The cut fibres are then passed through three of four toothed openers of progressive fineness which split the fibre bundles to the required degree. Dust is extracted between each of the openers.

Yarns produced with these new ‘affined’ flax fibres are blended principally with cotton or polyester, and to a lesser extent with wool and acrylic staple fibres. The resulting blends can be ring spun to counts of 50 tex in a 40/60 flax/cotton blend or rotor spun from 22 to 66 tex in blends with cotton containing from 25% to 50% flax. It is also possible to spin 100% flax yarns on the cotton spinning system if the flax fibres are carefully selected for length and fineness.

There are two ways of spinning flax blends on the woollen or worsted system. The flax fibres can be affined either on a flax or on a wool card with suitable adjustments being made to card clothing and swift-worker’s relative speeds and settings, or the flax fibres can be broken to the required length on a ‘cracker’. It is, however, essential to clean all machinery thoroughly after processing flax if all-wool yarns are to be subsequently produced on the same machines. Otherwise the yarns will be contaminated by the remaining flax fibres and this contamination will show clearly when the yarns, or fabrics produced from them, are dyed.

Many new types of fabric, especially for apparel, have been developed from these flax blended yarns and depending on fashion, the annual production of affined flax has become substantial. No detailed statistics of the production or consumption of affined flax are available but, in western Europe only, the quantity must be of the order of three to five thousand tonnes per year. Originally it had been hoped that this system would become a means of adding value to fairly low quality flax tow but experience has shown that although either scutched or hackled tow can be used, depending on the intended use of the yarns, if yarns of good technical quality and appearance are to be produced it is necessary to start with good quality fibres.

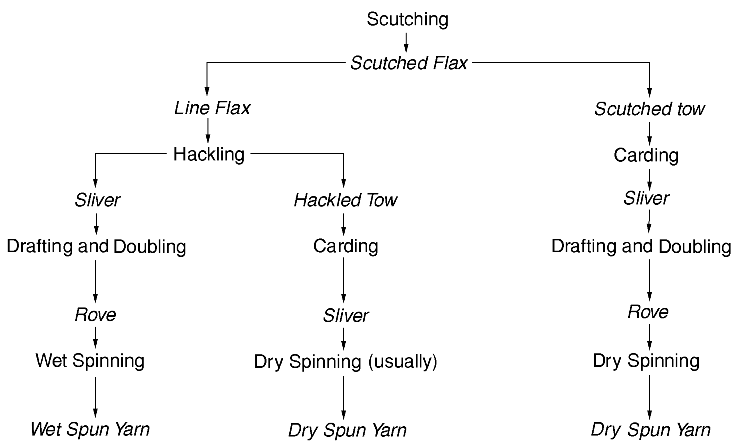
3.6 Yarn preparation and spinning

3.6.1 Introduction

Flax can be spun using several different spinning systems of which the two principal ones are wet and dry spinning. There is also the semi-wet system and flax, when blended with other fibres, can also be spun on the cotton, worsted and woollen systems (see affined flax above). The sequence of operations in wet and dry spinning are set out in Fig. 3.17.

The principal difference between the spinning of flax fibres and the spinning of other fibres is in wet spinning. Tow is both dry and wet spun, line is nearly always wet spun. Dry spinning is similar to the semi-worsted method of yarn production and uses the same preparation and spinning machinery. This system is used both for 100% flax yarns and for blends with other fibres. Wet spinning, on the other hand, requires specific yarn preparation and spinning frames.

In the description of the development of the fibres in the plant (3.2.2 above) mention is made of the pectins which cement the fibres to each other and to the other cells in the stalks. In straw that has the optimal degree of retting the pectins binding the fibre bundles to the rest of the straw have been removed, enabling the fibre bundles to be easily separated from the shiv during scutching. However the pectins cementing the fibres to each other within the bundles would not have been completely removed, unless the straw is over-retted. These pectins can be softened by placing the fibres in warm water at 60 °C. This softening enables the



Italic type denotes products; roman type denotes process.

Figure 3.17 Wet and dry spinning flowchart.

primary fibres to slide against each other when longitudinal force is applied, as it is in the drafting zone of a wet spinning frame. As the line fibres are relatively long this enables finer yarns to be spun to finer counts than would be the case if only the number of fibres in the cross-section of the yarn were taken into account.

3.6.2 Hackling and sliver forming

Hackling

Hackling is the word used in the flax industry to describe the process of combing line flax fibres. The purpose of hackling is to straighten, disentangle and parallelise the fibres, to remove short fibres and any extraneous matter such as shiv and seeds which have not been removed during scutching. To some extent hackling also separates the fibres within the fibre bundles. The process produces

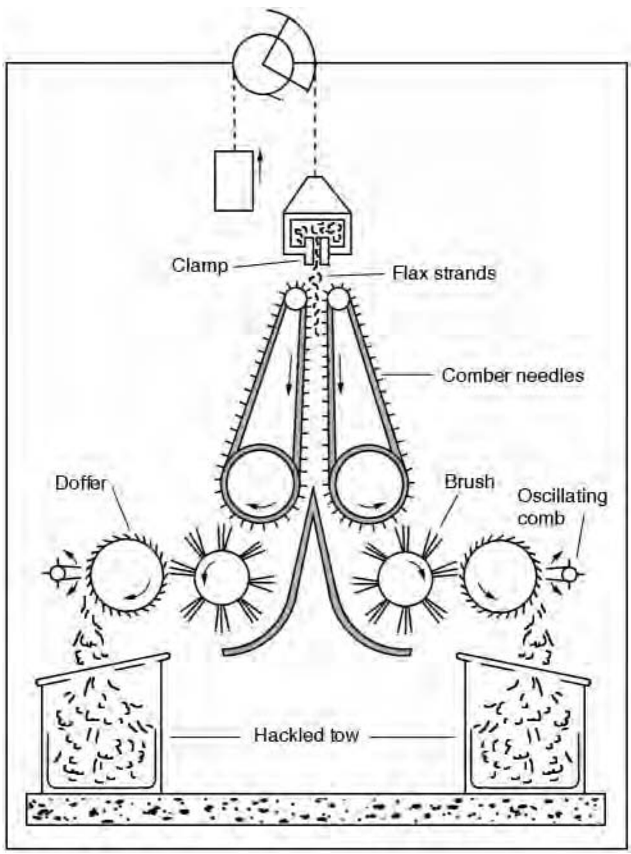


Figure 3.18 Continuous flax hackling. Source: *Linen: Technical aspects of production*, Confederation Internationale du Lin et du Chanvre. Courtesy: Institut Technique du Lin, Paris.

a sliver of clean, parallel line fibres and a textile by-product, hackled tow, This is used mainly for dry spinning, for composite materials and for affining, although some quantities are wet spun.

Hackling is carried out on hackling frames. These are large machines (some 10 to 12 m long by 5 m wide and 5 to 6 m high) in comparison to the smaller combers used for wool or cotton. Hackling can be either discontinuous or, on more modern hackling frames continuous. Feeding is done manually in 'hands' of 80 to 120 g although automation is being developed. Discontinuous hackling frames have two sides, the first side combs the top half of the hands of scutched fibre, after which they are inverted and the second side combs the root half. The combing action is vertical, the hands, hanging from clamps which are moved round the machine, are presented vertically to each of the combs in turn and pulled through them. These combs are of progressively finer pitch. Production can reach 60 kg per hour.

In continuous hackling the hands of line flax are either fed into the hackling frames in batches, by hand, or continuously if rolls of fibre have been produced as the final part of the scutching operation. They are then clamped between two conveyor belts and fed into the combs. Production can reach 120 kg per hour. The short fibre produced during hacking (hackled tow) falls to the bottom of the machine and is collected for further processing into yarn, usually by the dry spinning route, or pressure baled for despatch.

Sliver forming

After hackling the combed line fibres are placed manually on a slanted apron in which is a series of gills. As they proceed through the gills they are formed into a

Figure 3.19 Line flax sliver being wound into 'can' after hackling. Source: Masters of Linen.

sliver which passes through two callender rollers and is then either coiled into cans for further processing on draw frames or pressure baled for delivery to spinners. The weight of the sliver is usually between 20 g and 40 g per metre, depending on the yarn count to be spun from them.

3.6.3 Wet spinning

After the scutched line fibres have been hackled and the sliver prepared the spinning operations consist, as with other fibres, of yarn drafting and doubling, rove formation and spinning. However, the machinery used and the details of operation are specific to flax.

Yarn preparation (drafting and doubling)

The drafting and doubling frames are of the open-gill type. Pin densities increase from the first draw frame onwards. A typical set would include:

- A draw frame for doubling and drafting 6 to 1; in flax processing doubling takes place at the front of the frame – on the sliver plate.
- Four or five open-gill drafting frames which double and progressively draft the sliver to the required weight per metre; the drafting ratio varies from 8 to 12 approximately depending on the weight of sliver required. Another specificity of flax yarn preparation is that the flax slivers fed into the gill boxes are drafted separately before doubling, again ensuring greater fibre control during drafting which is necessary due to the low degree of fibre-to-fibre friction of flax.

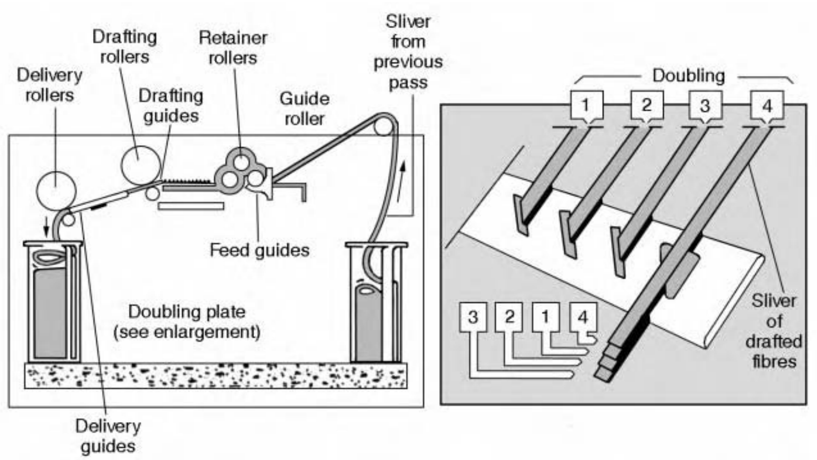


Figure 3.20 Drafting and doubling. Source: *Linen: Technical aspects of production*, Confederation Internationale du Lin et du Chanvre. Courtesy: Institut Technique du Lin, Paris.

- A roving frame; these, when processing other fibres, do not usually have gills but in the case of flax these are required again to provide as much fibre control as possible during drafting.[8] The rove is delivered on a perforated cylindrical package which eliminates the necessity of rewinding before the next process of rove degumming and bleaching.

To some extent the pins on the gills during drafting also increase fibre fineness by splitting the fibre bundles, as do the combs during hackling.

Rove degumming and bleaching

Up to the 1970s flax was spun ‘grey’ and the gums, lignin and pectins in the fibres removed by bleaching the yarns or the fabrics once they were woven. However, the degumming and bleaching of rove rather than fabric developed fairly rapidly and is now the preferred method in Europe. Substantial quantities of bleached rove yarn are also produced in China. Rove degumming and bleaching replaced ‘grey’ spinning for several reasons.

- It facilitates the spinning of finer yarns than is possible using grey rove.
- In the 1980s the apparel industry consumed 50% of the flax produced in western Europe, compared to 5% in the 1960s. Some of the fabrics required for apparel were yarn dyed so that colour woven designs could be produced (as opposed to plain white or piece dyed fabrics, which can be bleached and dyed in the piece). To be able to dye these yarns they had first to be bleached, which could be done either at the rove or the spun yarn stage. To be able to carry out this process at the rove stage eliminated the need for yarn bleaching.
- Yarns spun from bleached rove are more consistent in technical quality than those spun from grey rove. This is of great importance for the efficient weaving of 150 cm width finished fabrics required by apparel manufacturers. These are woven on rapier or projectile looms which, for efficient production, require yarns of consistent quality. Previously linen apparel fabrics were traditionally woven, because of the low elasticity of the yarns (see 3.7 below), on narrow, low shed looms. These produce fabrics of 27 inches (70 cm approximately) finished width supplied mainly to tailors and dressmakers. These looms were less demanding of yarn quality than more modern weaving machines.

Rove degumming is done by treating the rove with boiling sodium carbonate or sodium hydroxide. This removes most of the non-cellulosic substances. Rove bleaching is done after degumming by treating the rove, still on the perforated cylindincal packages obtained from the roving frame, with oxidising agents. The most widely used are sodium hypochlorite, sodium chlorite or hydrogen peroxide. Sodium chlorite is now little or not used in western Europe because of the toxic waste produced and also because the white colour produced using hydrogen peroxide or sodium hypochlorite is satisfactory for most purposes. Although it does not produce as pure a white as do chlorine compounds, hydrogen peroxide activated by sodium hydroxide at pH10 is now more usually used as a bleaching agent as it has no health and safety disadvantages (see 3.9 below). Several examples of formulations for rove treatment are given by Kirnagnahan and Kierkens in BAPF p. 358. After bleaching the packages of rove are placed directly on the creel of the spinning frame.

Wet spinning

A flax wet spinning frame is a ring spinning frame with a trough of warm water heated to about 60 °C placed before the drafting zone. As described above, treating the rove in this way swells the flax and softens the gums, allowing the primary fibres to slide over each other when being drafted. The flax yarn thus obtained is naturally grey or yellow in colour (unless it has been spun from bleached rove) and it is known as grey yarn. Once it has been dried and wound it can immediately be woven without further processing.

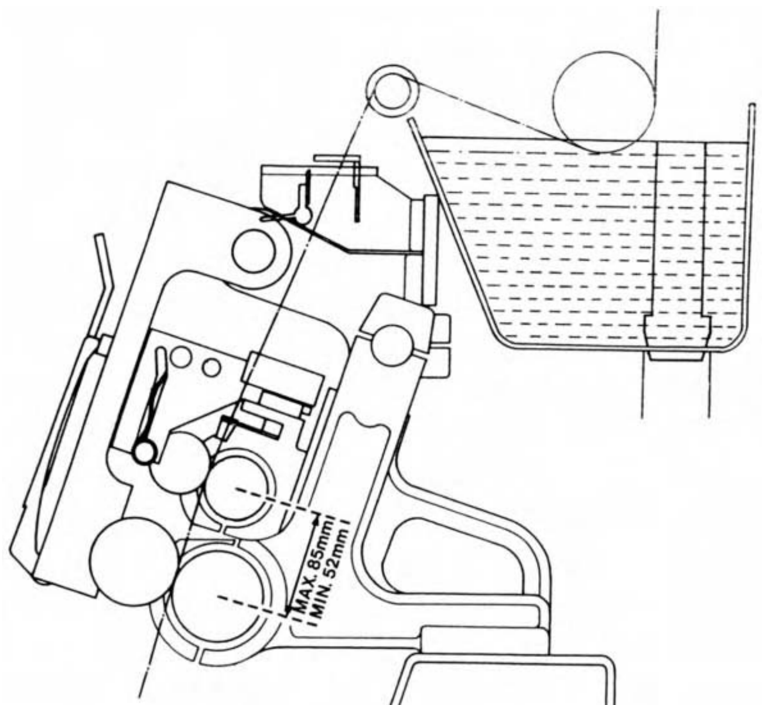


Figure 3.21 'Linmack' drafting zone. Source: *Biology and processing of flax*, M. Publications, Belfast, UK. Courtesy: Professor S. Sharma, ed.

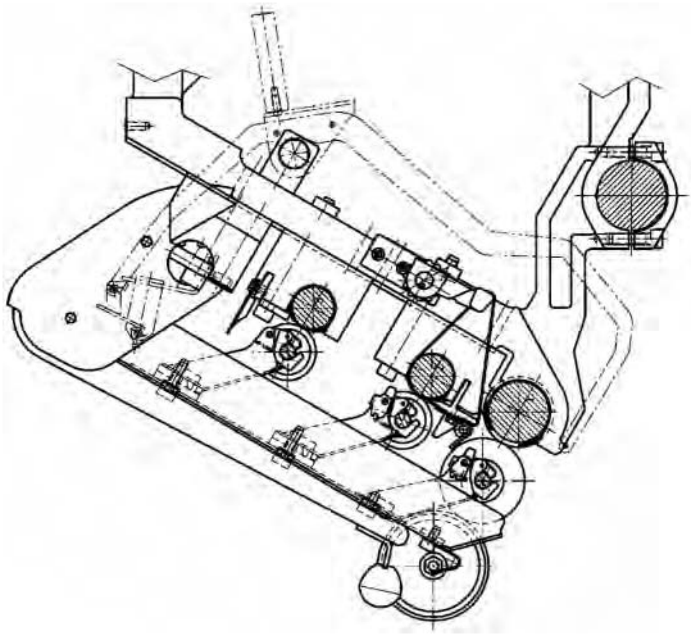


Figure 3.22 'Linimpianti' drafting zone. Source: Linimpianti Mod. 7002 Metier a filer au mouille (promotional leaflet) Courtesy: Linificio e Canapificio Nazionale Spa.

In the 1970s bleached rove became the preferred method of wet spinning flax and spinning machine manufacturers developed wet spinning frames more suited to this type of rove. Bleached rove spinning produces yarns of greater strength and lower CV than yarns spun on standard wet spinning frames. There are three suppliers of these wet spinning frames, Bridge Mackie (China), Linimpianti (Italy) and Orioltexmash (Russia).

There are variations between these frames, for example, two or three pairs of drafting rollers, the use of steel or nylon rings or the spindle ring can be fixed or moving. Although wet spinning is mainly used to produce 100% flax yarns – usually from line flax but sometimes from hackled tow, mixtures with other fibres, for example, polyester are technically possible[9] and flax mixtures with elastomeric yarns have also been developed. After spinning the bobbins of spun yarn are placed in dryers at temperatures not exceeding 80 ºC until their moisture content is reduced to the natural regain of flax of about 12%.

The normal counts produced in wet spinning are from 12s metric (81 Tex, 22s lea) to 36s metric (28Tex 60s lea) although finer counts are possible if the fibres are of sufficiently fine quality. The principal end uses for these yarns are medium and light-weight apparel fabrics, sheets, table cloths and handkerchiefs. However, in eastern Europe wet spun yarns are also used as weft in union fabrics of heavier weights suitable for furnishing fabrics.

3.6.4 Dry spinning

As stated above, the machinery used to dry spin flax is similar of that used on the semi-worsted system for wool. Dry spinning is not only used to produce 100% flax yarns but also for yarns blended with other fibres, for example cotton, wool, polyester, acrylic, etc. Counts produced are normally from 2.5s metric (450 Tex, 4 lea) to 9s metric (115 Tex, 15s lea) but depending on the fineness of the flax or of the other fibres in the blend, finer counts of up to 12s metric (82 Tex, 20 lea) can be achieved. The principal uses of dry spun flax yarns spun from scutched tow are for twines, ropes and cordage and industrial fabrics. Better quality yarns spun from hackled tow are used as weft in union furnishing fabrics and in 'bottom weight' apparel fabrics.

3.6.5 Semi-wet spinning

This type of spinning is basically dry spinning with the addition of a dip roller which transfers water from a trough to the surface of the yarn. This roller is placed on the final draw or roving frame, after the last drafting roller of the sliver or rove frame. This application of moisture markedly reduces the hairiness of the yarn. Semi-wet spinning is used principally to produce yarns for sewing threads. As the yarns are smooth they also have a more lustrous appearance and this is sometimes exploited in the design of apparel fabrics but as semi-wet spinning can cost as much as wet spinning, fabric designers generally find it easier to use wet spun yarns as the capacity for the production of semi-wet yarns is fairly small.

3.6.6 Spinning blends: affined (cottonised) flax

Various attempts have been made to modify flax fibres to enable them to be spun on cotton spinning machinery but none came to any lasting success until the 1980s. This new technology has enabled the flax fibre to be 'affined' which produces fibres capable of being blended with cotton, polyester, wool, acrylic, silk, and spun on the various spinning systems used for those fibres.

3.6.7 Yarn winding

After spinning wet and semi-wet yarns are dried at temperatures not exceeding 80 ºC to reduce their moisture content to around 12%. They are then wound on to packages (cones, cheeses, etc.) suitable for subsequent processing. During the winding operation any remaining impurities or faults such as shiv and weak places are removed. Modern high-precision winding machines suitable for cotton or other fibres are also suitable for flax. Owing to the specific characteristics of flax the use of winding frames equipped with optical slubcatchers is recommended. If the yarn is to be knitted it is softened by treating it with paraffin wax during winding.

3.6.8 Linen yarn count

Over the years and as with other fibres, the flax industry developed its own system of yarn counts, 'Linen Lea'. This is an indirect system whose unit of measurement is the number of 300 yard (274.32 m) lengths that weigh one English pound (abbreviation 'lb.', equivalent to 453 g). Whilst the lea system is still extensively used in the flax industry, the metric system (number of 1000 metres per kilo) is becoming increasingly preferred and will eventually replace the lea. The Tex system (number of grams per 1000 metres) is also widely used, especially in research and development as it is used for all fibres and thus allows immediate correlation with yarns spun from other fibres. Comparisons of the lea count system with others are set out in Appendix D.

3.7 Weaving

3.7.1 Introduction

Weaving is the principal method of making fabrics from flax fibres. Knitting consumes a relatively small part of flax fibre production. However, there is a growing use of flax in composite products (see Chapter 10). Up to the 1980s nearly all linen apparel fabrics were mainly woven on narrow looms with a reed width of approximately 100 cm. These were shuttle looms using comparatively flat shuttles which required a small shed. This was necessary because weaving the relatively inelastic flax yarns on wider looms with deeper sheds would have led to unacceptable levels of yarn breakages. In the 1980s a combination of market forces and technical developments led to the production of 150 cm finished width fabrics required by apparel manufacturers. These developments were individual thread tension devices on sectional warping machines, rapier and projectile looms, precision bobbin winding and wet spinning based on bleached rove. (For further discussion on the effects of these developments see pp. 4–5 *Biology and Production of Flax*.)

Yarn quality for weaving

As has been stated above, flax yarns are, in comparison with yarns spun from most other fibres, relatively inelastic. From a technical point of view therefore, they must not be selected only on the basis of their tenacity, which is high, but more particularly the variation in tenacity along the length of the yarn needs to be considered. This can be easily measured using equipment such as Uster yarn regularity testers and whilst this is often done for many other kinds of yarns it is particularly important for flax.

3.7.2 Warping and sizing

Warping

Up to the 1980s, when apparel fabrics constituted a small part of the total market for linen fabrics, warping and sizing was usually done on slasher sizing systems similar to those used for cotton. This was perfectly satisfactory for the production of a relatively small number of standard warps, nearly all of which were to be used to produce white or piece-dyed fabrics, linen colour woven fabrics being the exception at that time. However, when the demand for greater variety in fabric design developed as linen penetrated the fashion market, fabric suppliers realised that the lack of flexibility of the 'cotton' system of preparing warps prevented them from operating effectively under these new conditions. This lack of flexibility not only affected both their normal production processes but also the production of samples and short lengths required for the once or twice yearly collections of new fabrics and designs required by this new market.

Other fabric manufacturers operating in the fashion area, such as most woollen and worsted weavers, had solved this particular problem by using sectional warping machines which allowed both a great variety of design and a much smaller number of warp yarn packages. Previously, however, warping flax yarns on sectional warping mills had proved to be difficult because their relative inelasticity led to differential tensions developing between individual warp yarns and this led to the development of warp stripiness in the fabrics. This problem was solved by fitting individual thread tension devices to the warp creels and by the mid 1980s nearly all linen fabric manufacturers supplying the apparel industry were using these sectional warpers.

Sizing

Modern rapier or projectile looms produce a small shed. This, and the overall greater engineering precision of modern weaving machines compared to looms produced before the 1970s, together with the increasing use of the more regular bleached rove yarns has resulted in much less friction developing on the warp yarns during weaving. As a result, sizing of many flax warps is no longer necessary. Exceptions to this general trend are:

- With finer yarns, generally of Metric 22 and above, sizing is recommended especially if the fabric construction is fairly dense.
- In countries that habitually use warp yarns spun from weak flax sizing, in this case, will increase weaving efficiency.
- Sizing will also help in the case of particularly hairy dry spun flax tow yarns.

The most widely used sizes are PVA or starch and the deposit rate can vary between 4% and 10%. Double size boxes and double squeeze rollers increase sizing efficiency but on the whole sizing flax warps poses no particular problems. Cold sizing and pre-wetting are also possible.

3.7.3 Weft preparation

With very few exceptions rewinding the yarn package delivered by the wet or dry spinning frame is not necessary.

3.7.4 Weaving

Today the great majority of linen fabrics are produced on rapier weaving machines. Projectile weaving machines are used but only for very wide width weaving, of 3.5 metres width or greater because for smaller widths rapier looms are more economical. Air and water jet looms are not suitable for flax. The choice of weaving accessories is important, and in particular:

- A movable whip-roller; this diminishes or eliminates stretching the warp yarns as the shafts move up and down.
- Weft accumulators, to even out the tensions on the picks as they are inserted by the rapier.
- Programmable weft brakes, for the same reason.

Weaving conditions

Weaving flax produces a certain amount of 'fly' which is composed of dust, very short fibres, and possibly rubbed off sizing agents.[5] The short fibres and particles of size are the result of friction on the yarns during weaving. The amount of fly in a weaving shed needs to be minimised for two reasons:

1. Health and safety: the inhalation of small particles over a substantial length of time can lead to respiratory disorders.
2. Quality: the fly settles on surfaces, including warps and can be the cause of yarn breaks during weaving and of faults in the fabrics if small accumulations are woven into the fabric.

Good housekeeping is therefore necessary and in particular it is essential to clean all weaving machines regularly and install adequate air conditioning and purifying systems. Optimal weaving conditions for flax are temperatures of between 20 ºC and 23 ºC with a relative humidity of between 75% and 85%.

3.7.5 Blended and mixture fabrics

In addition to the many different types of 100% linen fabrics that are on the market we also need to take into account the large quantities of fabrics made from flax mixed with other fibres. In this connection and for the sake of clarity, a distinction needs to be drawn between blended and mixture fabrics. Blended fabrics are woven (or knitted) from yarns containing two or more kinds of fibres; wool and polyester, or cotton and flax for example. Mixture fabrics are produced from yarns spun from different fibres, but each yarn containing only one fibre. Perhaps the best known of these are linen unions, consisting of cotton warp and flax weft.

3.7.6 Designing linen woven fabrics

'Cover factors' are a useful and practical base from which to start designing any woven fabric as these express in figures the two main variables of cloth construction-yarn counts and cloth settings. The cover factor shows how much of the area of the cloth is actually covered by the yarns. In other words it is a measure of the surface density of the cloth. The cover factors for the warp (Kp) and weft (Kt) are calculated separately and these two figures are then combined to give a cover factor of the cloth. For example, to calculate the cover factors using threads per centimetre and metric count:

$$\mathrm{Kp} = \frac{\text{ends per cm}}{8.5\sqrt{\text{warp metric count}}}$$

$$\mathrm{Kt} = \frac{\text{picks per cm}}{8.5\sqrt{\text{weft metric count}}}$$

$$\mathrm{Kc} = \mathrm{Kp} + \mathrm{Kt} - \mathrm{Kp} \times \mathrm{Kt}$$

To calculate cover factors using the number of threads per inch and 'lea' yarn counts the constant 8 in the above equations is changed to 16.7.

Of course, the actual cover factor of a particular cloth will be modified by a variety of factors. For example, the theoretical maximum values for a plain weave cloth with equal numbers of warp and weft threads per unit of length, and assuming that the yarns have not been flattened are:

$$\mathrm{Kp} = 0.7, \mathrm{Kt} = 0.57, \mathrm{Kc} = 0.81$$

In practice the values for linen fabrics may be exceeded due to yarn flattening during finishing. Other considerations will also need to be taken into account, such as the appearance, drape and handle required, the weave of the fabric, the types of yarns used (wet or dry spun, bleached, yarn dyed, for example) and the type of finish and the expected shrinkage.

Yarn crimp

As with yarns spun from other fibres this is calculated as follows:

$$\text{Yarn crimp (\%)} = \frac{\text{Straightened yarn length} - \text{cloth length} \times 100}{\text{Straightened yarn length}}$$

and the percentage crimp must be taken into account when calculating the fabric weight per unit area. Compared to equivalent loom state cotton fabrics, linen fabrics will tend to have less weft crimp and more warp crimp.

3.8 Knitting

3.8.1 Knitting 100% linen fabrics and garments

As has been stated above, 100% flax yarns are relatively rigid and therefore do not take kindly to being bent around knitting needles. Nonetheless, they can be knitted and 100% linen knitted outerwear and mens socks are on the market, but the quantities and distribution are limited. The advantages of these articles are their comfort, lightness and lustrous appearance as they are knitted from wet-spun yarns. Their disadvantage is their high price. To knit flax yarns satisfactorily they need to be waxed which increases their flexibility.

As there is relatively little know-how on knitting these flax yarns in the industry (certain Italian companies are perhaps the most advanced) a manufacturer intending to develop a range of 100% linen garments or circular knitted fabrics would need to carry out a certain amount of development work. This would need to cover basic fabric structure, yarn and fabric tensions during knitting, the rate of knitting, and checking the dimensional stability of the fabrics after knitting. The following approaches may be useful:

- Physical or chemical treatment of the yarns, such as degumming, bleaching (if not already rove bleached) mercerising and softening will facilitate knitting.
- As flax yarns have a more irregular appearance than many others used in knitting the use of fancy yarns would cover this disadvantage, unless this irregularity is to be a design feature of the knitted garment.
- Using fancy stitches would also have the same effect.
- Knitting with 2/fold or 3/fold yarns would eliminate a great deal of the irregularity of the single yarns.
- Knitting with two threads or alternating two threads would have the same effect.
- Giving the fabric or garment an appropriate after-treatment aimed at introducing more bulk to the yarns.

3.8.2 Knitting blended yarns

If these are produced as hosiery yarns, as opposed to weaving yarns, knitting them presents no major technical problems. The most usual blends are with cotton, wool, polyester and acrylics. Three-way blends are also produced. The purpose in knitting garments or fabrics from these blends can be to take advantage of the 'linen look' without experiencing the technical problems of knitting 100% flax yarns, or to benefit from linen's high prestige in the marketplace, or both. It is difficult to establish the quantity of flax that is consumed as knitted products either in 100% form or in blends because none of the statistics available go into this kind of detail. However, when linen is in fashion the quantity of linen knitwear on the market increases, especially in blends and certainly reaches several thousand tonnes in a season.

3.9 Fabric desizing, bleaching, dyeing and finishing

3.9.1 Introduction

Flax and cotton are cellulosic fibres and with little variation the same wet treatment techniques, dye-stuffs, auxiliaries and equipment are used for both. Certainly, the fibre structure of flax is more crystalline than that of cotton and this will therefore require some modification of processing parameters. Another consequence of flax's higher crystallinity is its tendency to crease and poorer resistance to flexing. The bleaching, dyeing, and finishing of linen fabrics should therefore be done in open width machines. In economically developed markets flax yarn and fabric consumption, by end-use, is approximately as shown in Table 3.6.

The figures in Table 3.6 do not include flax fibre used for non-woven fabrics nor as fibre re-enforcement in composite products for the automotive industry. In linen woven textiles for apparel it is generally estimated that some 20% are woven from dyed yarns and the rest are either white or piece dyed. For household textiles (sheets, pillow cases, towels, etc.) the predominant colour is white and nearly all furnishing fabrics are either piece dyed or produced white for printing. In this flax is not very different from cotton, polyester or regenerated cellulosic fibres. The continuous, as opposed to batch, wet treatment of linen fabrics is possible but to be economically attractive, such high throughput and expensive production equipment requires a market for large quantities of standard fabrics. This was the case in the ex-Soviet bloc and their flax 'Combinats' did continuously scour, bleach and dye linen and linen blend fabrics but in western Europe the market requires a wide variety of fabrics in a wide variety of colours and this precludes continuous processing.

Table 3.6 Flax consumption by major end-uses

Apparel	60%
Household textiles	15%
Furnishing fabrics	15%
Industrial fabrics, sewing threads, etc.	10%
Total	100%

3.9.2 Desizing

If the warp has been sized the size will need to be removed by scouring. For starch or starch derivative sizes it is important to avoid using caustic products because these can fix the size to the fabric. This also applies, but to a lesser extent, to PVA sizes. Detergent scouring will remove synthetic sizes based on PVA, acrylic or vinyl co-polymers. Enzyme desizing of starch or modified starch sizes is strongly recommended but these sizes are gradually giving way to synthetic sizing agents and in western Europe these are now the predominant products used.

3.9.3 Fabric bleaching

The bleaching of textiles, by its very nature, is an aggressive process and it is important to control it so that the fabric being treated will not be adversely affected. The degree of bleaching required and the means of achieving it will depend on the type and end use of the fabric. For example, and to choose two extremes, bleaching 400 g/m^2 linen union furnishing fabric to be piece dyed or printed will be much less critical than bleaching lightweight white cambric handkerchief fabrics. It is therefore not possible to give standard recipes or processing conditions but experienced finishers are well able to achieve the results required. Some general comments are, however, permissible: in comparison with cotton, higher concentrations of bleaching and alkali buffer chemicals are required, and if the fabric is loom state (un-scoured) a wetting agent, applied cold, is essential.

The bleaching agents commonly used for treating fabrics are the same as those used for bleaching rove (see page 122). These are sodium hypochlorite, sodium chlorite and hydrogen peroxide. The use of sodium chlorite is now strongly discouraged on environmental grounds and this does have a disadvantage insofar as the bleaching of flax (and hemp) are concerned. Unless the shiv has been removed from the fabrics before the bleaching stage its presence will show as light coloured blemishes, called 'sprit', in piece dyed or printed fabrics. Bleaching with sodium chlorite does remove this but sodium hypochlorite and hydrogen peroxide do not.

Various combinations of alkaline pre-scour and sodium hypochlorite or hydrogen peroxide do greatly reduce the problem but there is no real answer other than by ensuring that the previous processes of retting, scutching, hackling (or carding and possible combing for dry spun yarns) and yarn preparation have reduced the amount of sprit to a level that is sufficiently low to permit its elimination by the environmentally acceptable methods mentioned above. (See also Kernaghan and Kierken *Biology and Production of Flax* p. 338.)

Fluidity and the degree of polymerisation

When bleaching flax, at whatever stage in manufacturing fabric from fibre, it is essential to avoid over-bleaching as this markedly reduces the tensile strength

Table 3.7 Fluidity and degree of polymerisation at various stages of manufacture

	Fluidity	Degree of polymerisation
Unbleached fibre	0.9–12	3,000–3,200
Cream yarn	2.5–3	2,300–2,450
Bleached yarn	<5	<1850

Fluidity values of up to 12 are acceptable and up to between 12 and 15 for adequate fabric performance. Values greater than 15 indicate that chemical deterioration of the fibres has taken place

and resistance to abrasion of the fibres and therefore the fabrics. The degree of bleaching is assessed by measuring the fluidity or the degree of polymerisation (DP) of the cellulose in the fibres after bleaching.

Fluidity values of between 12 and 15 are considered to be the maximum permissible for adequate fabric performance. Values greater than 12 indicate that chemical deterioration of the fibres has taken place. There is an empirical formula of the relationship between degree of polymerisation and fluidity

$$DP = \frac{18.200}{F + 5.5}$$

The fluidity of retted flax fibre will vary according to the degree of retting and can rage from a fluidity of approximately 0.7 (DP 2850) for unretted fibre to 1.5 (DP 3550) for retted fibre. The International Standards Organisation procedure for measuring the degree of polymerisation is ISO 5351:1.12.1981 and the relevant UK standards are BS 2601:1978, BS 3606-1:1981 and BS 3606-2:1982.

3.9.4 Mercerising

As with cotton, linen fabrics can be mercerised and in practice the same equipment and processing conditions are used. As considerable fibre swelling and fabric shrinkage occur during mercerising it is important that this is taken into account when designing the fabrics. The mercerising of linen fabrics is not very common, mainly because of costs, but it is occasionally used for apparel fabrics. Yarns are sometimes mercerised if they are to be used to manufacture sewing threads.

Liquid ammonia fabric finishing

This process was developed for cotton but it has been successfully applied to linen fabrics. Whilst the results are encouraging, giving a soft handle and improved crease and abrasion resistance, the process has not developed to any extent because very few finishers have the required plant and present liquid ammonia technology requires continuous processing. As we have seen above for continuous wet processing (3.9) the lack of sufficiently long runs of standard fabrics make these processes uneconomic for linen. The liquid ammonia finishing of linen fabrics also markedly improves their crease resistance and it is regrettable that the continuous processing that this treatment requires at present precludes its commercial development.

3.9.5 Fabric dyeing

As has been stated above, the crystallinity of flax fibres is greater than that of cotton and these fibres are therefore more lustrous. This gives linen fabrics their recognisable and much sought after ‘sheen’ but from the point of view of the dyer it will require changes in the dye recipes and dyeing conditions when compared to other cellulosic fibres. The greater crystallinity of the cellulose molecules also impedes the penetration of water into the fibres, and therefore slows fabric wetting and the diffusion of dyes into the fibres. This will also require changes in processing conditions when compared to cotton. Further points to bear in mind are:

- The resistance to abrasion of wet linen fabric is relatively poor. Therefore the use of dyeing equipment which may cause rubbing or chafing during processing is to be avoided.
  - The presence of sprit, which will appear as light coloured specks after dyeing should be minimised (see 3.9.2 above).
- As with other fibres, when dying thicker fabrics it is advisable to pre-pad.
  - When using reactive dyes, apply the dyestuff by padding followed by cold storage and open width washing down.
  - With vat dyes, apply by padding followed by jigger dyeing.

Obtaining satisfactory colour fastness to light and washing poses no particular problems but, in dark shades such as navy, dark brown and black problems of dye fastness to rubbing are occasionally encountered. The effect may be noticed as ‘staining’ of the dark shade on garments of lighter colour worn next to the dark coloured linen garment. In fact the lighter garment is not ‘stained’. The effect is the result of the fibrillation of the flax fibres during which extremely small particles of the dyed fibres are broken off and adhere to the lighter garment. They can usually be brushed off and should also disappear during washing or dry cleaning.

If the fibrillation is severe its effect on the linen garment will appear as a patch of lighter colour, which may be assumed to be a stain. However, its real cause is differential reflection of light from the fibrillated fibres on the surface of the fabric, and trying to ‘remove the stain’ by rubbing stain removal products onto the fabric may only make matters worse.

3.9.6 Yarn dyeing

Dyeing flax yarns requires the same equipment and processes used for other cellulosic fibres. However, to achieve good dyestuff penetration and to avoid poor colour fastness to rubbing, especially in dark shades, two precautions should be taken.

1. Winding tensions on the yarn packages should be sufficiently low so as to avoid the appearance of winding marks on the yarns after dyeing. Densities of between 0.35 to 0.9 are recommended.
2. It is important to ensure uniformity of density on the yarn packages through a given batch.

3.9.7 Fabric finishing

Again the finishing of linen fabrics resembles that of cotton but with differences required by the different structure of the fibre. As with all textiles the finishing routine will depend on the intended end-use of the fabric.

Singeing and cropping

Most linen fabrics are singed and cropped, sometimes immediately after weaving, sometimes after bleaching and occasionally both, depending on the end-use of the fabric. High quality apparel fabrics woven from wet spun yarn may be singed and cropped more than once.

Compressive shrinking

This is essential for all linen apparel fabrics and all those destined for use as tablecloths and other end uses where dimensional stability is required. In addition compressive shrinking improves handle by increasing the warp crimp without affecting the crisp and cool feel of the cloth.

Calendering

The purpose is to give even greater sheen to linen fabrics. The fabrics are passed between calenders under considerable pressure. This flattens the yarns and the fibres.

Softening

Fashion sometimes requires soft handling linen fabrics. The natural handle of flax fabrics is crisp but this can be softened by suitable finishing. Two methods are possible.

1. Air jet softening: the fabric is repeatedly passed in open width in front of fairly strong air jets, thus flexing the cloth and, to a certain extent, breaking the rather rigid fibres.
2. Softening by enzymatic (cellulase) treatment: the enzyme very partially decomposes some of the cellulose in the fibres. As with all processes based on enzymes this needs close control of temperature, time and enzyme concentration.

Easy-care and crease-resistant finishes

Up to the 1980s linen fabrics were occasionally given the same type of crease-resistant finishes as were cotton and viscose cloths; with the same more or less successful results and with the disadvantage that both the handle and the abrasion resistance of linen were affected. The development of formaldehyde free resins and more accurate process control has improved the results that can be obtained but present easy-care finishes rely increasingly on reactants. Three processes are currently used.

Dry cross-linking

Over 90% of crease-resistant linen fabrics are treated according to this technique which is also known as 'pad-dry-cure'. For cellulose, the chemical reaction takes place in an acid medium. The treatment consists of impregnating the fabrics, by padding, with an aqueous solution containing a cross-linking agent and a catalyst, then drying and polycondensing, these operations being carried out consecutively without any breaks. Resins such as melamine, previously used in the implementation of this technique, used to leave a high level of free formaldehyde on the fabric. Today, to comply with legislation, finishers use resins that either eliminate residual formaldehyde entirely, or keep it within the authorised levels. This treatment makes it possible to obtain a good level of crease recovery in dry fabrics as well as improved dimensional stability. In order to optimise the results, it is best to carry out prior softening and to keep drying temperature and duration down.

Damp cross-linking

This technique consists of padding the linen with the agent/catalyst mixture, partially drying in order to conserve a fabric humidity of around 8%, then stocking it for 15 to 20 hours on a rotating roller, at room temperature. In order to obtain a regular quality of crease resistance throughout the length of fabric being treated, the moisture content must be maintained at a constant level and, to prevent evaporation, the rolls of fabric should be covered by a waterproof plastic film. The fabric is then rinsed and washed. Damp cross-linking treatment is not used very frequently because it is difficult to maintain a sufficiently constant degree of humidity.

Wet cross-linking

Wet cross-linking consists of padding the fabric with a reactive solution and catalyst, rolling the wet piece on a roller without intermediate drying and stocking it at room temperature for 16 to 20 hours. The fabric is then rinsed and washed. This is the procedure that takes the best care of the flax fibre because it cuts out the drying operation that may produce dust or break the fibres. In addition, it confers properties of wet crease resistance that are required for machine-washable products, such as shirts, trousers or household textiles.

Other finishes

Flame-retardant, water-retardant, stain-resistant and anti-rot finishes can all be applied to linen fabrics in much the same ways as they are to cotton.

For further information concerning the wet processing of linen fabrics and in particular of the history, chemistry and past and present processing the reader is recommended to consult Kernaghan and Kiekens, Ch. 18 and Kernaghan, Ch. 21 in *The Biology and Production of Flax*.

3.10 Apparel manufacture

All linen apparel fabrics are nearly always in the light- to medium-weight range and should be handled in a clothing factory in similar ways to other such fabrics. Points to remember are:

- Linen cannot be 'shrunk into shape', as can wool fabrics, by steaming and ironing, therefore the correct shape has to be obtained by cutting and sewing only.
- The size and number of stitches per centimetre needs to be adjusted to the weight of the fabric.
- Linen clothes and household textiles are usually washed frequently. The fabrics should therefore be pre-shrunk and the sewing threads used should also not shrink in hot water. However, not only the sewing thread itself must not shrink but also sewing tensions must be set as low as is consistent with efficient sewing. Otherwise the seams will pucker when the article is washed and it may not always be possible to remove these puckers by ironing.

3.11 Products and applications

These are apparel, household textiles, furnishing fabrics and industrial (sometimes called technical) end-uses.

It is difficult to be precise concerning how the estimated present (2002) world production of flax is divided between these different groups of products but the estimates given in Table 3.5 are reasonable. The characteristics and properties of flax on which its success in various markets is based can be summarised as follows.

- The possibility of spinning relatively fine yarns from line flax enables a much wider variety fabric weight and structure than is possible from nearly all other bast or leaf fabrics.
- The two types of fibre, line and tow, and their different spinning systems used to produce the yarns also add to this wide variety of available fabrics.
- The rapid rate of moisture absorption and desorbtion, due principally to the presence of lumens in the individual fibres, in conjunction with a relatively low fibre rigidity, are the reasons why linen fabrics have a cool and pleasant handle and provide comfort in wear, especially under warm and humid conditions.
- The high level of crystallinity of the cellulose in flax fibres and the smoothness of the fibre's surface explain the 'sheen' characteristic of linen fabrics.
- Easy washability; being composed principally of cellulose, linen fabrics wash easily and dry quickly. The remaining gums that still cement the fibres to each other once the fabric is woven and finished soften in hot water but harden again when ironed producing the effect called 'dry back'; the return of the drape, handle and lustrous appearance to that of the original fabric.

3.11.1 Apparel

Up to the 1980s linen clothing was, to all intents and purposes, confined to men's and women's outerwear of the 'tropical suiting' kind. At that time apparel accounted for no more than 10% of western European flax production and its use was decreasing, due principally to its relatively high price compared to cotton and polyester-cotton clothing, and to its propensity to crease. However, three developments significantly changed this:

1. the Western European Flax industry's decision, implemented through their trade association – the Confederation Internationale du Lin et du Chanvre (CILC, now CELC) – to promote linen in the world of fashion (this promotion was assisted by the European Union)
2. the increasing disenchantment of some consumers of developed countries with clothing made from synthetic fibres, and their increasing interest in 'natural' and 'organic' products
3. certain technical developments in the manufacturing of linen fabrics which not only increased productivity but also enabled the production of yarns and fabrics of more consistent quality (see 3.7.1 above) and which were in keeping with the requirements of the fashion industry.

This combination of technical developments and the improvement in the acceptance of linen apparel by consumers in western Europe, North America and Japan led to a marked increase in the percentage of the overall flax fibre production that was, and still is, consumed by the world's apparel industries. Typical fabrics for apparel are woven from wet spun yarns of Nm 24 and Nm 26 and dry spun Nm 9.6, although in both cases other counts are also used, depending on the fabrics that are to be produced.

Linen blends and linen union fabrics

The renewal of consumers' interest in linen apparel in the 1980s also led to the development of the market for fabrics and garments made from various combinations of linen with other fibres. Although there are no statistics available which would enable us to establish the tonnage of flax used in the production of these fabrics the quantity and variety of fabrics on the market would lead us to estimate the use of flax in blended and mixture fabrics when linen is at the 'Top of Fashion' to be of the order of 10,000 tonnes of flax per year. The yarn counts used to weave these fabrics are as varied as those used to weave apparel fabrics spun from other fibres.

The fibres with which flax is blended include practically all of those used in the production of middle- and light-weight apparel fabrics, from silk to ramie, but the principal ones, by weight, are cotton and polyester. Apart from the increased consumption of linen blended fabrics the increased acceptance of linen by the apparel industry also led to the development and consumption of lightweight union (cotton warp-linen weft) fabrics. These types of fabrics were previously confined, with few exceptions, to heavier weight fabrics for the furnishing and household textile sectors.

3.11.2 Household textiles

This includes tablecloths and serviettes, place mats, sheets, pillow cases and duvet covers towels, tea-towels and glass and floor cloths. Tablecloths, serviettes and some place mats and sheets are woven from either wet or dry spun yarns. The other articles are usually made from dry spun yarns although some tea-towels produced in eastern Europe and China are woven from wet spun yarns. Nearly all these articles are produced both in 100% linen and from union fabrics.

Tablecloths, serviettes and place mats

The classic linen tablecloth and its accompanying serviettes are jacquard woven from wet spun yarns, usually white with satin and reverse satin weaves and are often referred to as 'linen damask' tablecloths and serviettes. The typical yarn used is wet spun Nm 26. These articles are expensive and justify their price especially in comparison with similar products made from cotton by their more attractive and lustrous appearance, drape and cool handle. Their principal outlet is in luxury hotels and restaurants although they are also available in the household textile departments of the more expensive retail stores and boutiques throughout the world. Other tablecloths, serviettes and place mats, usually piece dyed, are woven from good quality dry spun yarns of counts from Nm 6 to 9.6.

Sheets, pillow cases and duvet covers

As with linen 'damask' table cloths, those woven from wet spun yarns are expensive luxury articles. They justify their high price by their cool and luxurious feel and have the same distribution as linen damask tablecloths. They are used by top hotels and restaurants, luxury retail stores and boutiques. In some countries sheets woven from fine count dry spun yarns are produced. These are much lower in price than those woven from wet spun and their principal market is in state institutions (schools, hospitals, for example), where their good laundering and long-lasting properties make them cost effective in comparison with cotton.

Towels, tea towels and floor cloths

Although small quantities of linen terry towels are produced nearly all these articles are woven on standard rapier weaving machines. Many of them are made from linen union fabrics. Tea towels are usually in plain weave but other towels such as face towels and glass cloths, use twills, huckaback (diaper), crepe and other such weaves. The basic advantage of all these towels when compared to cotton is linen's more rapid absorption and desorbtion of water and the use of weaves with longer floats than plain weave enables the production of heavier fabrics which also absorb more water than would plain weave cloths.

3.11.3 Furnishing fabrics

Most linen furnishing fabrics are piece dyed or printed, fairly heavy (over 250 g/m^2) cloths woven from good quality dry spun yarns. Eastern European and Chinese linen weavers produce equivalent fabrics from wet spun yarns as their dry spun yarn quality is not good enough and their low cost bases allow them to use the more expensive wet spun yarns. Many of these fabrics are unions. Typical yarns used to weave these fabrics are Nm dry spun 4.2 and 6.

3.11.4 Industrial (technical) fabrics and sewing threads

The textile uses of scutched tow were agricultural twines, butchers' and other food-processing strings, ropes and cordage and, sometimes blended with hackled tow to improve spinning to produce heavy industrial products such as tarpaulins, awnings and post bags. In all these end uses flax is being replaced by synthetic fibres and particularly by polypropylene, which has the advantage of being cheaper, lighter in weight and therefore easier to handle and non-water absorbing. Therefore it is not subject to mildew, which removes the necessity of having to dry the fabrics if they have been wet. In these end-uses flax has therefore been relegated to certain niche markets where its particular qualities give it real advantages.

Flax string and ropes have lost the greater part of their traditional markets to synthetic fibres but maintain niche markets, which in some cases they share with hemp. Butchers' string is an example, where the resistance of flax to the heat of cooking is essential and most synthetics would melt under these conditions. Flax (and hemp) string is also used for tying salami and similar sausages and butchers' string. Flax twine is also regaining some of its market in agricultural twines

Linen sewing threads are particularly interesting. They are principally used for sewing leather, and in particular shoes and horse riding articles such as saddles and straps of various kinds. The particular advantage of flax in this end use is that the fibres can not only be spun to the fine counts required but also, when wet, the threads do not lose their already considerable tenacity and also swell. This causes the fibres, and therefore the sewing thread made from them, to increase in thickness and decrease in length. This in turn causes the threads to fill the holes made by needles during sewing (which are, of course, larger than the thickness of the thread) and makes these watertight. The contraction of the yarn tightens the seams and also makes them watertight. Sewing threads are often spun on the semi-wet spinning system (see 3.6.5 above).

Agricultural pollution

Twines made from natural cellulosic fibres (flax, hemp and sisal in particular) are also slowly reclaiming the market for agricultural twines where the lack of synthetic fibres' biodegradability causes severe pollution in the countryside. This is a particularly serious problem for the flax and wool industries because during the use of twines on farms or sheep stations a certain amount of waste twine remnants are inevitably distributed over the land. If the twine is made from natural fibres it biodegrades fairly rapidly but if it is made from polypropylene it is almost indestructible and these twine remnants are then caught in the sheep's fleeces or lifted with the flax stalks during harvesting. As there is no practical means of separating them from the wool or flax fibres these synthetic remnants go through the textile processes and their presence becomes visible only when the fibres, yarns or fabrics are dyed. They then become obvious as a major fault in the yarn or fabric. Major efforts have been made by the trade associations concerned to inform farmers of the consequences of using polypropylene twine on their farms and this situation, although still serious, is improving.

3.12 Economic and cost considerations

3.12.1 Historical background

Flax, like wool, has been an international business in Europe since at least the 16th century. Seeds, fibres and fabrics were traded between the Baltic States and Britain in the 18th and 19th century. Dundee in Scotland, which later turned over almost entirely to jute, was originally a flax processing and manufacturing centre; the linseed and the finer qualities of flax being imported from the Baltic States, the remainder of the required supplies of fibre being grown locally. After the industrial revolution substantial quantities of finer fabrics were exported from Europe to the United States, a business which is still taking place although not on the scale of the second half of the 19th century.

After the Second World War eastern European countries that produced flax, which was most of them, exported linen articles to nearly all the major developed markets. These were mainly household textiles but did include some other types of fabric and their principal sales advantage was price. Not only were their labour costs low, but, working in state economies, profitability took second place to the earning of foreign currencies. Most of those western European countries which had linen industries protected them by imposing import duties or quotas, or both. Nonetheless, these eastern European countries established substantial markets for the cheaper and less quality demanding articles such as tea-towels, floor and glass cloths. They also established markets in those consumer countries, such as the United States, which did not have flax industries of their own.

3.12.2 Recent developments

The last 12 years (from 1990 to 2002) have seen major changes in the world's flax industry. These followed the opening of East Europe and Russia to West European investment after 'Perestroika' and the expansion of China's exports of linen fabric to Western Europe, the USA and other developed markets after the relaxing of trade restraints following agreements within the World Trading Organisation (WTO). Before Perestroika, Russia and East European countries had well developed flax spinning, weaving, and finishing companies ('Combinats', some of which were huge, employing up to 5,000 people) but these suffered from several disadvantages when compared to West European companies.

- Most of them used Russian production machinery. Compared to production equipment manufactured in western Europe, these were not as efficient, nor as capable of producing a high and consistent product quality.

- Their quality control procedures and equipment were relatively poorly developed and not applied consistently.
- Their management and financial controls were inadequate.
- Their marketing and design competencies were inadequate.

But they did have some real advantages, in addition to their low cost base.

- Highly trained production supervisors and managers who, by western standards and against all the odds, were capable of using inadequate production, technical and management facilities to produce saleable products.
- Highly trained and disciplined workforces with several generations' experience of working with flax.

In a comparatively short period of time after the break-up of the USSR these advantages became obvious to western European flax spinners and weavers who were suffering from severe price competition, both from eastern Europe and from China. The obvious solution to this problem was to set up manufacturing operations in eastern Europe; financial and general management, design and marketing being run from their head offices in western Europe.

By 2002 there were practically no flax spinners or weavers of any importance who had not either acquired or set up production facilities in one or more low cost countries, mostly in eastern Europe but in two cases, both spinners and production facilities were established in Africa, one in South Africa and the other in Tunisia. This latter company also set up a new plant in Lithuania.

Before 1990 flax was grown, hackled, spun, woven, finished and made up into garments within western Europe, in some cases within a single country. These linen articles were then distributed throughout the world, the USA and Italy being the largest 'consumer' markets. Now (in 2003) we have a seemingly paradoxical but economically sound situation (if one ignores the ecological costs of transport); fabrics, garments and other linen articles may be designed, marketed, financed and their production and quality control organised by major branded manufacturers, designers or retail groups in western Europe and the USA but all their manufacturing is done in low labour cost countries. A perhaps extreme but not impossible example would be a pair of linen trousers made from flax grown in France that is hackled in Lithuania, spun in South Africa, woven in Poland (even perhaps finished in Northern Ireland) and made into garments in China. They would then be shipped directly to retail shops all over the world.

The organisational and shipping costs involved are more than fully covered by the lower manufacturing costs obtainable in these various countries. (See Appendix G for comparative textile labour costs throughout the world.) Whilst the western European flax industry was reorganising itself in this way, China, benefiting in flax as in most other high labour content manufacturing operations from one of the lowest labour cost bases of all, was steadily developing its production of both flax yarn and linen fabrics.

Flax spinners and weavers were of course not the only textile manufacturers to take advantage of the opportunity presented by the opening of these low cost countries. Cotton and polyester manufacturers had already moved in the 1970s and 1980s but in most cases not to Eastern Europe but to Asia, or in the case of the USA, to Mexico and the Caribbean Islands. Within the textile sector it was not only spinning and weaving which migrated to these low cost areas but also garment manufacturing, where the labour content is even higher than in fabric manufacture. It was natural therefore, that the lower cost linen fabrics produced in East Europe and China would also be made into garments in these countries. The arrival of these lower-priced garments onto the markets of developed countries, and particularly in the USA and West Europe, changed linen's profile. Prices were lower and these garments were no longer confined to 'Designer' labels but became available through major retail groups.

3.12.3 Cost comparison with other textile fibres

Despite the economies achieved by manufacturing in low cost countries flax remains a fairly highly priced fibre as is shown in Table 3.8 which gives indicative prices for various fibres used in the manufacture of apparel, household textile and furnishings. The total production of all textile fibres in 2000 was approximately 50 million tonnes. The difference between this total and that shown in Table 3.6 is because the latter figures do not include hard fibres such as jute or sisal (jute annual production is about three million tonnes) nor the luxury hair fibres such as mohair, cashmere and camelid fibres and silk whose total production is approximately 100,000 tonnes/year, nor synthetic fibres other then polyester staple fibre.

Table 3.8 Price comparisons of various textile fibres

	Production in thousand tonnes/year for year 2000	
	Prices (US$/tonne)	Production
Flax (line)	1,340–2,560	200
Flax (tow)	170	230
Cotton	1,140–1,800	19,000
Polyester SF	800	24,000
Wool	2,800–6,600*	2,000
Viscose	2,000	2,200

Flax (line), cotton and wool price brackets in euros/tonne Jan 1999–June 2003. Others, approximations for 2002 in US$ per tonne

* This price is for greasy merino but it should be noted that this can lose as much as 50% of its weight on scouring, the effective comparative price would there fore be around $3,000/t. Flax also suffers losses during primary processing which can also reach 50% of its scutched weight. The other fibres in the table do not suffer such losses, the cotton price is for ginned cotton whilst the others are synthetic fibres. The effective differences in prices between wool and line flax and the other fibres are therefore considerably greater than are indicated in the above table.

It should be borne in mind that the USA $2,600 (mid-2003) per tonne quoted for line flax in Table 3.8 is for western European flax, produced in France, Belgium and Holland. This flax is acknowledged as being higher in quality than that produced in other countries and therefore attracts a premium. As can be seen from Table 3.8 the fibres shown can be divided into two price groups. The more expensive fibres; flax and wool and the cheaper ones; cotton and polyester s.f. Other fibres take up intermediate positions.

There are several reasons why flax fibres and articles made from them are relatively expensive and three are listed below.

1. The production of the fibre itself is labour intensive, requiring the added operations of retting and in particular the need to 'turn' the stalks, and of 'lifting' the retted stalks. One also needs to consider the opportunity cost of the swathes of retting stalks occupying fields for several weeks (see 3.4.2 above). In addition the extra risk of the fibres being damaged during retting must necessarily also incur a cost and when this happens the cost is passed on to the market by reducing supply, which will cause the price to rise.

   The fact that flax produced in the European Union is subsidised (see Appendix E) is also relevant Were it not for this subsidy European flax prices would be even higher and this would encourage flax producers in eastern Europe and China to increase their prices, with the possibility that this might further decrease consumption in favour of cotton and polyester staple fibre.
2. Lower spinning efficiencies: the relatively small size of the flax industry has discouraged textile machinery manufacturers from developing machinery specifically for this fibre. This is not so important in dry spinning, warping, weaving, dyeing and finishing as the machines developed for other fibres can process flax approximately as efficiently as they can other fibres but this is not the case in wet spinning. Flax (and to a very small extent, hemp) are the only fibres that are wet spun and this requires spinning frames and preparation lines that are specifically designed to handle these two fibres.

   There are only three manufacturers of these spinning frames, Bridge Mackie (China), Linimpianti (Italy) and Orioltexmash (Russia), all of them small companies compared to manufacturers of equipment for the cotton, synthetic fibre and even wool industries. This has resulted in, over the years, correspondingly small amounts of money being invested in R & D and the result is apparent in that the productivity of a modern cotton spinning line is many times that of a modern flax line. Even when using state-of-the-art preparing lines and wet spinning frames the labour costs of a wet spun yarn come to 20% of total production costs, compared to 5% to 10% for cotton.

   The higher price of the fibres and the lower spinning productivity are, of course, reflected in the relative prices of the yarns: for example, in June 2003 a 30s M. cotton count was priced at €1.95 to 3.2 per kg, depending on whether the yarn was open end, carded or combed but the price of the same count wet spun flax yarn from a European spinner and spun from west European flax was €15 per kg.

3. A further cause of linen consumer products' high prices in relation to lower priced fibres is the scale of the industry. This has been mentioned above in relation to R & D and the development of spinning machinery but it also affects every other manufacturing and even retail operation. Since the quantities of any particular consumer product manufactured or distributed will be smaller for linen than it is for cotton or polyester, economies of scale achievable for cotton cannot be reached by flax. In the broadest terms and with the exception of the fine long cottons such as Egyptian and Sea Island, which always were luxury products, cotton and polyester clothing are mass market products, wool and linen are more upmarket.

   This was certainly true up to the 1990s but the situation is changing. The price of cotton is likely to rise because demand is increasing, due to the steady increase in the world's population of about 2.5% per year and the increase in the standard of living of this population, whilst supply remains static and it seems difficult to foresee any increase in the supply of cotton in line with demand for reasons set out in Appendix B.

Even though low labour costs in developing countries and especially China and Eastern Europe have changed linen's market position and image and it is now reaching a much wider market in the developed world than was possible in the late 1980s, the present lower prices of linen consumer articles are not likely to change the competitive position of linen *vis à vis* cotton. This is because China is also growing cotton on a large scale and manufacturing cotton apparel and household textiles, also on a very large scale and therefore the price differential, based on the three points set out above, is maintained.

3.12.4 The volatility of flax fibre prices

As with many other raw materials and commodities, flax prices can go through periods of considerable volatility, caused by variations in supply and demand and in fluctuations in the values of currencies. See Table 3.9 for line 1 flax prices from January 1999 to June 2003. The wool prices shown in the table are for scoured wool.

Supply and demand

Supply

This is affected by various factors, The weather in flax-growing areas of the world, the amount of stock carried over from the previous harvest, governmental decisions concerning support given or withheld (including subsidies or

Table 3.9 Flax, cotton and wool fibre prices January 1999–June 2003 (euros/kg)

Month	Line flax	Cotton	Wool
January 1999	1.34	1.23	2.81
February	1.32	1.24	2.75
March	1.37	1.28	3.06
April	1.37	1.32	3.34
May	1.43	1.35	3.23
June	1.39	1.41	3.43
July	1.39	1.41	3.48
August	1.40	1.34	3.54
September	1.40	1.25	3.54
October	1.47	1.23	3.32
November	1.54	1.14	3.65
December	1.65	1.17	3.62
January 2000	1.78	1.14	3.99
February	1.75	1.20	4.02
March	1.95	1.39	4.16
April	2.04	1.49	4.50
May	2.02	1.54	4.78
June	2.17	1.65	4.36
July	2.21	1.55	4.50
August	2.40	1.52	4.41
September	2.40	1.65	4.55
October	2.46	1.77	4.41
November	2.54	1.75	4.50
December	2.62	1.81	4.47
January 2001	2.56	1.80	4.43
February	2.65	1.68	4.66
March	2.51	1.62	4.44
April	2.43	1.51	4.64
May	2.16	1.44	4.81
June	2.14	1.45	5.00
July	2.16	1.40	4.83
August	2.19	1.35	4.72
September	2.48	1.25	4.50
October	2.49	1.16	4.10
November	2.56	1.08	3.99
December	2.43	1.08	4.36
January 2002	2.51	1.23	5.17
February	2.51	1.25	5.79
March	2.44	1.27	5.79
April	2.48	1.24	5.62
May	2.47	1.24	5.48
June	2.50	1.13	5.37
July	2.25	1.20	5.14
August	2.25	1.24	5.09
September	1.91	1.29	5.11
October	1.89	1.28	6.38
November	1.93	1.28	6.58
December	1.94	1.32	6.55
January 2003	2.01	1.38	6.52
February	1.98	1.37	6.35
March	1.97	1.38	6.10
April	1.96	1.44	6.04
May	1.94	1.43	5.06
June	1.88	1.28	5.25

production directives), and the views of the individual growers on the relative profitability of flax in comparison with other crops.

1. The influence of the weather: all crops are subject to the vagaries of weather but flax is doubly at risk because not only too much or too little rain will affect the rate of growth and therefore the height and fibre content of the stalks, which in turn will effect yield of fibre per hectare, but also because of the need to ret the stalks. During the several weeks retting period too much or too little moisture will affect the total yield of fibre and also the ratio of line to tow extracted from the stalks. As the value of the line flax is at least ten times that of tow any notable decrease in line yield per hectare will seriously affect the flax growers' profitability. The effect of the weather on the production of flax in a particular geographical area can be seen in Table 3.11. This shows that in France, Belgium and the Netherlands the production in 2001 was about half that of the previous year and less than half that of the following year for areas cultivated that were not dissimilar. A second example was in China in 2003 where the area sown to flax more than doubled compared to the previous year but the production of flax increased by only 20%. Both these considerable falls in production were due to inclement weather.
2. The amount of stock of fibre carried over from previous harvests: the distribution of flax fibres produced by scutchers is carried out by fibre merchants, mostly based in Belgium and northern France. These merchants hold stocks of fibres, as do scutchers and to some extent hacklers and spinners. The western European flax industry, through its international trade association. The European Flax and Hemp Confederation, (CELC) keeps and publishes statistics on the amount of stock held in their industry. Examples of these are set out in Table 3.10a and 3.10b. If, at the end of a season, this stock is estimated to be unusually high or low, growers will adjust the area they plant in the following spring according to their view of the future market. In this they may also be influenced by the opinions of their customers, the scutchers and merchants (see also Appendix F). Areas sown and fibre production statistics are also published by the relevant authorities in other flax-producing countries and these are collated and distributed by the Natural Fibres Institute in Poznan, Poland. However, although they are useful these are not as accurate and not available in as timely a fashion as the CELC figures, but they do cover countries other than those in western Europe.

In view of the present (2003) relatively high level of prices for line flax in western Europe one could reasonably wonder why farmers do not increase supply. The reasons for this are as follows:

1. Government support: the European Union, under their Common Agricultural Policy (CAP) annually places an upper limit on the number of hectares,

Table 3.10 (a) Line flax: stock, production and sales 1987/88–2001/02

	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02
A. SUPPLY															
1. Stock at beginning of season															
Straw	26,542	19,086	25,099	32,900	59,255	64,884	10,500	5,850	7,426	7,989	10,545	17,749	13,489	14,576	10,233
Scutchers							40,364	12,669	18,884	29,680	40,207	36,146	20,487	6,544	11,755
Merchants	5,000	6,781	7,436	5,584	7,119	8,150	7,452	6,310	4,455	4,844	6,140	7,177	4,887	3,585	3,500
Spinners	9,658	9,414	10,267	8,783	6,570	6,134	7,821	11,542	8,140	4,886	7,123	6,900	6,800	7,400	5,857
Subtotal	41,200	35,281	42,802	47,267	72,944	79,168	66,137	36,371	38,905	47,399	64,015	67,972	45,663	32,104	31,345
2. Season's harvest	52,931	58,118	55,985	73,054	54,900	32,442	37,255	67,250	54,970	71,400	75,010	59,000	84,974	89,900	46,647
3. Imports	7,800	3,900	7,141	4,222	2,255	3,855	13,519	13,027	3,655	5,500	3,700	2,400	6,900	5,045	12,653
TOTAL A	101,931	107,299	105,928	124,543	130,099	115,465	116,911	116,648	97,530	124,299	142,725	129,372	137,537	127,049	90,845
B. DEMAND															
1. EU															
Flax spinners*	37,803	35,995	32,861	24,722	26,150	25,281	31,436	27,276	18,070	25,100	28,400	30,350	32,600	31,600	25,550
Other	10,947	12,802	6,618	8,953	6,816	5,714	11,104	7,182	4,738	4,684	5,153	4,834	1,833	500	144
2. Exports	17,900	15,700	19,182	17,924	18,768	18,333	38,000	43,285	27,323	30,500	41,200	54,700	71,000	63,604	45,671
TOTAL B	66,650	64,497	58,661	51,599	51,734	49,328	80,540	77,743	50,131	60,284	74,753	89,884	105,433	95,704	71,365
C. END OF SEASON STOCK															
Straw	19,086	25,099	32,900	59,255	64,884	10,500	5,850	7,426	7,989	10,545	17,749	9,284	14,575	10,233	3,849
Scutchers						40,364	12,669	18,884	29,680	40,207	36,146	18,517	6,544	11,755	7,062
Merchants	6,781	7,436	5,584	7,119	8,150	7,452	6,310	4,455	4,844	6,140	7,177	4,887	3,585	3,500	2,846
Spinners	9,414	10,267	8,783	6,570	5,331	7,821	11,542	8,140	4,886	7,123	6,900	6,800	7,400	5,857	5,723
TOTAL C	35,281	42,802	47,267	72,944	78,365	66,137	36,371	38,905	47,399	64,015	67,972	39,488	32,104	31,345	19,480

Source: CELC.

* Including shipments to plants of W. European flax spinners located outside Western Europe

Table 3.10 (b) flax scotched tow: stock, production and sales 1987/88–2001/02

	1987/88	1988/89	1989/90	1990/91	1991/92	1992/93	1993/94	1994/95	1995/96	1996/97	1997/98	1998/99	1999/00	2000/01	2001/02
A. SUPPLY															
1. Stock at beginning of season															
Straw	17,744	42,340	38,682	32,240	46,545	39,495	6,700	3,600	4,366	5,326	6,292	9,087	6,607	6,425	4,646
Scutchers							25,372	12,576	12,095	13,004	16,761	18,066	25,323	17,966	13,679
Merchants	12,000	18,168	18,616	17,396	23,440	28,000	17,254	12,158	22,182	23,145	21,000	30,976	33,296	25,044	20,000
Spinners	6,991	6,970	9,678	8,780	7,924	6,218	5,068	3,455	2,782	2,890	4,189	5,550	4,200	4,250	3,122
Subtotal	37,735	67,478	66,976	69,416	77,909	73,713	54,394	31,789	41,425	44,365	48,242	63,679	69,426	53,685	41,447
2. Season's harvest	55,044	35,674	40,530	43,363	32,100	20,516	22,925	40,052	33,250	26,700	44,325	35,710	39,775	44,500	37,959
3. Imports	13,700	13,100	14,550	7,607	5,616	4,880	16,012	15,333	7,878	9,500	6,600	4,100	1,800	1,448	12,264
TOTAL A	105,479	116,252	122,056	120,386	115,625	99,111	93,331	87,174	82,553	80,565	99,167	103,489	111,002	99,633	91,670
B. DEMAND															
1. EU															
Flax spinners*	12,572	13,340	12,158	10,922	9,296	7,513	11,237	8,665	5,086	4,800	5,000	3,900	4,600	4,000	3,450
Other	12,329	25,336	26,540	21,213	22,284	18,235	17,305	23,052	24,444	20,023	20,788	15,345	29,017	30,127	30,423
2. Exports	13,100	10,600	13,982	10,342	9,789	18,969	33,000	14,032	8,658	7,500	9,700	17,400	23,700	24,059	22,964
TOTAL B	38,001	49,276	52,680	42,477	41,369	44,717	61,542	45,749	38,188	32,323	35,488	36,645	57,317	58,186	56,837
C. END OF SEASON STOCK															
Straw	42,340	38,682	43,240	46,545	39,545	6,700	3,600	4,366	5,326	6,292	9,087	4,836	6,425	4,646	3,219
Scutchers						25,372	12,576	12,095	13,004	16,761	18,066	24,512	17,966	13,679	12,105
Merchants	18,168	18,616	17,356	23,440	28,000	17,254	12,158	22,182	23,145	21,000	30,976	33,296	25,044	20,000	17,000
Spinners	6,970	9,678	8,780	7,924	6,761	5,068	3,455	2,782	2,890	4,189	5,550	4,200	4,250	3,122	2,509
TOTAL C	67,478	66,976	69,376	77,909	74,256	54,394	31,789	41,425	44,365	48,242	63,679	66,844	53,685	41,447	34,833

Source: CELC.

* Including shipments to plants of W. European flax spinners located outside Western Europe

country by country, on which they will pay subsidies (and, in this way, effectively limit production). This followed certain abuses which took place in the late 1980s when, in certain non-traditional flax-producing countries, farmers sowed large areas but after qualifying for the subsidy the crops were not harvested but ploughed in. (It should be explained that unlike most agricultural products, the subsidy for flax is paid on the area sown and not on the quantity of product harvested. This is because of the increased risk, compared to other subsidised crops, of damage to the crop during retting.) Details of this subsidy and how and to whom it is paid are set out in Appendix E. Certain eastern European countries also subsidise flax, but not to the same extent and others are considering doing so. When these countries become part of the European Union in 2005 their flax crops will also be subsidised, although not immediately to the same extent as in western Europe. However, it has been agreed by member governments of the European Union that the CAP is to be reorganised, with greater emphasis on supporting farmers and rural development and less on subsidising farm production and it is not known at present how this will affect flax.

2. As with many other crops, if high quality fibre is to be produced flax growing requires skill and experience, as well as fertile land and appropriate climatic conditions both for plant cultivation and the dew retting of the stalks. This is the case in the traditional flax-growing areas of western Europe, a belt about 150 km wide stretching from upper Normandy up to Belgium and Holland. In this area the land and weather conditions are good for textile flax (where it has been grown for centuries) and the local farming expertise has existed for generations. However, these farmers are subject to the EU quotas described previously.

   Outside these countries the quality and yields of fibre produced are lower and although the soil and meteorological condition may be good, the farmers' skill levels are generally not as high. The value of the crop is therefore lower than in western Europe and the lack of subsidies does not encourage the farmers to accept the extra weather risk of retting. They therefore have little incentive to grow flax rather than other crops. (For comparative yields see Table 3.16, Appendix A). However, some eastern European governments are conscious of the problem and are taking appropriate steps aimed at improving quality and yield.

Demand

Line flax

As can be seen from Table 3.11 the three traditional flax-growing countries of western Europe, France, Belgium, and Holland, supply a large part of total world line flax production. Their position is all the more dominant because the line flax produced by the other two substantial producers, China and the Russian

Table 3.11 World line flax fibre production (2000–2002/3)

	2000		2001		2002		2003	
	Hectares	Tonnes	Hectares	Tonnes	Hectares	Tonnes	Hectares	Tonnes
France, Belgium, Netherlands	71,016	89,900	87,836	46,647	86,153	122,542	97,755	130,896
Estonia	240	n.a.	27					
Latvia	1,600	1,100		est. 1,000	est. 1,200	est. 4,000		
Lithuania	8,600	2,900	9,600	1,400				
Czech Republic	2,240	2,235	est. 2,000	1,591	5,000	2,000	5,690	2,100
Poland	est. 4,500	est. 2,700	4,520	est. 2,712	3,000	1,300		
Bulgaria	300	est. 35	210	25	n.a.	n.a.		
Romania	2,000	300	300	100	300	est. 100		
Russia	107,610	51,170	127,361	58,000	100,000	30,000		
Belorussia	81,800	27,000	70,000	est. 17,500	40,000	16,000		
Ukraine	19,300	2,509	28,280	5,076	est. 30,000	15,000		
Egypt	14,500	14,000	est. 15,000	15,000	15,000	15,000		
China	100,000	31,000	100,000	31,000	80,000	25,000	est. 200,000	est. 30,000
Total	**413,706**	**217,849**	**445,134+**	**180,051**	**371,453+**	**230,942**		

n.a. = not available.
Source: CELC.

Federation is either weaker (China) or poorly scutched (Russia) and therefore both are of lower quality. As a very high proportion of the linen fabrics produced in these countries is exported to Europe, America and Japan, which require high-quality merchandise, they have had to improve the quality of their fabrics as the standards in their own home markets are not as high as those in these export markets. In the short and medium term the only way they can do this is by importing higher-quality line flax from western Europe and blending this with their own production, thus enabling the production of fabrics of adequate quality, if still not as good as those produced by European Union linen fabrics manufacturers.

Table 3.12 shows that, taking into account only China, Russia and Belorussia, these countries' imports of line fibre from the European Union came to nearly 60,000 tonnes in 2000, nearly 45% of EU production for that year. It is clear that it is these substantial exports which have maintained prices of line fibre at their present high level. Western European spinners, including the production of their mills situated outside the European Union (see 3.12.2 above) consume between 15,000 and 20,000 tonnes of line flax per year. Most of this is sold to west European weavers, who may well weave some of this yarn in their east European plants. Whilst eastern European and Chinese wet spinners export some

Table 3.12 Exports of line flax from EU countries 1998–2000 (tonnes)

		2000	1999	1998
To	China	48,128	36,150	22,297
	Russia	9,110	7,801	1,416
	Lithuania	5,695	6,316	4,370
	Poland	4,389	2,751	2,481
	Estonia	3,769	1,828	1,514
	India	3,638	2,660	1,572
	Hungary	3,235	2,663	2,078
	Czech Republic	2,796	2,999	1,726
	South Korea	2,393	1,291	1,697
	Hong Kong	2,358	3,044	1,624
	Belorussia	1,828	1,811	1,077
	Tunisia	1,808	2,020	1,503
	Turkey	1,581	1,135	757
	Brazil	278	3,316	2,895
	USA	1,054	2,219	1,345
	Japan	1,033	583	506
	Egypt	801	1,030	792
	Latvia	703	761	705
	Taiwan	584	815	633
	Chile	325	387	175
	Others	1,057	1,394	1,480
Total		**98,033**	**82,795**	**52,643**

Source: *Vlasberichten* (11.01.02) reproduced with permission.

quantities of yarn to west European weavers most of their production is used locally, by weavers who (as stated above) export a high proportion of their production to developed markets. Egypt exports a fairly high proportion of its small production of wet spun yarns.

Tow

As can be seen from Table 3.13, total flax scutched tow production is approximately estimated at 250,000 tonnes in 2000 of which about only 40,000 are produced in western Europe. Table 3.14 gives the details of import and export by country of tow by country for the years 1995 and 2000. The major operators are China and Japan, Poland and Taiwan. Between 1995 and 1997 Brazil was exporting and the Czech Republic importing substantial quantities. This trade is very price sensitive because one of the principal uses of scutched tow is for paper making where under normal conditions the maximum possible price is around US$160/tonne because of competition from wood pulp. At this price scutchers will do all they can, for example, by recombing, to add value to the product so as to be able to sell it for textile purposes or, in some cases, for the manufacture of composite materials.

The influence of exchange rates

Apart from the general unsettling influences of variations of currency exchange rates there is a particular reason why these affect the price, and therefore, potentially, the market demand of flax. So far in this chapter we have considered the production, import and export of flax fibre but we have not taken into account the consumption of linen apparel, household textiles and furnishing

Table 3.13 Flax scutched tow: production of ten major producers (2000)

Country	Tonnes
France	31,000
Russia	120,000
China	62,000
Belgium	7,500
Egypt	14,500
Netherlands	2,300
Czech Rep	4,000
Poland	2,600
Romania	600
Lithuania	4,300
Bulgaria	80
Total	**248,880**

Sources: *Journal du Textil*, Paris 02.09.2002 and *Euroflax* No. 1 01/2002. Natural Fibre Institute, Poznan and R. R. Franck.

Table 3.14 Imports and exports of scutched tow by country 1995–2000 (tonnes)

	2000		1999		1998		1997		1996		1995	
	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports
EU countries	18,437	3,663	1,760	4,149	15,372	7,052	11,246	8,228	12,251	1,197	17,306	12,789
China	6,850		4,395		1,031		545	206	2,734	73	2,277	48
Japan	3,225		3,786		3,023		3,025		2,174		2,157	
Poland	2,099	199	1,669	364	2,459	147	734	148		331	26	134
Taiwan	1,671		1,740		2,012		1,490		3,694		5,168	
USA	593		889		1,476		2,779		745		4,048	
Slovak Republic	578		53									
Lithuania	573	971	140	495	125	1,061	11	3,070		4,471		2,018
Egypt	256	835	251	2,431	48	2,896		1,481		2,692		2,275
Brazil	129		320		425		595		1,326		2,042	
Czech Republic		402		331		515	1,448	1,026		2,554		2,372
India		65		70		189	440		325		450	
Hungary		224		116		123	95	105	44	176	46	181
Turkey							45		155		256	
Hong Kong									769		40	
Canada		331	20									
Belorussia								717		760		2,189
Russia		247			12							
Ukraine								979		484		2,558

Source: *Vlasberichten*, Kortijk, Belgium, reproduced with permission.

Table 3.15 Influence of Euro/US$ exchange rate on the price of western European line flax

Date	€/$ rate	Price of line flax: €/tonne
June 2002	0.93	2,500
May 2003	1.19	2,250
December 2003	1.20	1,800

Source: *Vlasberichten*, Kortijk, Belgium, reproduced with permission.

fabrics country by country. From investigations carried out by the CELC it is clear that the most important consumer market is the USA, followed by Italy, Germany, France and then other countries.

The United States does not figure to any serious extent in any production or import, statistics of flax fibre and yarn. However, it does import substantial quantities of fabric, both 'bleached, prepared for dyeing and printing' and fully dyed and finished. These are then further processed by the buyers into furnishing fabrics or garments either in the USA or, more usually, by outsourcing to low-cost countries. It also imports substantial quantities of garments. It is estimated that in 2002, North America consumed some 70% of the world production of textile flax apparel, household textiles and furnishings.

This business, and also a great deal of other international business in flax or linen products of all kinds, is priced in US dollars. A fall in the value of the dollar relative to the currencies of flax-producing countries would then normally result in an increase in the price of linen consumer goods in the United States and in other countries whose currencies are more or less formally linked to the US dollar. American importers will naturally resist such price increases. As the major consumers they will be able to bring considerable pressure on their suppliers who usually find that they cannot pass on the full value, and sometimes none, of the rise in dollar prices caused by devaluation to their American customers. In turn these price decreases will be passed on to weavers, spinners, scutchers, flax merchants, and finally, growers. An example of the influence of the exchange rates of the dollar and the euro is set out in Table 3.15.

3.13 Marketing

The marketing of linen, in the proper sense of the word, has been confined up to now to western European companies. The International Linen and Hemp Confederation, (CILC) was set up in 1951 as a European association grouping all western European linen producers, from the fibre producers to finished fabric manufacturers. Initially the intention was to set up an organisation which would facilitate contacts between the five sectors of the industry; growers, scutchers, merchants, spinners and weavers. In 1973, more or less at the same time as American Cotton established their logo and ten years after the International

Wool Secretariat established the Woolmark, the forerunner of the present CELC, the CILC, created the 'L' logo as the identification mark of European linen.

By the early 1980s this organisation had developed a network of promotional offices in western Europe and the USA and by developing contacts with fashion designers and the appropriate trade and consumer press repositioned linen and the 'L' mark's image into fashion and apparel, where previously it was established only in the household textile and furnishing fields. This not only opened a new market for linen weavers but increased consumer awareness of both the 'L' mark and the products behind it. However, the stepping-up of competition at the end of the 1980s, the fall of the Berlin wall in November 1989 and the gradual deregulation of textile imports and exports by the World Trade Organisation led the CELC to review both its organisation and its promotional policy.

In 1995 the CILC, with its strictly European mission, became the CELC, the European Linen and Hemp Confederation, and created a new CILC, a venue for exchanging ideas between the CELC and other players, world-wide. The CELC then established the 'L' as a quality mark, 'Masters of Linen' which was granted to companies which accept the following three conditions.

1. Origin: the fibre, yarn and fabric must be produced in Europe.
2. Quality: the raw materials, yarns and fabrics must meet set certain quality specifications (these are available from the CELC, 15 Rue du Louvre, Boite No. 71, 75001 Paris, France).
3. Membership: all organisations contributing to the production of the fabrics must be members of a CELC affiliated trade body.

An essential and integral part of this promotional policy aiming at enhancing European linen's image was to analyse and develop the specific advantages of European linen, and to ensure that these became known to apparel manufacturers, the trade media and consumers. To achieve those aims the European promotion plans include:

- operations founded on the creation and development of new products, with closer collaboration with young designers of fabrics, fashion and household textiles from the best European colleges
- promotional operations aimed at informing apparel manufacturers, fashion editors and major retailers about the advantages of the Masters of Linen mark (POS promotion brochures, labels, training and product information)
- a presence at the leading trade fairs (e.g., Premiere Vision, Paris for apparel fabrics and Heimtextil, Frankfurt for household textiles and furnishings)
- conferences in the main European capitals and New York for the media and specifiers
- educational programmes aimed at textile and fashion colleges and universities
- a website to encourage a permanent dialogue with all target audiences, professional and others. (www.mastersoflinen.com).

3.14 Environmental and health and safety considerations

The growing of flax in western Europe, if optimal yields are to be achieved, requires the application of chemical fertilisers and weed and pest control chemicals, but in smaller quantities than are applied to many other crops (see 3.4 above). It is also interesting to note that the majority of these chemicals are returned to the soil during retting, thus reducing the quantities required by subsequent rotation crops. In eastern Europe and China the use of chemical fertilisers in agriculture is less widespread than in western Europe and this is probably one, but not the only reason for their lower yields.

In the manufacture of linen products the only negative effects on the environment come from the possible use of chemicals containing chlorine when bleaching rove and fabric, and from dealing with dyeing effluent. In this, linen its no different from other fibres such as cotton, viscose and wool and similar methods are used to reduce potentially harmful effects on the environment, for example, by neutralising waste liquor and using settling tanks for dye effluents. In rove bleaching chlorine compounds are being increasingly replaced by hydrogen peroxide and in fabric bleaching sodium chlorite has almost invariably been replaced by sodium hypochlorite.

The Natural Fibres Institute (Poznan, Poland) has shown that flax can be used to help remove heavy metal from contaminated soil.

Flax is non-allergenic. The only possible health problems that may arise during growing and manufacture are those common to other crops. For example, normal safety precautions need to be taken when handling weed and pest control chemicals. In scutching, yarn preparation, spinning and weaving 'fly' is produced. This consists of minute fragments of fibre and dust and may be a cause of bronchial and lung illnesses. It is therefore important that all operators be issued with and wear facemasks to prevent the inhalation of fly. This is usual and mandatory in western Europe but not, at present in other parts of the world.

Yarn preparation and weaving produce noise, and again according to Health and Safety directives, operatives should be issued with and wear adequate hearing protection and visitors to these processing areas should use ear plugs. When eastern European countries join the European Union they will need to apply the health and safety regulations that apply in western Europe at the present time and which prescribe the use of face masks and ear plugs or other protective hearing equipment.

3.15 Conclusion and future trends

The major issues which face the world's flax growing and manufacturing sectors can be summarised as follows:

- technical constraints on progress

- retting
- wet spinning

- Political and economic issues
  - subsidies
  - China
  - major actual and potential world trade groups
- the development of present and potential markets
  - composites
  - China
  - ecology and health.

3.15.1 Technical constraints on progress

Retting

It has to be accepted, for reasons given earlier, that even less flax than at present will be water retted in the future. It also has to be accepted that dew retting is expensive in time, labour and the occupation of land; and that this adds to the cost of producing the fibre. Over the past 20 years various alternatives to retting have been researched; for example, steam explosion, field desiccation, enzyme retting and new decortication technology. Steam explosion has been shown to be economically unviable and only short fibres are produced. Field decortication seems to be impracticable because of the difficulty of desiccating the standing crop of flax plants in such a way to ensure that the treatment is uniform over the whole crop. Enzyme retting shows promise but at present is too expensive. Of the various new technologies developed or being developed that are aimed at extracting good quality textile fibres from the green, freshly harvested stems only one seems to be both economically attractive and capable of producing good quality fibre (see Chapter 4) but this is held up at present due to lack of development finance.

It is clear that if good quality bast textile fibres could be extracted without the need to rett the stalks the world would benefit from what would, in fact, be a new fibre. These fibres would have prices closer to that of cotton than at present, and could grow in temperate climates where there is an abundance of available and suitable land whilst the supply of cotton seems to be limited to about its present production (see Appendix B).

Wet spinning

As has been covered in 3.13.3, wet spinning, as a process, in not nearly as efficient as the various cotton spinning systems and although progress has been made over the last two decades, there have also been advances in cotton spinning and therefore wet spinning remains comparatively inefficient and costly. Bearing in mind that flax fibres are rigid, smooth and cylindrical, whilst cotton is flexible, twisted and flat, it therefore seems fairly evident that flax will always present greater problems in spinning than cotton. However, it is possible that cotton is now near its maximum spinning efficiency and what is needed is a major technical break-through in flax spinning which would enable it to be spun at efficiencies which would enable flax yarns to sell at no more than reasonable premiums in comparison to similar count cotton yarns. However, the major spinning machinery manufacturers are unlikely to invest the finance that would be necessary to develop the required new flax spinning technologies as long as flax is 50%, or more, higher in price than cotton. Therefore it would seem that the only practical solution to this problem is to produce, as is suggested above, a good quality, reasonably priced fibre that can be spun on other than wet spinning frames.

3.15.2 Political and economic issues

Subsidies

These are directly important only to flax growers and scutchers in European Union countries but as they influence the prices of flax fibres generally they are of interest to all who are concerned with the fibre. The subsidies and method of payment at present in effect under the European Union's Common Agricultural Policy are set out in Appendix E. It has been estimated that the withdrawal of these subsidies, as would seem to be likely within five years or so, would result in a line flax price increase of about 20%. However, whether this price increase would actually take place would depend on the final consumer accepting the resultant price for the finished consumer goods; garments, table-cloths or furnishing fabrics, for example.

It is extremely difficult to form an opinion on the probable consequences of such an increase in the price of the raw material. It would be reasonable to suppose that this would result in a decrease in consumption but at the time of writing (February 2004) the price of line flax has decreased over the previous six months by 20% and there was no shortage of buyers at the former, higher, price. Also, as discussed above, it must be remembered that the price that actually matters is the price in US$ of the consumer goods in question and as the Euro/US$ exchange rate has also decreased by about 20% there should be no appreciable change in the price to the American consumer.

It is also necessary to take into account the effect of any loss of subsidy on the west European farmers who grow the flax. At the present lower prices, and taking the subsidy into account, they are probably still showing a profit but as stated on several occasions above, growing flax involves the farmers taking on the extra weather risk (compared to other crops) due to the necessity of laying out the stalks in the fields to ret for about six weeks. This risk, should prices continue to fall, may discourage some of the farmers from either growing flax at all or of maintaining their production at present levels. A further relevant point is that, as there are several thousand farmers involved, they are most unlikely to all take the same decision at the same time therefore their reaction to a new situation of low prices without subsidy would probably only take effect over a period of time.

Of course, line flax is not only produced in ‘subsidised’ western Europe but also in ‘unsubsidised’ eastern Europe and China, but as has been discussed above, the quality of the fibre produced in these countries is not good enough for ‘western’ markets and they will therefore need to continue to buy western European line flax until they improve their own quality. This is unlikely to happen on a sufficiently large scale within the next ten years and to try to supply the demanding and difficult ‘western’ markets with fabrics of inadequate quality would be a certain way of losing these markets altogether.

China

At the present time China is increasing its wet spinning capacity in order to supply its growing production of fabrics for export, and possibly also for the home market which is likely to grow with the increasing affluence of its growing middle class (see below). As has been discussed above, the considerable influence of China on the world’s flax and linen markets is to the advantage of west European line flax producers and flax growers but not to that of the European flax wet spinners and weavers, as, due to their lower costs, Chinese exporters of fabrics are increasingly penetrating the major consumer markets of Europe, North America and Japan. As long as, as at present, the Chinese weavers limit themselves to producing plain or relatively unsophisticated colour woven fabrics, western European weavers will be able to hold their own by reducing costs through manufacturing in low-cost countries and emphasising their lead in colour, design and customer service. However, in the medium to long term it is probable that China will develop their own expertise in these areas.

Major actual and potential world trade groups

Flax fibres and products made from them, common with nearly all sectors of the textile industry, are traded internationally. Growers and manufacturers therefore benefit from international trade being as open as possible. This, of course, is one of the objectives of various international organisations such as the International Monetary Fund, the United Nations and, more particularly, the World Trade Organisation. Whilst most major countries who are members of these bodies also profess to be in favour of free and open trade many are influenced by various lobbies and, as a consequence, international trading is not as ‘free’ as it might be. This overall situation is further complicated by the existence of established economic unions such as the European Union and the North American Free Trade Area. Several other such groups are either being set up (The South American and the Southeast Asia Free Trade Areas, for example) or being talked about (The Central American and The Group of 20 Free Trade Areas, for example). Whilst these regional associations undoubtedly encourage trade between their members they may, and often do, hinder trade between their members and other, non-member, countries.

As these regional associations develop, the flax industry is likely to be disadvantaged in its global development because its raw material and manufacturing are almost entirely situated within the Euro-Asiatic land mass. Unless these regional trade groups negotiate free-trade agreements amongst themselves flax and linen will find that it will have to bear duties and possibly quotas when being exported to its present major markets of the USA and Japan. As the United States market is so important to the flax industry this might lead to the necessity of setting up manufacturing plants in, for example, Mexico.

3.15.3 The development of present and potential markets

China

China has been identified above as a major player in the global flax/linen world, but essentially as an importer (of raw material) and exporter (of fabric and apparel) both directly and through Hong Kong. However, China, with a population of approximately 1.3 billion people and a rapidly growing, aspirational middle class estimated at about 4% of this number (about 50 million),[10] could itself develop into a major consumer of flax fibres and linen articles of all kinds. Whilst China, as a member of the World Trade Organisation, will in due course open itself to the exports of luxury linen designer brands from, for example, Italy and France, this is unlikely to materially affect the flow of trade as far as tonnage is concerned even though the sales turnover that this could generate could be considerable. However, of much more importance will be the development of the Chinese market for locally produced fabrics, apparel and other linen consumer goods. That this will happen is not in any real doubt but what is more difficult to estimate is the time-scale. Judging by the rapid increase in consumption of all kinds, from automobiles, through personal computers, to (genuine) Rolex watches[11] this internal consumption may develop earlier than has been expected up to now.

South America

Flax has been grown, wet and dry spun and woven into fabrics for many years in Chile and Brazil, even if only on a fairly small scale. Small quantities of fibre are regularly exported from Belgium and France to these countries; probably, as in China, to improve the quality of their yarns and fabrics by blending the imported fibres with the home grown production. At present the operation in Chile is geared to the supply of the small home market but Brazil has reasonably well established markets in North America. The development of the North American Free Trade Area can only help and encourage these exports from the south of the hemisphere, but particularly from Brazil, with its low cost base and more substantial production of both wet and dry spun yarns. In addition, at the present time Brazil seems to be overcoming its past economic problems and this should lead to the development of their present small home market. The conditions would therefore seem to be in place for the considerable development of the flax industry in Brazil, and perhaps also in Chile.

Ecology and health

Flax has certain advantageous characteristics in these areas:

- Ecology
  - Compared to other textile fibres its cultivation and manufacture requires less fertiliser and weed control chemicals than cotton.
  - It is a good rotation crop.
  - It selectively absorbs heavy metal pollutants from contaminated soils.
  - It grows in temperate climates where there is an abundance of good quality, available land (unlike cotton).
  - It is biodegradable (unlike synthetic fibres).
  - It requires no greater energy input during manufacture than do other fibres, and less than is required for synthetic fibres.
- Health
  - Flax is non-allergenic.
  - It is comfortable to wear due to its rapid absorption and desorption of moisture.
  - It is easily washed.

These advantages of flax and the articles made from the fibres are increasingly appreciated by those who have enjoyed the experience of using them but perhaps not by consumers in general. As, progressively, these ecological and health issues are assuming greater importance in the minds of the general consumer in developed countries, their interest in linen products should increase. However, the rate at which this increase in interest will take place and be transformed into purchasing decisions is bound to be fairly slow unless the flax industry takes positive steps to acquaint these potential consumers of these advantages and ensures the ready availability of suitable product at prices which, if higher than those made from cotton or polyester, nonetheless remain acceptable.

Composites

This new development is covered in Chapter 10. It is, however, interesting to note in this chapter devoted to flax that in 1995 no flax was used for this particular end use but by 2002, in Germany and Austria alone, some 9,000 tonnes of flax (out of a total of 17,000 tonnes of vegetable fibres) were consumed in the manufacture of pressure moulded composite products for the automobile industry. It is expected that the use of baste fibres in this end-use will continue to increase, especially as injection moulding technology using these fibres is also being developed.

3.15.4 A statistical view of the future

When considering the future it is sometimes interesting to try to produce some numbers; this can 'concentrate the mind'. We are therefore reproducing in Fig. 3.23 a graph sent to us by Mr Gordon Mackie, an acknowledged world expert in the area of bast and leaf fibres and whose work and assistance we have also used elsewhere in this book. As will be seen, he is neither pessimistic nor optimistic about the next 15 years for flax as a whole.

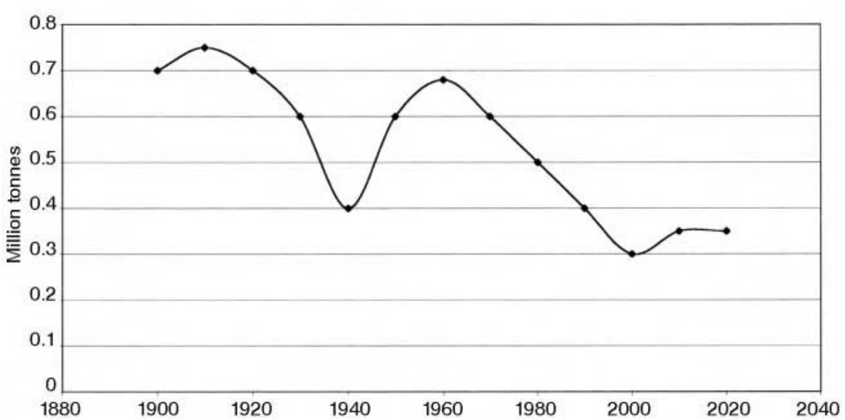


Figure 3.23 World flax fibre production. Courtesy: Gordon Mackie, International Textile Consultant, Northern Ireland.

3.16 Appendices

Appendix A: comparison of flax fibre yield in various countries

It is interesting to compare present yields of fibre per hectare and yield of line to tow in various countries for which data are available. The limited amount of information available from other textile flax growing countries suggests that their yields are no higher than those of the east European countries listed in

Table 3.16 Comparison of flax yields per hectare for several countries (t/ha)

Country	Year	Fibre/ha	Line /ha	Tow/ha	%Line/tow
Belarus	1996	0.62	0.18	0.44	41
Czech Republic	2000	0.78	0.32	0.42	76
Lithuania	2000	0.83	0.34	0.50	8
Russia	2001	N.A.	0.45	N.A	–
Ukraine	2001	0.48	0.18	0.30	60
West Europe	Average	1.5	1.2	0.5	240

Table 3.16, and in some cases may be lower. The reasons for the lower yields in these countries are well known and are:

- Generally low yields of agricultural products due to backward husbandry, lack of modern technology and agricultural machinery, also in some cases to low input of fertilisers and pest control products and the innate conservatism of peasant agriculture.
- Specifically for fibre flax, the accepted custom of not harvesting the crop until the seeds are mature, thus enabling the farmer to sell both fibre and seed. As has been covered earlier, this results in the production of lower quality fibre. Under a command economy where quantity was more important than quality this was perhaps a sound policy but with the freeing of the local and international markets for fibre and finished products, poor quality flax and products made from it are at a severe disadvantage.
- The machines developed and used in eastern Europe to process flax straw are not as sophisticated as modern machines produced in Belgium. In particular the mechanical action of their scutching lines are rougher and cause more fibre breakage than those made in Belgium, with again the same consequences as described above.
- These lower yields, both of total fibre per hectare and in the ratio of line to tow have profound effects on the economics of flax growing because of the considerable difference in the prices of these fibres. For example, in June 2003 medium quality line in western Europe was selling at between €2,000 and 2,500 per tonne approximately whilst the price of medium quality scutched tow was between €135 and €200 per tonne (source *Vlas Berichten* 13/6/03).

In China, although sound statistical information is difficult to obtain, general opinion is that yields are equivalent to the lower of the yields produced in eastern Europe. A further point to bear in mind is that although Chinese flax is fine and therefore agreeably soft to handle, it is, in general, weak when compared to western European flax. It is for this reason that Chinese spinners import such substantial quantities of western European line fibre so that they can strengthen their yarns by blending their flax with these imports.

Appendix B: world cotton production

- Despite increased demand the production of cotton has remained remarkably constant over the last 12 years (1990–2002). Supply has remained at about 20 million tonnes per year. The increase in cotton type textiles required by the world's increasing population has been met by a marked rise in the production of polyester staple fibre which increased from 7.8 million tonnes in 1990 to nearly 25 million tonnes in 2002.
- Both cotton and food crops require fertile well-watered land in sub-tropical or Mediterranean countries and the increase in the world's population mentioned above naturally increases the consumption of food. When a choice has to be made between the production of food or of fibre, which is the case as practically all the available land of this kind is now cultivated, food is likely to win.
- Efforts are being made to increase the yields of cotton per hectare through genetic engineering aimed at reducing the damage done to the crops by insect pests but it is difficult to see that this will make much difference because GM varieties have been used extensively in the USA for several years with no noticeable effect on the quantity of fibre produced although it has markedly decreased the quantities of pest control chemicals used. The results of trials in India in 2002 seem to be controversial. It is claimed that they have considerably increased yields per hectare but these results are questioned by organisations opposed to the development of GM crops.

Appendix C: flax cultivars – textile flax varieties approved by the European Union

The following cultivars are on the European Union's list of approved cultivars whose cultivation is subsidised as part of the Union's General Agricultural Policy.

Adelie	Agatha	Angelin	Alize	Argos
Ariane	Aurore	Belinka	Caesar Augustus	Diane
Diva	Drakkar	Elecra	Elise	Escalina
Evelin	Exel	Hermes	Llona	Laura
Liflax	Liviola	Marina	Marylin	Melina
Nike	Opaline	Rosalin	Venus	Viking
Viola				

Of these 31 cultivars, the four underlined account for by far the greater part of production in France. Belgium and Holland, the principal flax producing countries of western Europe.

Appendix D: relationships between different common yarn count systems

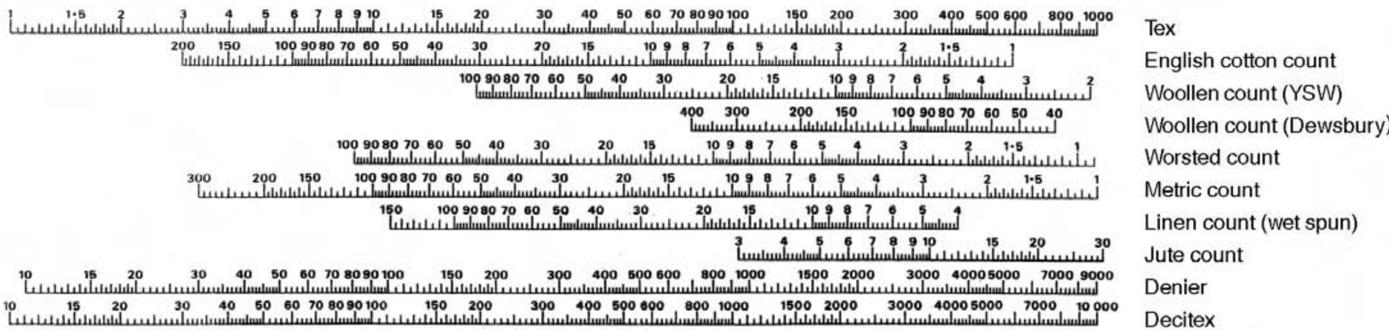


Figure 3.24 Relationship between common systems of yarn counts. Source: Slide rule. Courtesy: Bludell Harling.

Appendix E: the European Union's flax subsidy scheme (2003)

The subsidy consists of two payments

- *To the growers*: this is calculated on a payment per hectare multiplied by the number of hectares sown equivalent to the yield of cereal crops for the region concerned. For France this amounts to approximately €400/ha.
- *To the scutchers*: This is €160 per hectare for line flax, plus €90 per hectare for scutched tow whose percentage of impurities does not exceed 15% by weight.

The payments are made in this way to ensure that only flax that is actually harvested and scutched receives the subsidy (see 3.12). Farmers who grow textile flax for seed receive a subsidy of €28.38 per 100 kg of seed produced.

Appendix F: contractual relationships between flax growers and their customers in France

Perhaps because flax (and hemp) are the only agricultural products grown in temperate climates which need to be retted before they can be further processed, various relationships have developed over the years between the growers and their customers (the scutchers) and the fibre merchants.

- 'Normal' supplier-customer relationships: the farmer sows, harvests and rets his crop and sells the stalks to the scutcher.
- Selling the standing crop: the scutcher will view the crop before it has reached maturity and will make an offer for the crop. The agreement may involve the customer being responsible for harvesting, retting, turning and lifting.
- Contracting to grow: the scutcher will contract the farmer to grow a given number of hectares before sowing. The customer may provide the seed.

In all these cases the flax fibre merchant may replace the scutcher, and contract a scutcher to scutch the retted stalks. In France, where agricultural co-operatives, some of which are large organisations, are common, the members of the co-operative may not only grow the flax but the co-operative may also have a scutch-mill and process the stalks. One such co-operative owns one of the major European flax wet and dry spinners.

Appendix G: comparative labour cost (2002)

		NAFTA			European Union												
		USA	Canada	Mexico	Austria	Belgium	Denmark	France	Germany	Greece	Holland	Ireland	Italy	Portugal	Spain	Sweden	UK
1.	**Average cost per operator hour**																
(a)	Direct wages – local currency	11.69	14.66	15.13	10.91	12.12	17.76	8.82	13.27	5.35	14.52	9.59	8.71	2.90	6.93	11.25	7.04
(b)	Other costs paid to operator – local currency	1.03	1.88	2.26	2.87	3.10	3.38	2.12	3.43	1.04	2.02	1.16	1.87	1.28	0.94	1.89	0.91
(c)	Other costs paid by company – local currency	2.41	4.49	4.70	4.18	7.29	3.23	4.11	3.32	1.62	4.94	1.14	4.16	0.87	2.21	49.72	1.48
(d)	Total cost per hour – local currency	15.13	21.03	22.09	17.97	22.51	24.38	15.05	20.01	8.01	21.47	14.74	14.74	5.06	10.08	162.85	9.43
(e)	Rate of exchange as of 17 June 2002 1 US$ =	1.00	1.55	9.59	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	0.94	9.59	0.68
(f)	Total cost in US$	15.13	13.58	2.30	19.01	23.83	25.80	15.93	21.18	8.47	22.72	12.59	15.60	5.36	10.67	16.97	13.83
(g)	Ratio to US cost (%)	100	90	15	126	157	171	105	140	56	150	83	103	35	70	112	82
2.	**Operator hours**																
(a)	Normal hours/operator/day	8	8	8	7	8	7	8	8	8	8	8	7	8	8	8	8
(b)	Normal hours/operator/week	40	41	45	37	39	37	35	38	40	38	40	37	38	39	38	38
(c)	Normal hours/operator/year	1,940	1,933	2,276	1,750	1,765	1,650	1,628	1,663	1,797	1,658	1,910	1,726	1,710	1,847	1,773	1,763
(d)	Normal equivalent days/operator/year	242	237	236	241	227	223	212	220	225	218	241	236	225	237	233	230
3.	**Overtime (%)**																
(a)	Over normal pay – weekdays more than 3 hours	50	38	150	45	75	200	38	35	75	25	1	45	75	73	35	38
(b)	Over normal pay – national & religious holidays	100	41	5	117	125	100	50	63	75	0	1	33	200	3	50	75
4.	**Shift premium (%)**																
(a)	Second shift	0	0	0	3	6	15	0	14	0	50	5	0	32	0	23	13
(b)	Night shift	0	1	0	28	20	25	29	24	28	75	18	41	32	24	33	11
5.	**Mill operation**																
(a)	Mill operating days/year	313	285	326	268	280	255	239	307	281	284	333	292	288	315	267	223
(b)	Mill operating hours/year	7,506	6,806	7,812	6,436	6,680	6,120	5,741	7,378	8,753	6,336	7,980	7,008	6,912	7,561	6,418	5,352

		Other Europe								Middle East & Asia							
		Bulgaria	Czech Rep.	Estonia	Norway	Poland	Slovakia	Switzerland	Turkey	Egypt	Ethiopia	Israel	Kenya	Mauritius	Morocco	S. Africa	Tunisia
1.	**Average cost per operator hour**																
(a)	Direct wages – local currency	1.55	59.90	21.41	131.4	9.01	63.25	28.15	1,814,462	2.98	5.01	31.27	41.83	28.43	12.89	18.28	1.89
(b)	Other costs paid to operator – local currency	0.22	7.44	2.13	15.1	0.79	10.89	4.41	572,770	0.63	0.16	5.27	3.80	1.73	4.20	3.16	0.15
(c)	Other costs paid by company – local currency	0.31	8.74	7.17	19.2	1.78	15.45	5.16	488,947	1.06	0.30	3.66	3.33	9.80	3.83	1.39	0.38
(d)	Total cost per hour – local currency	2.08	76.08	30.72	165.80	11.59	89.59	37.72	2,874,199	4.66	5.47	40.20	48.96	39.95	20.92	22.83	2.43
(e)	Rate of exchange as of 17 June 2002 1 US$ =	2.06	32.24	15.48	7.85	4.00	47.12	1.56	1,350,000	4.60	8.81	4.92	79.01	30.15	11.05	10.55	1.37
(f)	Total cost in US$	1.01	2.36	1.98	21.12	2.90	1.90	24.12	2.13	1.01	0.62	8.17	0.62	1.33	1.98	2.17	1.77
(g)	Ratio to US cost (%)	7	16	13	140	19	13	159	14	7	4	54	4	9	13	14	12
2.	**Operator hours**																
(a)	Normal hours/operator/day	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
(b)	Normal hours/operator/week	40	40	40	38	40	40	40	46	48	48	44	45	42	48	45	47
(c)	Normal hours/operator/year	1,840	1,856	1,880	1,712	1,984	1,800	1,808	2,347	1,920	2,424	2,210	2,472	2,100	2,152	2,188	2,264
(d)	Normal equivalent days/operator/year	230	232	235	225	248	225	226	283	240	303	251	309	250	269	274	277
3.	**Overtime (%)**																
(a)	Over normal pay – weekdays more than 3 hours	0	0	100	60	50	43	25	90	50	150	150	0	20	25	40	88
(b)	Over normal pay – national & religious holidays	85	0	30	60	100	50	50	200	150	200	100	0	9	100	80	50
4.	**Shift premium (%)**																
(a)	Second shift	0	5	20	5	0	13	5	0	5	0	135	25	37	5	5	75
(b)	Night shift	6	10	75	30	50	32	35	0	10	0	165	50	37	20	15	75
5.	**Mill operation**																
(a)	Mill operating days/year	292	284	317	258	282	305	285	310	265	303	288	270	343	318	328	329
(b)	Mill operating hours/year	7,000	6,816	7,608	6,192	6,768	7,320	6,840	7,305	6,360	7,272	6,912	6,480	8,232	7,632	7,872	7,904

		Asia & Oceania														
		Australia	Bangladesh	China Coastal	China Mainland	Hong Kong	India	Indonesia	Japan	Malaysia	New Zealand	Pakistan	S. Korea	Sri Lanka	Taiwan	Thailand
1.	**Average cost per operator hour**															
(a)	Direct wages – local currency	13.39	13.69	3.30	1.88	38.01	18.08	3,246	1,727	3.25	11.32	15.02	8,129	26.98	160.25	47.16
(b)	Other costs paid to operator – local currency	1.76	0.68	0.96	0.58	7.08	4.04	733	661	0.89	2.18	3.02	570	3.18	44.88	3.42
(c)	Other costs paid by company – local currency	3.35	0.72	1.49	0.97	2.88	5.56	345	443	0.24	3.63	2.26	264	8.07	37.26	1.87
(d)	Total cost per hour – local currency	18.50	15.09	5.75	3.43	47.97	27.68	4,324.66	2,830.84	4.39	17.12	20.29	6,962.54	38.24	242.39	52.46
(e)	Rate of exchange as of 17 June 2002 1 US$ =	1.78	59.60	8.28	8.28	7.80	48.93	8,686	124.36	3.80	2.07	59.99	1,216	96.20	33.90	42.14
(f)	Total cost in US$	10.38	0.25	0.69	0.41	6.15	0.57	0.50	22.76	1.16	8.28	0.34	5.73	0.40	7.15	1.24
(g)	Ratio to US cost (%)	59	2	5	3	41	4	3	150	8	55	2	38	3	47	8
2.	**Operator hours**															
(a)	Normal hours/operator/day	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8
(b)	Normal hours/operator/week	39	48	45	48	48	48	40	40	48	40	48	48	45	48	47
(c)	Normal hours/operator/year	1,873	2,320	2,205	2,424	2,344	2,128	1,994	1,840	2,096	1,920	2,461	2,256	2,240	2,312	2,264
(d)	Normal equivalent days/operator/year	241	290	276	303	293	266	249	230	262	240	308	282	274	289	277
3.	**Overtime (%)**															
(a)	Over normal pay – weekdays more than 3 hours	75	100	50	25	25	50	100	20	25	0	117	50	55	117	75
(b)	Over normal pay – national & religious holidays	125	100	200	100	50	50	72	35	39	0	108	50	100	50	100
4.	**Shift premium (%)**															
(a)	Second shift	15	100	20	20	5	20	1	10	50	20	0	13	0	18	0
(b)	Night shift	30	100	20	20	10	20	1	50	50	20	0	50	0	37	3
5.	**Mill operation**															
(a)	Mill operating days/year	272	343	341	335	348	357	358	225	350	215	361	348	343	355	335
(b)	Mill operating hours/year	6,448	8,232	8,194	8,040	8,352	8,568	8,592	5,400	8,400	5,160	8,656	8,272	8,232	8,520	8,032

		South America				
		Argentina	Brazil	Colombia	Peru	Venezuela
1.	**Average cost per operator hour**					
(a)	Direct wages – local currency	3.98	3.98	2,918	4.07	1,497
(b)	Other costs paid to operator – local currency	0.66	1.23	623	1.20	280
(c)	Other costs paid by company – local currency	1.31	1.47	891	0.73	444
(d)	Total cost per hour – local currency	5.95	5.69	4,432	6.01	2,221
(e)	Rate of exchange as of 17 June 2002 1 US$ =	3.50	2.68	2,435	3.68	1,204
(f)	Total cost in US$	1.70	2.50	1.82	1.63	1.84
(g)	Ratio to US cost (%)	11	16	12	11	12
2.	**Operator hours**					
(a)	Normal hours/operator/day	8	8	8	8	8
(b)	Normal hours/operator/week	44	44	48	48	40
(c)	Normal hours/operator/year	2,063	2,138	2,304	2,276	2,080
(d)	Normal equivalent days/operator/year	257	245	240	237	260
3.	**Overtime (%)**					
(a)	Over normal pay – weekdays more than 3 hours	50	58	58	43	95
(b)	Over normal pay – national & religious holidays	67	73	90	117	150
4.	**Shift premium (%)**					
(a)	Second shift	0	0	18	22	12
(b)	Night shift	15	17	35	28	35
5.	**Mill operation**					
(a)	Mill operating days/year	298	338	294	332	306
(b)	Mill operating hours/year	7,166	8,120	7,081	7,964	7,344

Source: Werner International, Inc., Warmoesberg 11, B-1000 Brussels, Belgium (e-mail: info@wernertex.com).

The average labour costs shown in Appendix G might not always check with the official statistics of the respective countries for the textile industry. They are based on data collected and made available to Werner International Management Consultants and are a realistic representation of the actual labour costs.

Appendix H: 'Masters of Linen': technical criteria for finished products

Criteria	Decoration	Household linen	Clothing/wovens	Clothing/knits
Degree of polymerisation:				
for pure linen, linen union or blends	≥ 1900	≥ 1900	≥ 1600	≥ 1600
in case of ultra whitening treatment	–	≥ 1700	–	–
Dimensional stability to laundering	(*for loose covers, etc.*)		(except shirts ±3% & ±3%)	
weft	±3%	±4%	±4%	–
warp	±3%	±7%	±4%	–
Dimensional stability to dry cleaning	(*for loose covers, etc.*)		(except shirts ±3% & ±3%)	
weft	±3%	–	±4%	–
warp	±3%	–	±4%	–
Colour fastness to light	≥4	dyed linen ≥4/5	grey linen ≥3/4	–
			dyed linen ≥4/5	dyed linen ≥4/5
			'optical white' ≥4	'optical white' ≥4
Colour fastness to laundering	(*for loose covers, etc.*)			
degradation	≥4	≥3/4	≥4	≥3/4
staining	≥3/4	≥3/4	≥3/4	≥3/4
Colour fastness to dry cleaning	(*for loose covers, etc.*) ≥4	≥4	≥4	≥4
Colour fastness to ironing	–	≥4	≥4	–
Colour fastness for rubbing/dry	≥3	≥3	≥3	≥4
Colour fastness for rubbing/wet	≥2/3	≥2/3	≥2/3	≥3
Colour fastness to perspiration:				
acid (staining)	–	≥3/4	≥4	≥4
basic (staining)	–	≥3/4	≥4	≥4
Percentage of filling agent tolerated	3%	3%	3 % (except shirts 2%)	–
Tensile strength	≥100 N	≥100 N	–	–
Tear resistance	≥15 N	≥15 N	≥10 N	–
Resistance to abrasion	≥ to EN 14465 (seats)	–	–	–
Resistance to pilling	≥3	≥4/5	≥4	≥4
Seam slippage	≤6 mm	≤6 mm	≤3 mm	–

3.17 Bibliography

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3.19 Glossary of terms

Breaking Part of the scutching process which breaks up the woody matter in the flax stems.

Decorticating *see* scutching.

Dew retting Retting by laying swathes of flax straw in the fields as they are pulled (also called ground retting).

Divider The machine, part of the scutching process, that draws out the layer of flax straw about to be scutched.

Dry-back The effect of recreating linen fabrics' crisp and cool handle by ironing after washing.

Ground retting *see* dew retting.

Hackled tow Short flax fibres produced by the hackling operation.

Hackling The operation of combing the line flax in order to remove short fibres, parallelise the remaining long (line) fibres and also remove any extraneous matter which might be mixed up with the line flax presented to the hackling frame.

Hands Packets of line fibres collected from scutching turbines and fed into hackling frames.

Lea The indirect yarn count system of the flax industry. (Number of 300 yard lengths that weigh one pound.)

Line Long flax fibres.

Puller Agricultural machine which harvests flax stems by pulling.

Pulling The harvesting of flax stalks by pulling them out of the ground, rather than cutting them as is usual with other crops.

Retting The decomposition of pectins that bind fibres to the other parts of the stems or leaves, usually by the action of enzymes produced by bacteria or fungi.

Rippling The process of removing seed pods from harvested flax stalks.

Scutched tow Short flax fibres produced by the scutching operation.

Scutcher The machine used to scutch flax (and hemp). Also the person who operates the machine

Scutching The process of removing line fibres from tow and extraneous matter such as shiv, earth, pebbles and weeds. When referring to this process in connection with other fibres the word ‘decorticating’ is usually used.

Shive or Shiv The woody matter of flax stalks that is removed during scutching.

Sprit Small fragments of woody matter that may not have been removed during fibre and yarn processing and which can appear as lighter coloured specks after fabric dyeing.

Tow Short flax fibres.

Turner Agricultural machine used to turn swathes of flax straw.

Turning The process of manipulating the swathes of flax straw lying on the ground whist they are retting so as to ensure that the retting is uniform throughout the swathe.

Water retting Retting by placing bundle of flax straw in water.

4
Hemp

J SPONNER, L TOTH, S CZIGER
and R R FRANCK

[*Editor's note*: Unlike the chapters in this book on the other fibres, this chapter is divided into two parts. The first is a detailed study of traditional hemp production in Hungary, one of the few countries in Europe that is still growing hemp and manufacturing it into textile products, and the second is a general account of the present situation of the fibre and of current developments which, if they are successful, may lead to a marked improvement of the present prospects of the fibre.]

PART 1

4.1 Introduction: hemp in Hungary

Hemp was first mentioned in chronicles of the 12th century, after the Hungarian settlement of the Carpathian Basin. In 1198 the customs tariff of Esztergom enumerates numerous plants including hemp and flax. Another record mentions that the owner of a cart carrying hemp or flax had to pay four bundles of hemp or flax as duty and according to other records dated 1309 a 42 acre hemp field was required for every 57 acres of land held in villeinage.

In the Middle Ages hemp processing, spinning and weaving were quite common and this work was an intrinsic part of the villeins' feudal obligations. According to a document dated 1324, of the 17 industries listed in Hungary, spinning and weaving seem to have been the most important.

It is evident that in the life of the Hungarian people hemp has a history of a thousand years, and knowledge of the growing and processing of hemp was already well established when they settled in the Carpathian Basin. According to established practice flax was used to make finer, thinner fabrics whilst hemp was used to make harder-wearing fabrics. Hemp served other requirements as well and rope, twine, bags, tarpaulins, etc., were produced for agricultural and other purposes.

On small farms and later on large estates hemp was essential. On the estates the first machines that were operated by mobile steam engines replaced manual tools and these engines were fuelled by hemp hurds. In this way hemp process waste was used to generate energy for the machines. Gradually the demand for hemp products grew and production increased to satisfy these wider markets. Hemp followed the economic and social changes of this lengthy period; it was part of the industrialisation of the country and it formed the basis of its textile industry.

The city of Szeged played an important role in the development of the Hungarian hemp industry. With the help of its natural waterway, the Tisza, Szeged – an extensive stockbreeding centre – became one of the biggest collecting and distributive markets in the southern part of the country. According to medieval sources, agricultural products, livestock and industrial products from distant regions were sold in large and busy fairs. The city was not only a trading centre but also an important staging post for traffic to Italy, the Balkans and the East and the traveller of the time could find a relatively well-developed guild life within its walls. In 1522 the tithe register of the Diocese of Bács lists 291 independent tradesmen, two of them being ropemakers. After gradually expelling the Turks from the country the fight for freedom against the Habsburgs prevented the economy from developing and this situation improved only in the middle of the 18th century. The prosperity of the economy was greatly helped by settled German craftsmanship and the guilds of the city flourished. The development of shipping on the river Tisza (especially transporting wheat and other agricultural products) stimulated the shipbuilding industry, heavy canvas and rope manufacture. The rope manufacturers of Szeged received their first charter of incorporation from Maria Theresa on 20 May 1743.

The processing of hemp and manufacturing was done in small guilds that could be found especially in the southern cities of the country. At this time 'factory size' hemp processing did not exist and only in the last two decades of the 18th century do we find three 'factory sized rope-walks'. All three were situated on the coast at Fume, in present Croatia.

The raw material for the numerous little guilds was mainly supplied from abroad as the limited production of hemp from the small farms was not sufficient to satisfy the 'hungry' industry's requirements. The local authorities in the country became aware of this situation and took important steps to develop hemp processing; in other words, it became essential that hemp processing develop into a manufacturing industry. A survey was made in order to establish which areas were most suitable for the cultivation of hemp and flax and 20 tonnes of high fibre yield seed was bought from Italy. Peasants from Bologna, who had several decades of experience in the growing and processing of hemp, were settled in the southern part of the country. In 1865 Count Rezso Chotek founded the first hemp factory in Hungary in Futak-Ojvidik (today Novi-Sad, in present Yugoslavia). This plant included scutching and other primary processing of the hemp. Following the establishment of this factory others (spinning, weaving, ropewalks, etc.) sprang up like mushrooms.

This industrial processing of hemp was the consequence of the modernisation of the more than 100 years old rope-laying guilds and of the expansion of the range of products and the mechanisation of production that was of revolutionary importance at this time. Examples of these developments were the predecessor of Elso Magyar Kenderfonó Rt. in Szeged, the rope making factory of Nandor Bakay in 1877 and in 1888, also in Szeged, Elso Szegedi Kenderkikeszito Gyor Rt., (this company is now well known as Heavytex Újszegedi Szövo Rt.).

By 1878, 93,500 ha of hemp were cultivated. Production increased and by the beginning of the 20th century Hungary was an important producer. Production continued to increase until 1940 and from booklets advising on the cultivation of hemp we learn that several hundred factories of various sizes processed the enormous hemp crop of Bácska (formerly part of Southern Hungary) at the beginning of the 1940s, where annual production reached between 40,000 and 50,000 tonnes. After the Second World War hemp processing mills and 34 smaller fibre processing plants were taken into public ownership; at that time 31,000 farms were growing hemp.

Hemp, as an agricultural crop in the Hungarian economy, has stood the test of time and as the basis of an industry has been an important factor in the industrialisation of the country. Bast fibres (hemp and flax) were, apart from local wool, the only textile raw materials which did not need to be imported. They were a major source of industrial raw materials which were not imported and which never received any state subsidy. Hemp provided a living for nearly 20,000 people in agriculture and the bast fibre industry.

Today the situation is different. Hemp has lost its former competitiveness in the economic growth of the country and in the world. Its environmentally friendly characteristics, excellent agricultural potential, the present under-exploitation of arable land, together with a new policy of restoration and subsidy and more vigorous lobbying, might improve hemp's role in the national economy. There are only a few countries in Europe that can provide 100% of their raw material for a sector of industry from within their own borders.

4.2 Hemp varieties and their cultivation

Hemp belongs to the Mulberry family (Moracea) and cultivated hemp varieties belong to the *Cannabis sativa* species. These hemp varieties can be very different in height and leafage, for example. They are usually named after their country of origin so that we have Italian, Turkish, Chinese, Indian, etc., hemp. Two hemp types have developed under the influence of climatic conditions, northern and southern types. As far as fibre yield is concerned the southern type is more important and is the most common type in Hungary. Hemp is an annual plant, its growing season is from the middle of April to the middle of September. The plant can be monoecious or dioecious. The dioecious variety is more common in Hungary.

The cross-section of a hemp stalk is nearly orbicular at the foot and angular higher up. The stalks are normally 4–10 mm thick with a height of 1.5–2.5 m. If the stalk reaches a height of 3–4 m its cross-section at the base can be as much as 20–25 mm. Similarly to flax the bast layer (phloem) of the stalk contains the valuable textile fibres. The fibre bundles form several layers in the bast and the bundles contain few unit cells. At the foot of the stalk the number of bundles increases so as to improve the stability of the plant.

4.2.1 Hemp varieties

Attempts to improve Hungarian hemp varieties were carried out in the 1930s and these trials were continued after the Second World War. The research centres in Kompolti and Szeged achieved major results. Later research work was completed in Szeged in 1970. ‘F’ Hemp, improved in the 1930s, was used as the basis for the research work. The aim of these researches was both to increase the yield of fibre per hectare and to maintain the fineness and strength of the fibres. (‘F’ hemp was named after Rudolf Fleisman, who developed this variety.)

The varieties resulting from this development work are listed below.

1. *Kompolti* (1954).
   Improved from ‘F’ hemp by selection.
   Southern type, dioecious.
   Growth period (fibre hemp) 110–115 days.
   Stalk yield: 11–12 tons/ha.
   Fibre yield: 31–35%.
   Developed by Iván Bocsá and partners.
2. *Unikó* – B (1965).
   Improved by crossing *Kompolti* (dioecious) and *Fibrimon* (monoecious).
   Southern type, if sown for fibre ratio of pistillate plants is higher (5% male 95% pistillate).
   Growth period: 105 days.
   Stalk yield: 10–11 tons/ha.
   Fibre yield: 29–31%.
   Developed by Iván Bocsá.
3. *Kompolti* (yellow stalk) (1974–1980).
   Improved by repeated back-crossing *Kompolti* and mutant types.
   Growth period: 100–105 days.
   Southern type, dioecious.
   Stalk yield: 7–8 tons/ha.
   Fibre yield less than that of green hemp.

4. *Kompolti* hybrid TC (1983).
   Improved by crossing Chinese dioecious, Chinese Unisex SC and *Kompolti* varieties.
   Light green hybrid, ratio of pistillates is high.
   Growth period: 115–118 days.
   Southern type, dioecious.
   Stalk yield 13 ton/ha.
   Fibre yield: 28–30%.
   Developed by Iván Bocsa and partners.
5. *Fibrikó* TC (1989).
   Improved by crossing Chinese dioecious, Chinese Unisex SC and *Kompolti* yellow hemp varieties.
   Colour of stalk is green.
   Growth period: 100–105 days.
   Southern type, dioecious.
   Stalk yield: 11–12 tons/ha.
   Fibre yield: 32–35%.
   Developed by Iván Bocsá and partners.
6. *Tiborcszallas* (2000).
   Southern type, dioecious, dark green, early type.
   Growth period: 95–100 days.
   Stalk production: 10–11 tons/ha.
   Southern type, dioecious.
   Fibre yield: 25–30%.
   Developed by Dr Antal Gyorgy.

All varieties except *Kompolti* (yellow stalk) have green stalks. The above hemp varieties all have some common characteristics. Those varieties that show an increase in stalk yield per hectare also show a decrease in fibre fineness and fibre strength. It is important to weigh these advantages and disadvantages in order to achieve the optimal balance between quantity and quality. There are also other factors to take into account when considering the production of dioecious as opposed to monoecious plants. The advantage of the higher yield of dioecious hemp is considerably weakened by the greater damage that the male plants suffer during reprocessing, and especially during chemical defoliation. Although the yield of monoecious hemp is lower, its stalk production is more even and healthier and its fibre quality is better.

Variety developers endeavour to take these factors into consideration. The first step is to produce seed for the production of fibre hemp. Good hemp seed yield is obtained on soil rich in nitrogen. Currently considerable quantities are produced in the Szabolcs–Szatmar-Bereg area of Hungary. In Hungary hemp seeds are usually planted in April with a seed density of 60 to 80 kg/ha. Fertilising is applied at the following rate.

N 80–110 kg/Ha
P.202 0–50 kg/Ha
K.20 50–200 kg/Ha

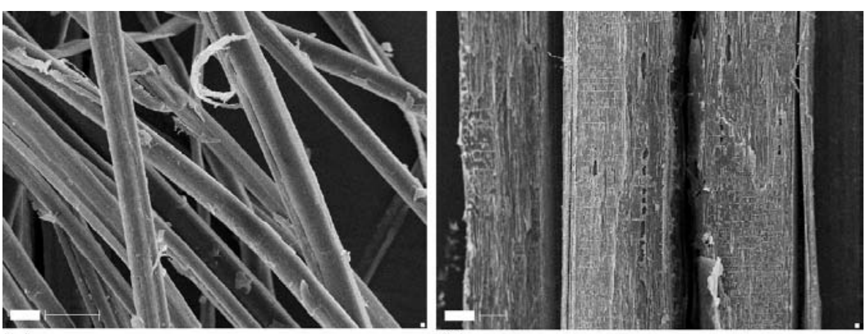
More than 110 kg/Ha of nitrogen increases the yield but decreases fibre quality. If available, farmyard manure and stable litter are preferable to chemical fertilisers.

Depending on material conditions during growth, harvesting usually takes place about 100 days after planting, at the flowering of the male plants. Usually male plants produce finer fibres than pistillate plants. Fibre yields per hectare of between 0.5 tonnes to 1.2 tonnes are considered to be satisfactory. This fairly wide variation depends on several factors, including the variety planted, weather conditions, the efficiency of the farmer and of the primary processing of the stalks. (Scutching: see 4.4 below.)

4.3 Physical and chemical characteristics of hemp

The fibre bundles are in several layers within the hemp stalks. A bundle consists of several fibres and bundles are connected by unit cells. The bundles in the inner layers are usually shorter and finer than those of the outer layers. The shape of unit cells ranges from triangular to heptagonal with rounded corners and a large pith. Unit cells are connected by lignified pectins and the basis of hemp processing lies in loosening and dissolving this bond.

The diameter of the unit cells is from 15 to 50 microns. The average length of the cells is 35–40 mm but it can vary from 5 to 100 mm. The length of fibre bundles is about 1500–2500 mm. The breaking strength of hemp fibre is a little higher than that of flax fibre; its elongation is low (2–3%). Its flexibility depends on the fineness of the bundle. The longer bundles require less twist during spinning. Although the elongation of the bundles is low their flexibility is high



(a) (b)

Figure 4.1 Photomicrographs of (a) hemp stalks and (b) longitudinal section of hemp stalks. Source: DeMontfort University, 2004.

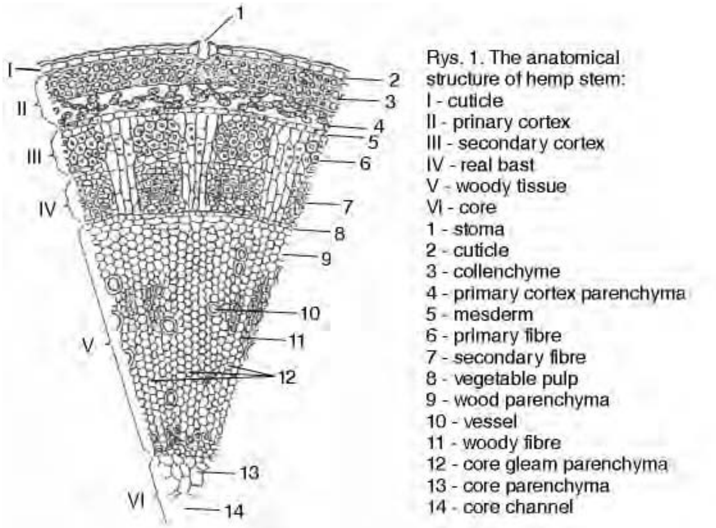


Figure 4.2 The structure of hemp stalk. Source: Akademia Rolnicza im. Augusta Cieszkowskiego w Poznaniu.

and this can cause problems during spinning. Blending flax with hemp improves both the elongation and the flexibility of the yarns, which is low in 100% hemp yarns. However, these blends also decrease the strength of the yarn.

Due to the hygroscopicity of hemp its moisture regain is good and this has a favourable effect on all fibre processing. Moisture increases the turgidity of the fibre. Normally accepted fibre regain is 12%. In order to compare and describe

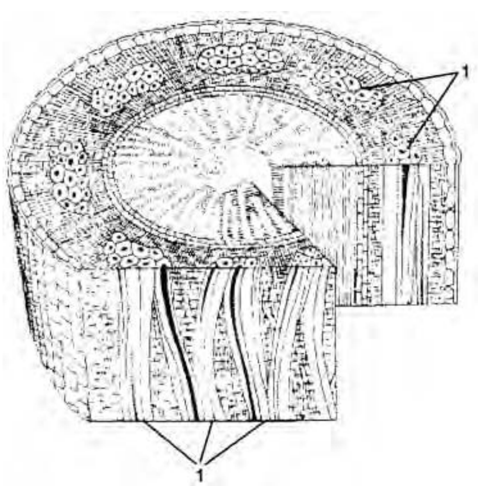


Figure 4.3 (a) Line drawing of cross- and longitudinal section of hemp stalk (1 = distribution of fibre bundles and joints between fibres by anastomosises). Source: PWRiL, Warsaw, Poland.

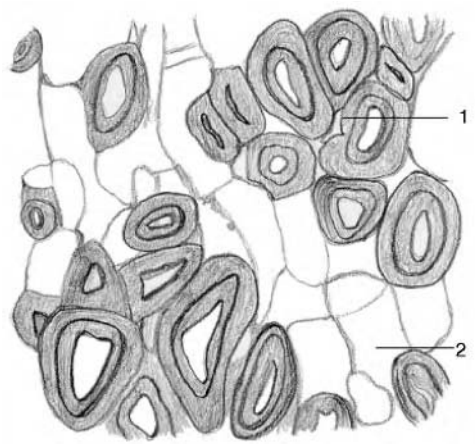


Figure 4.3 (b) cross-section through hemp fibres (1 = fibre bundle; 2 = cortical parenchyma). Source: Gesamtverband der Deutschen Versicherungswirtschaft. Courtesy: www.tis-gdv.de.

the physical characteristics of hemp fibre bundles the following measurements are usual:

- length of fibre bundles
- weight of these bundles
- breaking strength of bundles (10 mm test length)
- drape of bundles: this is a measure of the flexibility of the fibres. A 'hand' of flax fibres 27 cm long is suspended at its middle and the distance between the ends is measured. This can vary between 2 and 10 cm. The shorter the distance the finer the fibres.
- torsional stiffness of bundles.

The fineness and degree of separation and spinnability, for example, are also used to describe hemp fibres.

The principal constituent of hemp fibre is cellulose, at about 77% of the total weight. The remainder consists of pectins, lignin, vegetable waxes and fats, various water-soluble substances and about 10% of hygroscopic water. As hemp is

Table 4.1 The chemical constituents of hemp fibre

Pectin/lignin	9.5%
Water soluble substances	2.1%
Vegetable wax and fat	0.6%
Mineral matter	0.8%
Hygroscopic water	10.0%
Cellulose	75.0%
Other	2.0%
	100%

Table 4.2 The physical characteristics of hemp fibre

Diameter	15–50 microns
Length	1500–2500 mm
Tenacity	40–70 N/Tex
Elongation at break	23%
Regain	12%

more lignified than flax its cellulose content is smaller but it is less sensitive to chemicals. It is resistant to bases and only strong acids can damage it. Hemp is less subject to rot than flax. Further information on the physical and chemical characteristics of hemp fibres can be found in the tables of the appendix to Chapter 1.

4.4 Primary processing of hemp stalks, fibre separation

The fibre yield of unretted hemp straw is about 25%. The yield of long fibre of unretted straw varies from 10% to 13% and of short fibre from 12% to 15% (see also Fig. 4.2). The retting, breaking and scutching of hemp is similar in principle to that of flax (Chapter 3) and the machinery and processes used are also similar. However, the greater length and thickness of the hemp stalk compared to that of flax needs to be taken into account and hemp processing machinery is generally larger and more robust.

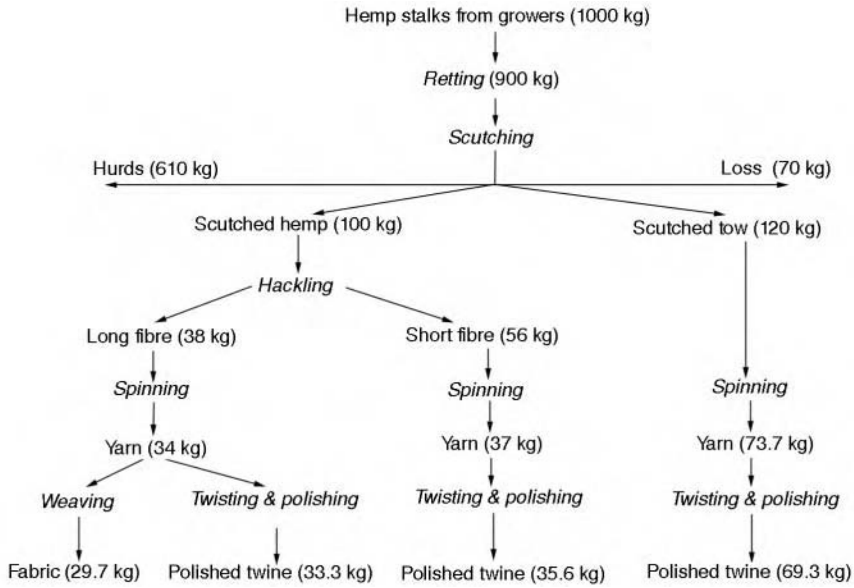


Figure 4.4 Hemp textile fibre production flowchart and yields.

The different technical and mechanical processes applied during primary processing produce scutched hemp (long fibres) and tow (short fibres) that are suitable for spinning. The residual product, hurds, is used for various non-textile purposes and particularly for animal litter. The purpose of primary processing is to separate the flexible bast fibres from the ligneous hurds as gently as possible or when necessary, using more powerful biological and mechanical processes. Naturally the application of these processes is determined by the economics involved:

- the quality of the hemp stalks; colour, length, diameter, etc.
- the required fibre yield and acceptable ratio of long and short fibres
- the quality of the fibres, colour, strength, fineness, cleanliness, etc.

Different technical and mechanical factors are taken into account as to which process should be chosen and which particular technology is chosen depends on the quality of the stalks. These are classed as follows.

1st class; water retted, used for finer yarns
2nd class; water retted, for medium count and thicker yarns
3rd class; unretted, fibres mechanically separated and used for blending or spinning coarse yarns.

Fibre separation may be done by using biological, mechanical or chemical methods or more usually a combination of retting, breaking and scutching.

Table 4.3 Yields during primary processing

Before retting	Raw hemp stalks	100%
After retting	Retted hemp stalks	90%
Mechanical processing	Hurds	61%
	Scutched hemp	10%
	Hemp tow	12%
	Waste	7%

4.4.1 Retting

Retting is a biological process that removes the pectic substances that bind the fibres to the other constituents of the hemp stalk. Retting precedes the mechanical separation (scutching) of the fibre from the stalk and is essential if fibre breakage during scutching is to be minimised. During retting the moisture content of the stalks is increased. This encourages the growth of certain bacteria and/or fungi which selectively attack and remove the pectic contents. There are two methods of retting, ground retting and water retting

Ground retting

In ground retting the stalks are laid in swathes on the ground as they are harvested. The combined action of dew and showers of rain provide the necessary conditions for the development of the micro-organisms on the stalks. Ground retting is effective if rainfall reaches 600 mm per month at harvest time.

Water retting

In water retting the necessary increase in moisture content is obtained by steeping bundles of stalks in concrete tanks containing water. Typical sizes of tank would be within the ranges of 50 m to 100 m in length, 5 to 10 m in width and 1 to 1.2 m in depth. The bundles of stalks are lifted into the tanks by mobile cranes and held beneath the surface of the water by wooden or iron frames which cover the tanks. The tanks are then filled with water. Both surface water from rivers, at temperatures of around 15 ºC to 20 ºC or from bore-holes from between 25 ºC to 30 ºC are used. The higher the temperature the shorter the retting period, at the lower temperatures retting typically takes seven to ten days but only five to six days at the higher temperatures. Naturally, meteorological conditions also affect the length of retting time and it is for this reason that in Hungary, for example, water retting is carried out only between April to October.

When retting is sufficiently advanced the stalks are gathered and stooked in the open fields so that they can dry. This stops the retting process and the stalks are then stacked in large ricks until they are required for further processing. These are thatched with bundles of hemp stalks to protect them from the weather. The advantage of ground retting over water retting is that it is more economical. The disadvantage is that the process is difficult to control and depends entirely on favourable meteorological conditions

4.4.2 Mechanical processing

The purpose of mechanical fibre separation, or decortication, is to separate the flexible fibres from the stiff and more brittle ligneous woody parts (called hurds) of the stalks. The entire operation is carried out in a ‘scutching line’ consisting of two pairs of scutching turbines and associated mechanisms which separate and remove shorter fibres (also used as a textile raw material), hurds, dust and earth and other waste matter from the long fibres.

Breaking

The stalks are delivered to the primary processing plant in bundles or ‘sheaves’. The first step is to open these sheaves; the stalks are then either fed into vertical breaking rolls or placed on a conveyor which feeds them through several pairs of horizontal parallel breaking rolls. The first breaking operation consists of splitting the stalks down their lengths. This requires considerable mechanical force. The actual breaking process is done by the action of pairs of smooth and ribbed breaking rolls on the stalks. The weight and pressure of the smooth surface rolls splits the stalks lengthways and the ribbed rollers of gradually reduced pitches then transversally and progressively break the hurds into smaller and smaller pieces. Most of these separate from the fibre and fall through or out at the end of the machine before the start of the next operation. The hurds are collected and used for various purposes.

The effectiveness of the breaking process depends on the quality of the stalks.

- It is possible to use raw (unretted) healthy stalks. In this case the broken stalks contain more than 60% fibre but the end product is more suitable as a raw material for paper manufacture.
- Stalks of green fibre hemp that are thin and easily breakable, contain 50–55% fibre and the fibres produced are suitable for spinning.
- In the case of dew-retted hemp stalks further mechanical separation can produce fibre suitable for the long and short fibre spinning systems.
- Breaking is most effective when the stalks have previously been retted. (The proportion of hurds is diminished and fibre content is over 50%.)

Scutching

The principal purpose of scutching is to remove the hurds which still adhere to the fibres bundles. Also scutching further softens and affines the fibre bundles and removes lignin from the fibres. Scutching produces long (‘line’) fibre, short (‘scutched tow’) fibre, hurds and waste matter (dust, earth, etc.). In past times scutching was done by hand and this produced good-quality fibre. However, productivity was low and the process was therefore uneconomical; in due course it was replaced by mechanical (turbine) scutching.

In turbine scutching the broken stalks are fed into grippers that present the stalks, held vertically, between two scutching turbines, which are placed horizontally, parallel and close to each other. These turbines have three or four blades which, as the turbines rotate in opposite directions, beat the stalks and thus remove the hurds. A scutching line consists of two pairs of turbines, the grippers reversing the presentation of the stalks when passing from the first pair to the second thus ensuring that the whole stalk is scutched. (See also Chapter 3 Flax.)

The effectiveness of scutching is controlled by varying the speed of rotation of the turbines (peripheral speed) and the rate at which the stalks proceed through the two pairs of turbines. Turbine scutching produces fibres whose quality is the average of the batch being processed. It does not enable any selection of fibres of different quality.

Hemp tow processing

The preliminary mechanical processing of the dried stalks involves some fairly vigorous handling of the raw material, including breaking, scutching and the separation of the line fibres from the tow and other by-products. The stronger, more solid fibre bundles keep their original lengths and parallelism. During breaking and scutching the weaker and shorter fibres (tow), especially those at the foot of the stalks, break away and are removed together with the hurds, dust, soil, etc., by a pneumatic suction system placed below the scutching turbines.

After scutching the tow fibres are separated from the hurds and other impurities by passing them over a high output reciprocating screen. The hurds are removed pneumatically and may be sold for use as a natural fertiliser, for the heat insulation of buildings, as fuel or as animal litter (especially for horses and poultry). The hemp tow is then passed through a conveyer drier that can use either hot or cold air. To achieve the required quality the tow moisture content needs to be within the range of 7% to 10%. After drying the tow is passed through various breaking and cleaning rollers and over further reciprocating screens, all aimed at cleaning the fibres and removing impurities but in addition, the high pressure breaker rollers further split and affine the tow fibres. These are all high output processes.

In the past tow fibres of various qualities were produced. These differed, for example, in cleanliness and length and were used by industries such as paper manufacture or textiles. Today, however, tow processing is simpler and only one or two different qualities are required. Fibre cleanliness, colour and yield are the determining factors.

[*Editor's note*: recently, with the rapid development of the use of bast fibres in composite products (see Chapter 10), the differing technical specifications of hemp tow required for this growing demand is again increasing the variety of qualities required.]

Chemical fibre separation

Chemical fibre separation was an experimental process and consisted of scutching unretted stalks The long fibres were retted by steeping in an alkaline solution, which was then neutralised and rinsed off. (The neutralising of the fibres is essential because, if they were left in an alkaline state they would suffer damage.) Tow and long fibre were then further processed in the normal way.

4.5 Hemp spinning and spinning machinery

Scutched hemp and tow fibres used to be spun using different technologies and these were clearly separated. Different types of machines and equipment were developed and used to produce different yarns. Today these differences are hardly noticeable, the two technologies overlap and the same machines are suitable for both types of fibre. In Hungary and in most other hemp producing countries, some traditional technologies and machines have totally disappeared, for example wet spinning and the chemical separation of hemp fibres.

[*Editor's note*: wet spinning is still carried out to a limited extent in Romania where counts of up to 30s metric are available. Similar counts are also produced in China but in this case their processing is more akin to their methods of processing ramie.]

Fibre blending, the fundamental element of 'old-time' spinning, has completely changed. Previously hemp fibres of different character, handle and degree of separation were used depending on the spinning mill processing the fibres and the intended end-use of the yarn to be spun. Today scutched hemp fibres of different qualities and origin are used as blending components. Sometimes hemp-jute blends are also used in normal hemp processing and not only for the production of hessian type fabrics. The increasing variety of synthetic fibres (polyamide, polyacrylonitrile, polypropylene, texturised polypropylene, polyethylene, viscose, etc.) are also now blended with hemp.

The purpose of blending different fibres, or different qualities of hemp, is to satisfy the following requirements:

- the production of cheaper yarns
- to compensate for shortages of hemp fibre
- to improve spinnability
- to improve quality
- to decrease production costs.

4.5.1 Long fibre spinning

Yarn preparation

The purpose of yarn preparation is to make fibre 'hands' (bundles of parallel fibres that can be fed onto the aprons of the first draw-frames) of the same length and thickness from scutched hemp and also to further divide them in order to increase the fineness of the fibres and produce an even sliver.

Fibre softening

The process of fibre softening helps to increase the fineness of the fibre bundles. The fibre-pressing machine that is used for this purpose has ribbed rolls loaded with springs that greatly soften the fibres as they move backward and forward through the machine. Softening can be made more effective if the hemp is treated with a water-oil emulsion before it is fed into the machine. This also significantly decreases the release of dust during processing.

Fibre cutting

Before hackling, softened scutched hemp has to be reduced to a certain length (usually 60–70 cm) so that the fibres can be processed on the hackling frames. The rough roots and tangled tips of the scutched hemp are also removed during the cutting process. This shortening is done on a cutting machine, which does not really cut the fibres but tears them. The scutched hemp is fed into the machine by hand and firmly held until the ‘cutting’ has taken place. After cutting the hemp – cut to size – is baled or tied into packages of 20 kg (the capacity of the cutting machines) and after resting for three to ten days in conditions of high relative humidity the packages are then hackled.

Hackling

The purpose of hackling is to

- parallelise the fibres
- separate and ‘affine’ (split) the fibres
- remove short fibres (tow) and knots of tow
- remove the remaining hurds and other impurities that have not been removed during previous processing.

Hackling is the term used in hemp (and flax) processing to denote the process which, for other fibres such as wool, cotton and synthetics, is called combing. During this process the hemp fibres are drawn through ‘pins’ held by wooden boards. The short fibres produced as a by-product of hackling (hackled tow) is used to spin the better qualities of short fibre yarns. The hackled hemp is then baled and, if possible, rested. No further selection is carried out.

Hemp fibres leave the hackling frame in the form of a sliver which receives a preliminary drawing operation before the yarn preparation (spinning and drawing). This is done on machines which are in fact modified drawing frames but in addition can insert small amounts of twist to give the sliver greater cohesion. Each frame has four horizontal belts separated from each other. The hackled hemp is placed on these belts, suitably overlapped so as to form as even a sliver as possible, drawn and doubled, fed into the drafting zone and wound onto the bobbin.

Drawing and doubling

As in the spinning of other textile fibres the purpose of these operations is to further separate the fibres and regularise the slivers. Five consecutive drawing

Table 4.4 Yield of scutched hemp during hackling and cutting

Long fibre	3.8%
Short fibre	5.6%
Waste	6%

The percentages indicated are percentages of the original weights of hemp stalks (Tables 4.6–4.7).

and doubling operations are usual. The last of these introduces a small amount of twist and produces a rove. During these drawing and doubling stages, selecting cans of the same length but of different weight ensures the production of slivers of uniform fineness. Gill boxes are usual in these drafting and doubling operations. Intersecting gill drawing frames are not common in the hemp industry due to limited demand, high production costs and small development budgets. Today only a few old machines of this type are in operation. Refurbished machines manufactured by Mackie (UK) Bolelli (Italian) and LCS (Russia) from the 1960s are used at present.

It is preferable to combine as many slivers as possible during the first drawing operation. This ensures satisfactory blending and evenness of slivers. The length of sliver produced can be measured during processing. After the production of the required length the operative is informed by a visual signal. The filled can is then replaced by an empty one. It is also possible to obtain the linear density of the sliver by weighing the coiler can. The rove weights produced for long fibre spinning are between 2.5 to 5 g per metre. This is the final operation of yarn preparation. A hemp roving frame is similar to a flax tow roving frame but somewhat larger and heavier.

Spinning

Wet spinning used to be the more important of the two types of spinning system used for hemp, but this has now disappeared in Hungary (see 4.5). This general demise of hemp wet spinning is due to unfavourable working conditions, changes in demand, high production costs and regulations concerning the protection of the environment. Today, in Hungary, hemp is only dry-spun; Mackie (UK) and Bolelli (Italy) are the most commonly used spinning frames. The quality, evenness and tensile strength of the yarn depend on the raw material and the technology used. Usually the envisaged end-use determines the counts of the yarns produced.

The most commonly produced hemp yarns today are for weaving, usually 100% hemp, and are produced from selected fibres in the count range of Nm 3.5–5 (285–200 tex). Hemp yarns of similar counts are produced to make special twines and binders, sometimes blended with flax. In recent years there has been a demand for yarn of Nm 2–0.60 (500–1666 tex) for the manufacture of special ropes of high tensile strength. The raw material used is hackled long fibre hemp blended with good quality scutched flax fibre. Spinning takes place on Bolelli spinning frames of the semi-worsted type.

Winding

Hemp yarn is wound on cone winders. During winding thin sections and knots are removed. Yarn breaks during spinning are hand knotted. Hemp winding is labour intensive, modern automatic machines are not in common use and the usual yarn package is a cone containing 2–2.5 kg. The winding of heavy count yarns is done on cross winders similar to those used for short fibre.

4.5.2 Short fibre spinning

Yarn preparation

Two kinds of fibre are used in short fibre spinning, the short fibres produced during scutching (scutched tow) and the short fibres produced during hackling (hackled tow). Tangled (where the ends of the scutched fibres may be uneven and tangled together) and scutched tow with high hurd content can be used as part of the blend to produce good quality yarn of this kind and the raw material usually used is tangled tow of different lengths, fineness and cleanliness. As in all spinning the objective is to produce a yarn containing parallel fibres in the count required and the blending constituents chosen for producing yarn spun from short fibre depend on the envisaged end use. Blending is usually more varied than it is in yarns made of long fibre. The counts of yarn produced vary from Nm 0.20–1 (5000–1000 tex) to Nm 1–5 (1000–200 tex).

Table 4.5 Process weight loss during long fibre processing: (a) weaving; (b) twine manufacture

(a) Weaving		
Spinning	Loss during preparation, spinning and winding	10%
Twisting		2%
Weaving		1%
Finishing		13%
(b) Twine manufacture		
Spinning	Loss during preparation and spinning	10%
Twisting		2%
Polishing		
Finishing		4.3%

Pre-carding

The purpose of pre-carding is, as the name suggests, to prepare the fibres for carding; this involves the removal of the remaining hurds, untangling the tow, forming the sliver and coiling it into cans. The diameter of the cylinders and other rolls of the pre-card are larger than in final carding and the card wires stronger. This process carries out the rough cleaning and cards the fibres. Hungarian practice is not to blend fibres during pre-carding. The card slivers produced at the pre-carded stage are kept separate and blending takes place during final carding.

Final carding

The purpose of final carding is the further removal and the elimination of knots, blending and paralysing the fibres, affining them and forming a carded continuous sliver. The final cards (Mackie (UK), CST-1 15, Russian) usually consist of the following units:

- feeder
- card
- drawhead.

In the feeder the pre-carded coils of sliver are unwound and fed into the card. The card web is led between the condensing and main cylinder and after carding the slivers are led off the main cylinder into the drawhead that draws and doubles the sliver.

The length of the sliver can be measured continuously. A scale in front of the drawhead measures the irregularity of the weight of the sliver and varies the rate of drawing the lap through the drawhead. This continuous control of the lap weight enables the production of a final carded sliver of uniform weight per metre. As a can contains 400 metres the linear density of the sliver may also be established by weighing the can. Blending is usually carried out on the final card. The different coils are fed into the card as required by the blending ratio; carding, then doubling, ensures good blending of the different components.

Drawing and doubling

The draw frames are similar to those used to produce long fibre yarn. An important difference is the shorter drafting zone due to the shorter fibres being processed. The slivers pass consecutively through three draw frames. In the first and second stages of drawing gill boxes with chains are used, a special chain moving the pinned gill-bar. These gill boxes cannot produce evenly drawn slivers. In the third stage a gill box with a pulley is used. These are not suitable for correcting the defects of the slivers produced in the first two stages. These three-stage gill boxes are more suitable for spinning the rougher and thicker yarns. It is preferable to use gill boxes with pulleys (not chains) when producing finer and level yarns of good quality.

Spinning

Spinning is done on frames similar to those used for the spinning of long fibres except that, as in draw frames, the drafting zone is shorter. The fineness of the yarn to be spun determines the type of the spinning frame used. The tensile strength of the blend of fibres used can affect the fineness of the yarn. Improving the composition of the blend by, for example, blending long fibre with short improves spinnability. In practice there are two main machine types. One frame is used to produce thicker yarns and handles sliver weighing from 10 to 14 g per metre. The other frame is a modified fly-frame and handles sliver of 3 to 8 g per metre. Both these frames produce counts in the range of Nm 0.20 to Nm 1.

Winding

Fine and thick yarns require different winding machines. Fine yarns spun from long fibres to counts of between Nm 1 to Nm 6 and from short fibres to counts of between Nm 1 to Nm 15 are wound on cone winders. Usually 2 to 2.5 kg packages are made when subsequent processing justifies this length of yarn. Thicker yarns in the range of Nm 0.20 to 1 (spun from long or short fibres) are wound on cross winders, with a stroke of 8–10 inches. The weight of the cheeses produced can be varied between the limits of 4.5 kg to 10 kg. A considerable advantage of these cheeses is that due to their hardness they can be shipped on pallets, which also saves space.

4.6 Weaving

The quantity and variety of hemp fabrics produced in the last 15 years has decreased significantly. Former weaving companies have either left these particular markets or changed to weaving fabrics for the same end-uses but made from other fibres. For example, the demand for hemp canvas, covers and sacks had decreased as their users, both general consumers and the armed forces, have changed over to fabrics made from synthetic fibres which are easier to handle and resist mildew and other kinds of natural degradation. Also, in many cases, these fabrics made from synthetic fibres are cheaper than those made from hemp.

Other factors that encouraged the decline in hemp fabric production were the disappearance of wet spinning (in Hungary), and of the chemical separation of hemp fibres, and the deterioration in quality of both locally produced and

Table 4.6 Process weight loss during fibre processing: (a) short fibre; (b) hemp tow

(a) Short fibre	
Pre-carding	9%
Fine carding	14%
Spinning	15%
Twisting	4%
Polishing	
Finishing	4.5%
(b) Hemp tow	
Pre-carding	15%
Fine-carding	15%
Spinning	15%
Twisting	5%
Polishing	
Finishing	8%

imported scutched hemp. All these trends led to a decrease in the production of hemp yarns of suitable quality and price. On the other hand a more positive factor was, in some fabrics, the replacement of hemp warps by cotton warps. This helped maintain the level of fabric production and eased the shortage of quality hemp yarns. In turn this helped to maintain an efficient level of fabric production.

This situation lasted until the collapse of the former Comecon market but the development of an interest in natural products, especially flax and hemp fabrics suitable for clothing, increased market demand in the beginning of the 1990s. The flax industry increased its yarn and fabric production by significantly increasing spinning and weaving production facilities. The hemp industry, as it could spin only fairly coarse counts, was not so well placed to produce yarns for apparel fabrics but nonetheless did take the necessary action to enable the industry to be able to supply a part of this market. Firstly, hackled fibre was produced from quality selected scutched fibre, then Nm 5 yarn was spun from this fibre and used to produce 500–700 g/m^2 hemp fabrics, or, secondly, after yarn preparation, the rove was chemically treated (bleached rove). This could be spun to finer counts to produce fabrics of 250 g to 300 g/m^2.

Hemp yarns have lower elasticity than cotton yarns, for example, this limits their use to simple weaves such as plains and twills. Today (2002) hemp has achieved only a token penetration of the apparel market. The volumes are small and the costs are high and the possibilities of market and technological development are therefore limited but, despite the substantial decrease in hemp woven production, weaving, both for fabrics and carpets, remains the most important outlet for hemp yarns.

4.7 Fabric finishing

Finishing hemp fabric requires considerable experience. The objectives are to remove dirt, regularise fabric structure, bleach it slightly and ensure maximum dimensional stability. Hemp fabrics are usually sold in their natural colour, but to produce a level shade a mild bleaching treatment is used. This process is similar to that used for flax fabrics of similar weight.

The first stage of fabric finishing is scouring, using a gentle alkaline liquor. This removes dirt and also the natural waxes, proteins and pectins that are present in the fibres. After scouring and bleaching the fabric is dried and dimensionally stabilised, usually in a stenter. Normal maximum shrinkage standards are 2.5% in the warp and 1.5% in the weft. Drying hemp fabrics is similar to drying flax fabrics. The fabric may shrink significantly and the rates of shrinkage in warp and weft are usually different. It is therefore important to remove warp and weft tensions and stabilise the fabric as much as possible. For certain end users the fabric is used in its unfinished state. This is the case for example in articles made from leather where the hemp fabric is used as trim or accessories. A soil resistant finish is sometimes applied to these fabrics. Due to limited production and consumption and despite it being the major consumer of hemp yarn, the finishing of hemp fabric is limited to only a few thousand square metres per year. This gives little incentive to weavers and textile machinery manufacturers to develop new finishes.

4.8 Production of other hemp products

The largest demand for hemp yarns that are to be further processed is for the production of string, twine, cord and rope. These are yarns made from both long and short fibres. The precise type of yarn used will depend on the intended use of the final product, the required strength and desired aesthetics.

4.8.1 Twine

Two or more yarns are twisted together. The purpose is to make a product of greater regularity and strength than the original yarns. The yarn on yarn friction that results from the original yarns being twisted around each other produces a greater tenacity that the sum of the tenacities of the original yarns. Twines, cords and ropes are described by the number of yarns from which they are made. If more than six yarns are plied the yarns will be assembled in several stages. Usually identical count yarns are assembled to produce these products. Various types of twisting frame are used to ply the yarns; for instance, fly doublers and cap doublers. In addition to their use in the manufacture of twines, strong ropes and cordage, hemp yarn – but in its original unpolished state – is also used in agriculture as baler twine and in pre-cut lengths for use as binders.

4.8.2 Twine polishing and balling

Twine is made from hemp singles or twisted hemp yarns; its surface is smooth, even, shiny and clean. These surface effects are obtained by using a starch finish and polishing with wax and paraffin on a polishing frame. Depending on the demand of the market, twines are made from long or short fibres. Twines made from long fibre yarns are strong, level, attractive and suitable for special purposes. Twines made from short fibre yarns are less even, of lower quality and are for more general use. Twines are usually two or three stranded but can be produced with four to six strands. Twines with several strands are made from finer yarns. In a polishing machine the structure of the yarn is loosened and the handle softened in a warm soapy bath. The twines are then passed over cleaning rollers which remove 'proud' fibres, knots and sliver. During this cleaning process the twines receive a further intensive warm wash.

After the application of a starch finish the twines are bleached or, if required, dyed. Excess moisture is then removed by squeezing rollers. Finally the twine is dried by passing over heated cylinders. Drying temperatures depend on the thickness of the twine and are approximately 100–120 ºC. Polishing is carried out by two pairs of polishing cylinders covered with polyethylene or hemp rope. These cylinders also apply paraffin to the surface of the twine, which is already saturated with starch, producing a shiny and attractive appearance. Twines are usually packaged as balls, but cross-wound spools or skeins are also possible and can be produced to defined lengths. Balling frames may be automatic or manual. The latter are suitable only for satisfying special demands and have low productivity. Automatic balling frames can satisfy most usual requirements.

4.8.3 Cord and rope production

Cords are assembled from yarn or twine. The individual components are 'pre-twisted' during production. The degree of twist imparted during this operation determines the softness or stiffness of the cord. Cords normally have 3×2 strands and are usually called six-stranded cords. Rope structure is similar to that of cord. Usually products with diameter above 5 mm are called ropes and the number of yarns to be twisted and assembled to form them will depend on the fineness of the yarns and the thickness of rope required; they are usually assembled from three or four strands. The diameters of currently produced ropes range from 5 mm to 40 mm. These are packaged on rolls of various sizes.

4.9 Environmental and health and safety considerations

The main natural processes involved in growing and processing hemp are mostly environmentally favourable, but some may be harmful. Growing hemp is beneficial to the environment. It is biodegradable and in addition to being a good rotational crop has the ability to selectively absorb pollutants, such as heavy metals, from soils. Its very rapid growth and high leaf cover eliminates weeds by smothering them and therefore avoids the necessity of applying weed control chemicals during its growth period. Also hemp cultivation needs only low levels of chemical fertilisers and in some cases none. The hurds and leaves can be ploughed back into the soil as natural fertiliser or used for other purposes such as animal litter, after which it finds further use as an (enhanced) natural fertiliser. The hurds are also used in the manufacture of paper and for fibreboard in building and furniture making. Little or none of the plant is wasted.

On the negative side, water retting requires large amounts of clean water. However, after retting the used water is polluted, it is poor in oxygen and rich in floating and dissolved organic matter. Cleaning and regenerating this polluted water in an industrial plant would require an enormous provision of energy and the costs are such that they would jeopardise the viability of hemp production. Present procedure is natural water regeneration, which requires adequate areas of land. Organic matter is allowed to settle and the lack of oxygen is remedied over time. Reed bed filtration has also been shown to be effective. Polluted water is also produced during the polishing of twine. Fortunately only small quantities of water are involved so this is not a major problem.

During scutching and spinning hemp dust and fragments of hurds and short fibre become airborne; air filtration systems are therefore required to improve the quality of the air and of the working conditions generally. The wearing of facemasks to protect the health of operatives is a legal requirement in many countries, but is not always strictly enforced. During the processing of hemp – breaking, scutching, softening, cutting, hackling, drawing, spinning – significant amounts of dust are released. This amount is much larger than the amounts released during the processing of other natural fibres. This is due to the size and structure of the dried hemp stalk, the composition of the fibres, the gradual separation of the epidermis, pectins and lignin and also because the machines used in hemp fibre processing were built 30–40 years ago or use the technology of that period. These have many open working surfaces with the result that the large amount of dust that they generate is not enclosed and eliminated but distributed throughout the atmosphere of the enclosed areas of the hemp factory. However, even with more modern enclosed machines a certain amount of dust is inevitably released into the air.

Dust that is not removed by air-conditioning plants can cause mild fever, coughing or in more serious cases bronchial or lung diseases. However, hemp dust, due to its relatively larger size, cannot penetrate deeply into the body and therefore its harmful effects are less than that those of diseases caused by the absorption of smaller particles produced by some other industrial processes.

Another disadvantageous effect of hemp processing is the noise levels in some of the working areas of the factory, which are usually higher than acceptable. These high noise levels are caused by the machinery used, and more particularly by their age. The possibilities of decreasing the noise levels in these old mills and with old machines are limited. The prevention of hearing loss can be solved by the use of individual protective equipment ranging from simple earplugs to modern protective earmuffs, but here again, although their use may be mandatory these health and safety regulations are not always applied.

Beside the constant use of individual protective equipment regular medical examinations are also very important. Different screening tests for ears, lungs, bronchial tubes and possibly legs should all be part of a preventative health policy. Equipment and machines used in hemp processing are potentially dangerous as there are many moving parts and these parts often cannot be protected from accidental or intentional body contact. Where possible, potential points of danger are protected by housings, barriers, wire nettings, etc. In highly dangerous machines multiple protective locking systems are built in. Their purpose is to prevent the machine being started until it is safe to do so. Accidents can be prevented by regular machine checks. The observation of well planned technological handling and maintenance programmes and instructions will ensure safe operation. Also a thorough knowledge of safe working practices by all the operatives concerned is essential.

4.10 Production and market trends

After an initial increase, continuous decline marked the period between 1960–2000. After 1990 (change from the command economy) the unviable companies, unwilling or unable to move with the times, did not survive. Only five hemp and flax mills out of the former 15 operate today (2002), three hemp and two flax mills. The trend is shown in Tables 4.7–4.9. The causes of these large-scale changes are as follows:

1. Discontinuation of subsidies.
2. The period from sowing to producing finished products is 1.5–2 years. This lengthy period can be financed only by significant increases in costs.

Table 4.7 Hemp, flax and jute production 1960–1991

1960	69.8% (Value HUF 1.343 million, gross production)
1965	88.7%
1970	88.5%
1975	95.2%
1980	100.0%
1985	118.4%
1990	88.7%
1991	55.1%
1993–2000	N.A (estimate approx. 25–30%)

Table 4.8 Hemp, flax and jute industry: number of employees

1960	13,640
1970	12,974
1980	13,805
1985	12,312
1990	9,322
1991	4,783
1993–2000	N.A. (estimate approx. 2,000 employees)

Table 4.9 Hemp area under cultivation

1950	20,000 ha
1960	10,000 ha
1985	5,000 ha
1990	1,000 ha
2001	700–800 ha

3. Hemp products can be partly replaced by synthetic yarns and fabrics.
4. Synthetic products are considerably cheaper
5. These trends were evident in both the hemp and flax industries and textile machinery manufacturers saw little point in developing new and more productive equipment for a rapidly declining market.
6. Market demand for hemp products decreased dramatically, especially in Hungary, due to 3 above.
7. Export demand also decreased in Europe and although demand increased in North America this did not compensate for the decline in Europe.

4.11 Conclusions

4.11.1 Hopes for the next decade

1. As protection of the environment assumes greater importance it is likely that the consumption of hemp products will cease to decline.
2. New end-uses for hemp and flax may increase the volume of hemp cultivation.
3. Beside the traditional end-uses the manufacture of specialised products may also increase production and consumption.
4. There is and will continue to be a need for closer co-operation between research and development institutes and industrial hemp companies in the fields of production technology and product development.
5. More powerful and aggressive marketing will be needed emphasising the advantages of natural fibres.
6. Continuous cost analysis is needed to achieve decreases in costs.

The Hungarian hemp industry has been through enormous changes in the last decade and in particular the number of mills has decreased significantly. However, this fact could, for the next few years, be an advantage as the volume produced today of a more up to-date variety of products can meet market demand. It is therefore possible that a better balance will be achieved between production and sales. This is probably the most important and encouraging factor for companies at present operating this industry.

[*Editor's note*: This, in fact, is happening as a new market is developing in composite products for the automotive market.]

PART 2

4.12 Present trends

As has been described by the authors in the first part of this chapter, and as is confirmed on a global scale by Table 4.10, production of hemp fibre has decreased dramatically over the last 45 years, and again the causes of this global decline have been similar to those in Hungary. These can be summarised as the loss of the captive markets in eastern Europe, the ex-USSR and China, all of which were major producers and consumers of hemp and hemp products. In turn, this decline was due the lack of investment and of technological and product development; all whilst having to face increasing competition from synthetic fibres, both in their export markets and to some extent, in their own and adjoining countries' markets.

World production for the years 1997 to 2003 by country is set out in Table 4.11 and the areas cultivated for certain countries and years are indicated in

Table 4.10 World production of hemp fibre (tonnes) 1961–2003

Year	Tonnes	Year	Tonnes	Year	Tonnes	Year	Tonnes
1961	299,923	1972	271,467	1983	154,636	1994	51,509
1962	304,549	1973	266,777	1984	152,906	1995	56,636
1963	310,775	1974	260,460	1985	157,157	1996	65,837
1964	339,596	1975	236,234	1986	*c.* 163,000	1997	63,506
1965	340,821	1976	238,046	1987	167,516	1998	73,629
1966	368,373	1977	233,658	1988	152,049	1999	61,140
1967	348,338	1978	215,318	1989	107,814	2000	50,618
1968	300,486	1979	207,200	1990	83,997	2001	60,917
1969	297,691	1980	186,443	1991	66,442	2002	67,950
1970	280,278	1981	149,097	1992	76,331	2003	77,450
1971	282,269	1982	133,792	1993	63,568		

Source: FAOstat.

Table 4.11 World production of hemp fibre by country 1997–2003

	Hemp fibre and tow production (million tonnes)						
	1997	1998	1999	2000	2001	2002	2003
World	63,506	73,629	61,140	50,618	60,917	77,450	67,950
Chile	4,000	4,000	4,000	4,048	4,095	4,095	4,095
China	19,225	16,896	13,000	14,000	20,186	35,000	38,000
France	260	400	370	370	260	360	360
Hungary	2,086	1,989	350	129	150	120	120
Italy			507	437	221	1,281	1,281
Korea, Dem. People's Rep.	11,000	12,000	12,000	12,500	12,500	12,500	
Korea, Rep. of	448	267	326	263	235	224	224
Poland	150	50	50	50	50	50	50
Romania	9,600	11,100	7,300	1,400	800	800	800
Russian Fed.	3,000	2,200	4,100	7,100	5,400	6,000	6,000
Serbia and Montenegro	457	200	200	30	20	20	20
Spain	9,980	22,527	17,160	7,047	15,000	15,000	15,000
Turkey	2,300	1,000	777	1,244	1,000	1,000	1,000
Ukraine	1,000	1,000	1,000	2,000	1,000	1,000	1,000

Source: FAOstat.
Courtesy: Food and Agriculture Organization of the United Nations.

Table 4.12 Hemp areas harvested (ha) in certain countries outside the EU 1996–1999

	1996	1997	1998	1999
Bulgaria		48	8	8
Canada	0	0	2,000	1,200
Chile	4,200	4,200	4,200	4,200
China	58,000	15,000	15,000	15,000
Croatia	14	14	14	14
Hungary	1,200	900	1,077	1,077
Korea, Dem. Republic of	17,000	17,000	17,000	17,000
Korea, Republic of	250	250	250	250
Romania	1,000	2,000	3,080	3,000
Russian Federation	11,490	9,490	6,260	10,230 16,980 (2000)
Ukraine	4,000	3,500	2,000	2,000
Yugoslavia, Fed. Rep. of	679	1,000	1,000	1,000

Source: FAOstat. Russian Federation statistics: A. Surinov, General Director, State Commit. of the Rus. Federat, on Statist., (GOSKOMSTAT of Russia), Dep. Of Foreign States Statistics and Intern. Cooper., Moscow, Russia. Canada, China, Hungary, Romania, Ukraine, Fed. Rep. of Yugoslavia Statistics: Michael Dr Karus, nova-Institut für politische und ökologische Innovation, Nachwachsende Rohstoffe, Thielstr. 35, 50354 Hürth Germany. Courtesy: Prof. Dr R. Kozlowski.

Table 4.13 Hemp areas harvested (ha) in certain countries of the EU 1996–2001/2

	1996	1997	1998	1999	2000/01	2001/02
Austria	661	938	974	289	287	860
Belgium			0	1	0	0
Denmark			26	23	7	7
Finland	2	53	1,218	93	59	2
France	7,588	10,980	9,682	9,515	7,700	6,900
Germany	1,362	2,766	3,553	3,993	2,967	1,948
Italy	0	0	255	197	151	200
Ireland	0	23	28	22	6	0
Luxembourg	5	13	13	0	0	0
Netherlands	893	1,322	1.055	872	806	946
Portugal			770	185	4	0
Spain	1,450	4,828	19,860	13,473	6,103	784
Sweden					0	0
Switzerland	150	200	250	250	250	
UK	1,697	2,293	2,556	1,517	2,245	2,566
Total EU	**13,658**	**23,216**	**39,990**	**30,179**	**20,404**	**14,213**
Poland	1,296	240	158	36	53	153

Source 1996–1999 statistics: Michael Dr Karus, nova-Institut für politische und ökologische Innovation, Nachwachsende Rohstoffe, Thielstr. 35, 50354 Hürth Germany. Source 2000/2001 and 2001/2002 statitsitcs: Mr Jordi Petchamé Ballabriga, Administrator, Olives, huile d'olive et plantes textiles, D.G. VI.C4 Loi 130 7/126, European Commission, Rue de la Loi 200, B-1049, Bruxelles, Belgium. Courtesy: Prof. Dr R. Kozlowski.

Tables 4.12–4.14. There are discrepancies between the figures provided by the FAO and the INF, particularly in that the production of Canada Austria, France, Germany, Italy, UK, the Netherlands and few other countries producing small quantities are not included in the FAO data. The total areas harvested by these countries come to about 15,000 Ha and assuming a yield of two tonnes per hectare this would add 30,000 tonnes to the FAO total in 2002 of 77,450 tonnes (Table 4.11). However, this estimate of 30,000 tonnes is perhaps high because

Table 4.14 Russian federation: area cultivated and fibre produced 1995–1999

Year	Hemp cultivated area in Russia Total (ha)	Summary output of hemp fibre (tonnes)
1995	9,170	4,300
1996	11,490	4,030
1997	9,490	2,980
1998	6,260	2,190
1999	10,230	4,140
2000	16,980	7,070

Source: A. Surinov, General Director, State Committee of the Russian Federation on Statistics (GOSKOMSTATof Russia), Department of Foreign States Statistics and International Cooperation. Courtesy: Prof. Dr R. Kozlowski.

market research carried out by the nova-Institut[1] on behalf of the European Industrial Hemp Association (EIHA) in 2003 shows EIHA members production of hemp fibre in 2000 at around 20,500 tonnes (Table 4.13). Although not all European Hemp production is included in the IIHA figure their report estimates that they do account for 80 to 90% of EU hemp fibre production. Taking, therefore, EU production at approximately 23,000 tonnes world production in 2002 would have reached 100,000 tonnes.

FAO figures for 2003 (Table 4.11) show a decrease of about 10,000 tonnes over the previous year but EU production certainly increased, therefore world total for that year would be between 90,000 and 95,000 tonnes. However, it must be remembered that not all of this production is for textiles as considerable quantities are used for paper and composite products (see below).

4.13 Future trends

It is clear that, since the mid 1990s, hemp is experiencing a renaissance. This is based on two factors; the development both of new markets and new technologies.

4.13.1 Recent technical developments

The fact that retting is necessary for the effective extraction of the fibres from most bast and leaf fibre producing plants places them at a disadvantage when compared to other fibres. If fibre extraction processes involved could be improved or retting eliminated both the quality and the prices of these fibres could be improved. During the 1990s and especially in the cases of hemp (and flax), efforts have been made to remove the need to ret the stalks before fibre extraction. These have all relied on the fact that if the stalks are processed immediately or soon after harvesting the gums binding the fibres to the rest of the plant have not solidified. It is then possible to peel the long ribbons of fibre from the rest of the stalks without damaging them, as happens when mechanical force is used during traditional scutching. Two German companies developed large harvester-decorticators. These aimed at producing short fibres suitable for industrial (mainly non-woven) and not apparel or furnishing end-uses. These two machines have not been commercially successful and one of the companies has closed down.

A different approach was adopted by an Australian company and has, at the time of writing (2004) been successfully developed to prototype level. In this case the decorticators are mounted on the rear of a self-propelled harvester. This produces ribbons of fibres which are automatically bagged by the harvester-decorticator, and hurds, which can be either spread over the field being

1. *European Hemp Industry 2002*. M. Karus, nova-Institut, Hürth, Germany.

harvested to be ploughed in for the next crop, or bagged for sale (as animal litter or for particle board or paper manufacture, for example). The bagged ribbons of fibre are then processed, degummed, either by washing, chemically or by enzyme treatment, and after drying are suitable for spinning on cotton, worsted or other spinning systems. Sample quantities of 100% hemp, hemp/cotton and hemp/wool yarns have been produced and further trials are at present (early 2004) taking place.

4.13.2 New markets

Apparel

The major problem with traditionally produced hemp is that the fibre is relatively coarse (15–50 μ) and capable of being spun only to a finest count of 3s metric, which for all practical purposes limits its use to heavy industrial fabrics. By using selected hemp fibre and by spinning from bleached rove (see the first part of this chapter), 'bottom weight' apparel fabrics can be produced. However, they are expensive when compared to cotton and coarse when compared to linen, but they do have a niche in the 'environmentally conscious' market.

Composite materials

This is a new market for bast and leaf which started developing in the mid-1990s (see Chapter 10). When compared to reclaimed cotton or wood fibre, which have been used up to now, the use of bast and leaf fibres improves the performance of the press-moulded composite panels which are used for the interior trim of cars. This market has developed rapidly and in 2000 consumed over 28,000 tonnes of vegetable fibres, of which 3,500 tonnes was hemp (source: nova-Inst.).

So far nearly all these panels have been press-moulded and the use of these fibres for making composites using this technology is expected to continue to develop. But considerable R & D is taking place in the use of these fibres for injection-moulded composites. At present the major fibre used for this purpose is glass fibre, priced at around US$3,000 per tonne. Bast and leaf fibres are selling into this purpose at between €500 and €600 per tonne and if the development of vegetable fibre injection moulded technology succeeds the consumption of these fibres will increase substantially. However, one must also bear in mind that hemp produced in the European Union is subsidised under the Union's Common Agricultural Policy (CAP), as are flax and many other crops. Whilst it is not expected that these subsidies will be removed in the immediate future they may well be reduced and it is difficult to foretell what the effect of an increase in hemp (and flax) prices, in comparison with those of jute, sisal and coir, will have on the relative consumption of these fibres for this particular end-use. Nonetheless, it is difficult to be pessimistic about hemp in the medium term and the forecast of Mr G. Mackie, who is a long established consultant in this area of textiles, expects present production to double by 2020.

[*Editor's note*: The present (2004) rate of the EU subsidies for cultivation and processing hemp are as follows:

	€/hectare
Cultivation	350
Short fibre processing	90]

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4.15 Glossary of terms

Affine *see* glossary Chapter 3.

Breaking *see* glossary Chapter 3.

Can Cylindrical receptacle about 1 m high into which slivers and rovings are collected after being processed.

Cannabis sativa Hemp's botanical name.

Cheese A type of yarn packet in the form of a cylinder similar to the shape of certain cheeses.

Hackling *see* glossary chapter 3.

Hurds Non-fibrous woody matter produced as a by-product of scutching.

Retting *see* glossary chapter 3.

Scutching *see* glossary chapter 3.

5
Ramie

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5.1 Introduction and history

5.1.1 Introduction

Ramie is the name given to the product of one or more species of the genus *Boehmeria*, a member of the order *Urticaceae* and closely allied to the stinging nettle genus (Urtica), from which, however, it differs in the absence of stinging hairs. Some confusion has arisen on the use of the various terms *Chinagrass, Ramie and Rhea*. Two plants are concerned. One, *Boehmeria nivea*, China-grass, has caused some confusion to arise on the use of the various terms *Chinagrass, Ramie and Rhea*, cultivated by the Chinese from very early times under the name Tschou-ma. This is known as white ramie. The other, probably a variety of the same species (*Boehmeria nivea, var. tenacissima*), though sometimes regarded as a distinct species (*B. Tenacissima*), is the Ramie (Malay zamf) of the Malaysian Islands and the Rhea of Assam. This is known as green ramie. Ramie is a member of the group referred to as the bast fibre crops.

There are at least two acceptable pronunciations for the word. Some authorities call it 'ray-mee' while others say 'rah-mee'. Traditionally ramie is used to make cloth, and is usually found in combination with cotton in knitted sweaters. It is also used to make tablecloths, napkins, and handkerchiefs. Ramie fibre is used in fine fabrics for clothing fabrics, upholstery, canvas, filter cloths, sewing threads, gas mantles, fishing nets and marine packaging. The main areas of application for naturally produced plants, including ramie, are

- textiles
  - woven
  - non-woven
  - knitting
  - technical
- pulp and paper
- composites
- agro-chemicals.

5.1.2 History

Ramie is a plant fibre that has been used since ancient times. It is one of the oldest vegetable fibres known and has been used for thousands of years. Ramie was well established as one of the principal fibres of the Far East. Long before the introduction of cotton it was used in mummy cloths in Egypt during the period 5000–3300 BC and has been grown in China for many centuries. In the Asia of those days the main areas of ramie cultivation were China, Indonesia and India.

In Africa the main areas of ramie's cultivation were the present territories of Algiers and Congo. *Boehmeria cylindrica* was used by Indians of the New World as twine to attach spear and arrow heads to shafts. Europe was introduced to ramie in 1733. The first cultivation trials were undertaken in Holland in 1808–09. However, according to Karpowiczowa[1] the first notification concerning the cultivation of ramie in Europe is dated 1786 in Bologna, Italy.

Ramie in China and the Orient is usually harvested by hand as the canes mature. The strands of ramie tend to be uneven, making harvesting difficult. Pounding and scraping is necessary to separate the fibres. After being separated from the woody matter and soft tissues, fibres remain in ribbon-like strips because they are held together by gums and pectin. The fibres must be degummed by boiling in lye or acid; this frequently weakens the fibre and it is very expensive. Machines are not yet capable of performing all the steps necessary which is why ramie is not widely used.

The first attempts in the mechanisation of ramie processing were undertaken by the government of India in 1869 and then by the French government leading towards the design of a hand-fed raspador decorticator patented in the United States in 1896. Floridians (USA) have found that hydrogen peroxide and lime can be used for degumming – these are much less harmful than the chlorine and sulphuric acid currently being used. In these regions ramie is locally spun and woven into coarse cloth, often without degumming, in China it is also used to make fine oriental textiles. Brazil began production in the late 1930s with production peaking in 1971 at about 30,000 t/yr. Since then, production has steadily declined as a result of competition from alternative crops, such as soybeans, and the importation of synthetic fibres. Production in the Philippines began in the early 1950s, peaking in the mid-1960s at 5,500 t/yr. Since then production has declined steadily.

Nowadays, the main producer counties are reported to be China, Brazil, Philippines, India, South Korea and Thailand. However, the available statistics are not reliable but the best available are those of the FAO (Table 5.1) and from these and for all practical purposes the only country of any consequence is China. Ramie usage in the US increased in the mid-1980s with the fashion emphasis of natural fibres and the fact that this fibre was not covered by the multifibre agreement (see below).

Table 5.1 World production of natural fibres (million tonnes, average 1998–2000)

	Fibre	Million tonnes
1.	Cotton	19.32
2.	Jute and similar fibres	3.52
3.	Wool and other fine animal hair	1.52
4.	Flax	0.6
5.	Sisal (agave and similar fibres)	0.386
6.	Kapok	0.195
7.	Ramie	0.17
8.	Abaca	0.095
9.	Silk, tussah and similar wild silks	0.1135
10.	Hemp	0.08
	Total natural fibres	26.0

The main importing countries are Japan, Germany, France and the United Kingdom. Only a small proportion of production enters international trade as most is used in the country of production. Under the MFA, ramie, and garments made of more than 50% ramie, could be imported into the United States without import quota limits. Legislation was passed in 1986 eliminating this quota-free status of ramie.

5.2 Classification and description

Boehmeria nivea is a shrubby plant with the growth of the common nettle but without stinging hairs, sending up each season a number of straight shoots from a perennial underground rootstock. The long-stalked leaves recall those of the nettle in their shape and serrated margin, but their backs are clothed with a downy substance and have a silvery appearance. The minute greenish flowers are closely arranged along a slender axis.

The variety *tenacissima* differs in its more robust habit and larger leaves, which are pale green on the face and a very much paler green on the back. They

Table 5.2 Classification of ramie[2]

Division:	Magnoliophyta
Class:	Magnoliopsida
Subclass:	Hamameliade
Order:	Urticales
Suborder:	
Family:	Urticaceae
Sub-species family:	
Species:	Boehmerieae
Sub-species:	

are not downy, however, and this affords a ready means of distinction from true China-grass. *Boehmeria nivea* is sometimes found wild in India, Malaya, China and Japan, and is probably a native of India and Malaya. China-grass and ramie are widely cultivated not only in China, Formosa and Japan, but also in Brazil, Mexico and the southern states of North America, and also in Southern Europe.

Ramie is a member of the *Urticaceae* or nettle family and is a hardy perennial which produces a large number of unbranched stems from underground rhizomes. The true ramie or *China grass* is also known as *white ramie* and is the Chinese cultivated plant. It has large heart shaped, crenate leaves covered on the underside with white hairs that give it a silvery appearance. A second type, *Boehmeria nivea* var. *tenacissima*, is known as *green ramie* or *rhea* and is believed to have originated in the Malay Peninsula. This type has smaller leaves which are green on the underside and it appears to be better suited to tropical conditions.

Boehmeria nivea is an erect, usually non-branching, tall fast-growing herbaceous perennial, one to two metres high. The leaves are green on the topside with a felty-white underside, the whole being covered with inconspicuous hairs. As the plant matures, the leaves defoliate naturally from the lower part of the stem. The small seeds are dark brown in colour, ovate and produced in very large quantity. Ramie stems are slender, sometimes striated and range in diameter from 8 to 16 mm at the base. They may attain a height of two to two and a half metres in 45 to 60 days under ideal growing conditions. They are usually hollow at maturity, being filled with dried pith and may be readily crushed between the fingers.

Ramie differs from the other bast fibre crops in several important characteristics. The principal difference is that ramie is a hardy perennial which under suitable conditions can be harvested up to six times a year. Also the useful crop life ranges from 6 to 20 years. *Boehmeria nivea* is a dicot and angiosperm, it is adapted to moist tropical climates and deep soils, is a perennial plant, occupies the land year round and when cultivated, is without branches (apical dominance, apical buds pinched off).

5.3 Properties of the ramie fibre

Ramie is classified chemically as a cellulosic fibre, as are cotton, linen, rayon and others. Leading producers of ramie are China, Taiwan, Korea, the Philippines and Brazil. Until recently ramie has been unknown in the ready-to-wear apparel market, but its use in this market is now increasing. It is often blended with cotton and available in woven and knitted fabrics that resemble fine linen to coarse canvas. Ramie usage increased in the mid-1980s with fashion, the emphasis on natural fibres and a loophole in the textile import regulations of the Multi Fibre Agreement (MFA).

Ramie's fibres are found in the bark of the stalk. The process of transforming ramie fibre into fabric is similar to producing linen from flax. The fibre is very fine and silk-like, naturally white in colour and has a high lustre. Ramie is a term that is appearing with increased frequency in the labelling of sweaters and some linen-look textiles.

5.3.1 Physical and chemical characteristics of ramie compared to other cellulosic fibres

Because ramie is a bast fibre the technology of its extraction from the plant is different from that of cotton, where the fibres have to be separated from the seeds. It is therefore difficult to establish a direct comparison of the properties of ramie with those of other fibres but Table 5.3 gives some of the chemical and physical characteristics of ramie, flax, hemp and cotton. These figures illustrate some of the advantages of ramie over other fibres and in particular the lengths of its ultimate fibres and their tensile strength. Other tables comparing Ramie's characteristics with those of other fibres can be found in the appendix to Chapter 1. The ultimate fibres are the longest known in the plant realm[3] with one report claiming the fibres range up to 580 mm, averaging about 125 mm. Another report describes the ultimate fibre as ranging between 48 and 290 mm in length. Also reported is the range of bark fibre lengths as 5 to 36 mm and the fibre width as 41.8 microns.

Ramie fibre is very durable. It is reported to have a tensile strength eight times that of cotton and seven times greater than silk. However, other reports claim that the tensile strengths of cotton, flax, hemp and ramie are similar. These discrepancies can be partly attributed to the effects of sources of supply,

Table 5.3 Some physical and chemical characteristics of ramie compared to other cellulosic fibres

Characteristics	Ramie	Flax	Hemp	Cotton
Ultimate fibre length in mm				
minimum	5	1	5	9
average	120–150	13–14	15–25	20–30
maximum	620	130	55	63
Ultimate fibre diameter in microns				
minimum	13	5	10	12
average	40–60	17–20	15–30	14–16
maaximum	126	40	50	20
Tensile strength in kg/mm^2	95	78	83	45
Moisture regain in %	12	12	12	8
Chemical composition in %				
cellulose	72–97*	64–86	67–78	88–96
lignin	1–0	5–1	6–4	0
hemicellulose, pectin and others	27–3	31–14	27–18	12–4

* Minimum and maximum cellulose contents refer to decorticated and degummed ramie respectively.

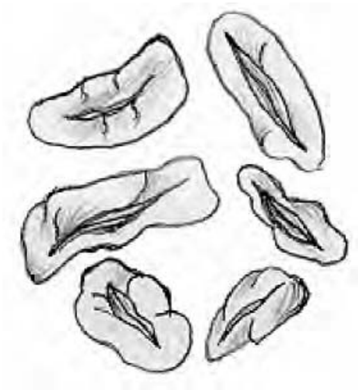

Figure 5.1 Cross-section through ramie fibres with lumen (cavity in fibre). Source: Gesamtverband der Deutschen Versicherungswirtschaft. Courtesy: www.tis-gdv.de.

methods of processing, the test conditions, and the influence of temperature and humidity on the fibre. Ramie's tenacity increased by 25% on wetting. It is the least affected by moisture. Ramie fibre, after extraction and primary processing is strong and durable, ranking first amongst all vegetable fibres in this respect. It also has the particular advantage of resisting rot when exposed to weather conditions or immersed in water. The fibre is exceptionally white, comparable to bleached cotton, and also has a high lustre, exceeding linen in this respect.

The long, fine ramie fibres are naturally white and lustrous with an almost silky appearance. The inner structure of ramie differs from that of other plant fibres in that the physical form of the cellulose is rigid and crystalline, like linen, but has a more porous sieve-like form providing it with even better absorbency than other cellulose fibres. The unevenness of the fibres has a strong resemblance to the thick and thin appearance of linen but at a reduced cost. In addition, ramie is softer and has better dyeability. Ramie's fibres are found in the bark of the stalk. The process of transforming ramie fibre into fabric is similar to producing linen from flax. The fibre is very fine and silk-like, naturally white in colour and has a high lustre. Ramie is a term that is appearing with increased frequency in the labelling of sweaters and some linen-look textiles.

Like linen and cotton, ramie has poor resiliency and wrinkles easily. Application of wrinkle-resistant finishes or blending with synthetic fibres can reduce the problem in woven fabrics. Because of its high absorbency, ramie is comfortable to wear, especially during warm weather. Other properties include resistance to alkalis, rotting, light and mildew. Resistance to insects is good unless the fabric is heavily starched. Ramie is not harmed by mild acids but can be damaged by concentrated acids. The fibre has some natural stain-resisting ability with ease of stain/soil removal similar to that of linen, which is better than cotton. Dyes appear to have good wet-fastness in laundering but there can be a tendency for crocking in dark or saturated colours. Precautions such as wearing dress shields can reduce crocking problems. Dark colours may lose their vibrancy over repeated launderings.

5.4 Cultivation and harvesting

5.4.1 Cultivation

Ramie is easy to cultivate and thrives in almost any soil but grows best on open type, and rich warm sandy soils that are very well drained. Also suitable are soils of volcanic origin, including pumaceous types and friable sandy loams. It can be propagated by seeds, cuttings or layers, or by root separation. Ramie is intolerant of wet soils. It does best in areas with high temperatures and high humidity plus a rainfall of 1100 cm evenly distributed throughout the year. Sudden changes of weather result in irregularities of growth and these have a tendency to produce plants that vary in strength. It tolerates a pH in the range 4.3 to 7.3 but prefers slightly acid soil conditions. Calcareous soils are totally unsuitable despite the high demand of ramie for calcium. This is a very greedy plant and can soon impoverish a soil. All plant remains, after the fibre has been removed, should be returned to the soil or organic or inorganic fertilisers should be added. The plant can be grown from seed or layers but it is generally propagated vegetatively, using rhizome or stem cuttings. Production begins to decline once roots become overcrowded. Roots suffering overcrowding require thinning out or the area must be replanted.

The following characteristics of the ramie crop would influence its suitability in farming systems:

- it is a perennial crop with a life of 6 to 20 years.
- it is capable of producing high yields of biomass and if the harvesting system involves total removal of this biomass, there would be a rapid decline in soil fertility.
- Ramie is subject to a number of pests and diseases, including nematodes.

5.4.2 Harvesting

Two to four harvests per year are possible depending upon the climate but under good growing conditions ramie can be harvested up to six times per year. It is harvested as the stems turn brown. Harvesting is done just before or soon after the onset of flowering, since there is a decline in plant growth at this stage and maximum fibre content is achieved. The timing of the harvest of a particular stem is important as fibre yields are reduced if it is immature. Also there are difficulties in removing the fibre from the stem if it is over-mature. According to Buchanan, it is best harvested as the female flowers open.[5] The outer bark is

Figure 5.2 Mechanical harvester for bast fibres developed by the Institute of Natural Fibres, Poznan, Poland.

removed and then the fibrous inner bark is taken off and boiled before being woven into thread.[6]

Stems are harvested by cutting just above the lateral roots or the stem can be bent, to enable the core to be broken and the cortex can then be stripped from the plant *in situ*. Mechanical harvesters have been developed but are not used commercially (Fig. 5.2). After harvesting, stems are decorticated whilst the plants are fresh as the bark gets harder to remove as the plant dries out. The bark ribbons are dried as quickly as possible to prevent attack by bacteria or fungi.

5.4.3 Crop and fibre yields

The dry weight of harvested stem from both tropical and temperate crops ranges from about 3.4 to 4.5 t/ha/year; a 4.5 tonne crop yields about 1,600 kg/ha/year of dry un-degummed fibre. The weight loss during degumming can be up to 25% giving a yield of degummed fibre of about 1,200 kg/ha/year.

5.5 Primary processing

Ramie's fibres are found in the bark of the stalk. The process of transforming ramie fibre into fabric is similar to producing linen from flax. The fibre is very fine and silk-like, naturally white in colour and has a high lustre. Ramie is a term that is appearing with increased frequency in the labelling of sweaters and some linen-look textiles. After soaking the stems in water for a few hours, the inner fibre is stripped away from the skin using a blunt knife or something similar. Having dried the fibre in the shade, it is then split into narrow strips with the fingernails, whilst occasionally wetting the fingers. According to some authors the extraction process of the fibre bundles is carried out in two stages: firstly, the cortex, comprising the bast and outer bark, is removed from the stem; this is sometimes called decortication and can be done by hand or machine. Secondly, this cortex is scraped to remove most of outer bark, the parenchyma in the bast and some of the gums and pectins. Extraction of the bundles is followed by washing, drying and degumming before the ultimate, spinnable, fibres are obtained.

5.5.1 Stripping

Stripping consists of removing all the phloem (including the fibres), some parenchyma and some outer bark (epidermis in young plants, periderm in mature plants). The resulting strips are often referred to as *China grass*. Hand stripping is always carried out on fresh stems and is said to yield better quality fibre than that produced by decorticating dry stems.[7,8] Some authors affirm that hand stripping gives higher yields of fibre than mechanical ribboning; hand stripping is a slow, laborious process and is economic only where cheap labour is plentiful. According to Dempsey[9] stems are cut before stripping, in the Chinese method[10,11] uncut stems are stripped.

The harvester removes the cortex containing the fibre from the fresh stems as a strip by gripping the growing stem and bending it over to the right; its woody core fractures about 23 cm above ground level. Then, whilst still pressing the stem downwards, he moves it over to the left, fracturing the woody core again. He then inserts his finger into one side of the stem between the core and bast, and runs it upwards, separating the top half of the bast from the stem and breaking off the small branches in the process; he then run his finger down to the butt (root) end where the strip is easily broken off. The process is repeated on the other half of the stem, thus two green strips are removed from each stem.

Bark and parenchyma are removed from the strips by pulling them between a scraper and a bed plate held in the same hand. The bed plate is a strip of bamboo about 13 mm thick, 16 mm wide and 60 mm long; it is held by the thumb through a metal ring, which is securely anchored to the bamboo. The bamboo lies between the thumb and forefinger with its long axis along the thumb. The scraper has blunt edges and is similar in shape to a shoe horn; the narrow end is held between the forefinger and middle fingers with the concave side towards the harvester and the long axis lying along the long axis of the bamboo. The harvester holds a strip in his other hand, by its butt end, and places it under the scraper as close as possible to the butt. In one swift movement, which is usually sufficient to scrape the strip from within 15 cm of the butt to the tip, he pulls the strip under the scraper. The strip is then reversed and the butt end is scraped. The process is quick and it is rarely necessary to give more than two scrapes in either direction.[12]

5.5.2 Ribboning

Ribboning consists of removing the outer bark/epidermis and the bast from the woody core of the stem; in fact the entire cortex is removed. Ribbons thus contain more of the outer parts of the stem than strips. To remove the ribbons, the stems are usually fed between longitudinally fluted rollers which crush the woody core and knock any wood fragments out of the bast. However, ribbons may also be obtained by using a modified decorticator in which the core is removed from the stem by the action of a moving drum; but it is still essential first to pass the stems through crushing rollers.[13] A simple ribboning machine with only one set of rubber rollers which crush the stem is also effective. Possibly the rollers distort and envelop the stem, and thus subject its circumference to differences in the peripheral speeds of the rollers over the area of the distortion; this could cause the bast and outer bark to be detached from the stem.[14]

5.5.3 Decortication

Decorticated fibre consists of bundles of phloem fibres still bonded together and parenchymatous cells. Recently, the most promising way of decorticating ramie is mechanical. This is carried out on either fresh green stems or dry stems. Dry decortication is said to be quicker and need not be confined to the harvesting season, thus reducing the number of decorticators needed. However, decortication of fresh stems is said to produce a better quality fibre.[15,16] Although various mechanical decorticators are available they are usually built on the principle of subjecting the stem to a succession of blows to break up the woody core. The stem is held against a rotating drum fitted with blunt blades, which pass over a fixed plate leaving only a restricted clearance. The edge of the

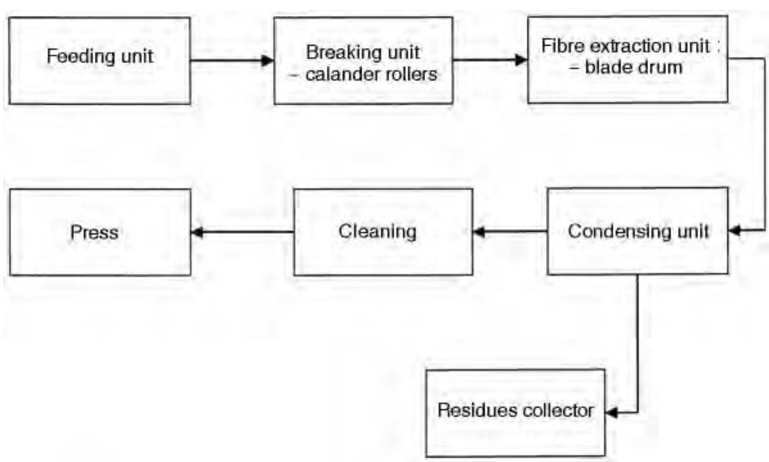

Figure 5.3 Schematic diagram of decortication line.

plate supports the stems with their long axis lying along the radial axis of the drum. The stems are fed into the drum where the high velocity blades disintegrate them, causing the fibre to separate, fan out and bend down into the restricted space between the blades and fixed plate. The blades then scrape away the epidermal, parenchymatous and woody tissues from the fibre; much of this is removed between the blades and fixed plate, but the fibre tends to travel around the drum where the licking action of the blades cleans it further.

Decorticators developed for ramie include small mobile types suitable for use in the field and larger machines designed for central operation. Use of decorticators in the field saves the cost of transporting unwanted plant material to a central decorticator and allows the plant waste to be quickly returned to the soil. Decorticators vary in complexity. The simplest and cheapest is the raspador; this consists of a covered drum on a stand.[17] Some decorticators are fitted with a conveyor system for the stems, and the most complex and most expensive are the large cross-feed machines.

5.5.4 Washing and drying

Washing of fibre from fresh stems during or immediately after decortication has been shown to remove water-soluble gums which reduces the dry weight of the fibre by 8%.[18] This reduces transport costs to the degumming site. The extracted fibrous material, after washing, should be immediately dried or degummed to prevent the development of mildew. Degumming of fresh ribbons prevents loss in fibre value caused by mildew which develops in slowly or incompletely dried fibre. Kundu[19] has shown that immediate drying is advisable since dried fibre is 10–15% stronger than undried fibre and also it is unlikely that, in the producing countries, the wet fibre could be delivered to the degumming plant before it begins to deteriorate.

5.5.5 Degumming

Raw ramie fibre produced either by hand scraping or decortication contains a fairly large percentage of gums and non-fibrous cells, or parenchyma (30–35%). These gums and cells are, for the most part, insoluble in water and must be removed before the fibre can be mechanically spun to fine count yarns. These gums are composed principally of arabans and xylans which are readily soluble in alkaline solutions. Many chemical degumming processes have been developed for ramie over the years. These all follow a similar pattern, consisting of the following basic steps:

- boiling of the fibre one or more times in an aqueous alkaline solution with or without pressure and agitation, and with or without penetrants or reducing agents

- washing with water and neutralizing
- bleaching with dilute hypochlorites or hydrogen peroxide
- washing with water and neutralizing
- oiling with a sulphonated hydrocarbon.

These steps may be carried out on the undried or dried fibre although Hoefer's[20] findings indicate the latter is preferable. Most of the processes involve a treatment with caustic soda to dissolve the residual pectins and gums. (A detailed recipe and description of a degumming process is set out in Appendix A.)

Although ramie fibres are usually degummed chemically, there have been promising developments in microbial degumming (retting). Additionally, some researchers report that the use of ultrasonic vibrations speeds up the degumming process. The undegummed fibre can be used as a jute substitute.[21] None of the methods used for the removal of the gum are entirely satisfactory because none achieve complete uniform degumming and most are covered by patents. Infrequent attempts have been made from time to time to devise microbial methods for degumming but it does not appear that micro-organisms are in common use for this purpose. The feasibility of a combination of microbial and chemical processes has also been investigated. Enzymatic treatment also seems to be promising.

5.5.6 Microbial degumming (retting)

This degumming method appears to be still at the experimental stage since no reports were found in the literature of it being used on a commercial scale. This method consists in the utilisation of several mixed bacterial cultures isolated from different sources. Each culture, containing several species of bacteria, is grown in association with others. The experiments with four of these cultures show promising results (see Table 5.4).[22] These researches indicate that attempts to separate individual organisms for isolation and identification failed, since they do not grow separately, probably owing to their dependence on the metabolic products of other organisms in the mixed culture for nutrition and growth.

Microbial degumming with mixed bacterial cultures is thus a good alternative to chemical degumming, as this process involves several treatments to obtain good-quality fibres. The mixed degumming method is simple and economical in that less alkali is required, the treatment is less drastic, and such fibre properties

Table 5.4 Bacterial cultures for degumming

Mixed-bacterial culture	Isolated from rhizosphere of
R_{IV}	Ramie (*Boehmeria nivea Gaud*)
SW1	Sunn fibre (*Crotalaria juncea Linn*)
Di and DII	Dhaincha (*Sesbania aculeata Pers*)

as softness, feel, and lustre are also much improved. The combined microbial and chemical method is also simpler and more economical. We must remember that the development of a commercial degumming process will require considerable development work since the temperature of the process and the quantities and concentration of chemicals in the liquor govern the fibre yield and strength, and also because the requirements for degumming fibre of different origins vary.

5.5.7 Chemical degumming

In the process of chemical degumming, hot alkali is used to dissolve the pectic substances which bind the ultimate fibres into bundles. Details of the degumming processes tend to be regarded as confidential information by the ramie mills concerned. According to some authors commercial degumming with sodium hydroxide, sometimes mixed with sodium carbonate is preferred on economic grounds. The main factors which affect the efficiency and economics of chemical degumming are:

- the concentration
- pH
- ratio of mass of liquor to mass of fibre
- the duration of degumming
- the freedom with which the alkaline liquor circulates through the fibre.

Degumming can be carried out both below ('low temperature') and above ('high temperature') atmospheric pressure; during the latter the yield of degummed fibre tends to be low (about 75% on washed decorticated fibre). This is because at temperatures above boiling point not only the pectic substances and adhering epidermal tissues are removed, but also hemicelluloses and sometimes some of the true cellulose.[23]

Two further aspects require consideration if chemically degummed fibre is to be suitable for spinning. Firstly, care must be taken to avoid tangling of the fibre during degumming and subsequent washing, especially if much mechanical agitation is used. Secondly, thorough washing after degumming is very important. Most of the published chemical degumming methods use water as either the sole or the final washing agent.

5.5.8 Further processing

Bleaching

After degumming process the degummed fibre, or filasse, is fairly white; if pure white fibres are required the filasse must be bleached. In the past the fibre was bleached before being made into yarn or cloth but nowadays it may be possible to bleach cloth. Bleaching results in a small loss of weight and of fibre strength[24] and it should therefore be carried out only when absolutely necessary.

Softening

Since degummed fibres may be stiff, harsh and dry, and not completely separated, they need to be softened before spinning by the application of a suitable agent, for example, glycerine, oil, fat, soap, paraffin, wax or tallow, and left for some time to condition. The fibres can be further softened and separated by passing them through a series of paired fluted rollers and then through a pair of smooth rollers; if necessary, they can be passed through these several times.[25]

5.5.9 Fibre classification

According to J. B. Pears[26] the oldest qualification criterion has been established in China. It consists of eight grades:

1. *Piao-chuang* – best quality fibre of length up to 150 cm
2. *Tsu-piao* – same length as above but less delicate
3. *Tow-chuang* (Tow-tze) – first class, length up to 135 cm
4. *Er-chuang* (Er-tze) – second class, length 120 cm
5. *San-chuang* (san-tze) – third class, fibre length 105 cm
6. *Pai-chuang* – fibre length 60 cm
7. *Tsuo chuang* – same length as above but lower quality
8. *Chiao-chuang* – fibre length 45 cm.

Since 1954 in China a new qualification criterion is in force. This is shown in Table 5.5.

5.6 Spinning

Ramie is spun both by hand and on industrial equipment

5.6.1 Hand spinning

This is done on spinning wheels. It takes a great deal of patience and experience to be able to produce a yarn of an even thickness and consequently most of the people doing this arduous work are women in their eighties.

5.6.2 Industrial spinning

This is a multi-stage process which consists of the usual three basic steps of carding, drawing, and spinning. Ramie may be combed and spun by several methods. The finest yarns are produced on the spun silk system developed by the

Table 5.5 China: new classification of ramie fibres

Grade	Fibre length in cm	Fibre colour		Fibre softness	Fibre purification after decortication	Fibre faults
		Green non-bleached fibre	White bleached fibre			
Extra	Over 150	Green or green with white shade of high gloss	White or white with light yellow shade of high gloss	Soft with high resilience	Good	Insignificant
I	Over 120	Green or green with white or yellow shade of high gloss	White or white with yellow shade of high gloss	Soft with high resilience	Good	Very small
II	Over 90	Green or green with white or tanned shade of gloss	White or white with yellow shade of gloss	Soft with medium resilience	Acceptable	Small
III	Over 60	Green or green with white or tanned shade of small gloss	Wgite or white with yellow or tanned shade of small gloss	Medium soft with lower resilience	Unacceptable	Little
IV	Over 40	Green or green with white or tanned shade of indistinctly gloss	White or white with yellow or tanned shade of indistinctly gloss	Low softness and resilience	Insufficient	Visible

Japanese, but this system is labour intensive. In Europe, Brazil and the Philippines, some modifications are made. This produces coarser count yarn but much less labour is required. Ramie may also be spun on the worsted and long draft cotton systems, but in the latter case stapled noils are used and usually blended with cotton or synthetic fibres. Since ramie fibre is relatively coarse in comparison with cotton, it is never spun into fine count yarns on the cotton system. It is apparent that the main difficulty in spinning ramie results from the combination of high tensile strength with the long fibre length; the breaker cards cannot break the fibre into staple lengths suitable for subsequent spinning. Therefore it is usually necessary to pass the fibre through a stapling machine. This breaks rather than cuts the fibre into the staple lengths required. The advantages claimed for this method of stapling include reduced fibre loss, easier spinning resulting from the more uniform length within a given staple, and smoother yarn resulting from feathered as opposed to blunt ends.

5.7 Weaving and finishing

The weaving of ramie yarn does not pose any problem and all kinds of linen and cotton looms are used for this purpose. Ramie can be top, yarn or piece dyed and its dyeing properties are similar to those of linen and cotton. Very rich in cellulose, ramie remains snow white after exposure to the sun. Textiles woven from ramie yarn show excellent wearing properties and cover a vast range, from very fine shirtings to heavy uniform suitings.

5.8 Applications of ramie

5.8.1 Strengths

Ramie is recognised in the clothing industry as a premium, high quality product.

5.8.2 Weaknesses

- Ramie fibre is subject to strong competition from cotton and synthetic fibres.
- The fibre is high cost which reduces its competitiveness against other textile fibres.
- The lack of ready supplies of satisfactory quality fibre has discouraged the industrial sector from promoting the crop.
- There is a traditionally high labour requirement for production, harvesting and decortication.
- There is a need to degum the fibre prior to processing.
- The high demand for nutrients and the consequent decline in soil fertility would require special attention to crop rotation.
- Many alternative crops can be expected to be more profitable.

Opportunities

There appears to be a small niche market for the textile fibre and improved cultivars are available from China, Argentina and India. Planting and harvesting can be mechanised and would greatly reduce labour requirements and the cost of production and processing. Improved processing procedures are available to further improve the economics of fibre production.

5.8.3 Textile applications

Blends are more common than pure ramie with the most typical being 55% ramie/45% cotton. The uneven linen-like texture is generally apparent in the blend, but the lustre is lost. Blends are readily available in woven and sweater knit form. When polyester and other man-made materials are included in the blend, wrinkle resistance is improved and help provide easy care and shrinkage control. When used in mixtures with wool, shrinkage is reported to be greatly reduced when compared with pure wool.

Advantages and disadvantages of ramie as a fabric

- Advantages: resistant to bacteria, mildew, and insect attack. Extremely absorbent. Dyes fairly easily. Increases in strength when wet. Withstands high water temperatures during laundering. Smooth lustrous appearance improves with washing. Keeps its shape and does not shrink. Can be bleached.
- Disadvantages: low in elasticity, lacks resiliency, low abrasion resistance, wrinkles easily, stiff and brittle.

5.9 Conclusion

Ramie fibre is acknowledged as a high quality fibre but its production mainly in developing countries is labour intensive and unlikely to be economic under current conditions. The need for biochemical, chemical or enzymatic treatment to extract the fibre has also been seen as a serious disadvantage. Also the fact that most of the well-equipped research centres in Europe and North America do not include ramie in their fields of interest, with the exception of Italy,[9] is another major disadvantage. However, experience with many other newly introduced crops has shown that all aspects of production and processing can now be mechanised and improved, and that could make growing this fibre competitive with production from traditional growing areas.

The potential for production of ramie and the likely demand for this high-quality fibre would appear to warrant a more detailed assessment of the opportunities. This assessment would need to establish the level and value of current imports of fibre and fabric and seek to establish likely future demand. It would also be important to identify the potential growing areas and assess the likely profitability of ramie production relative to current crops. Such assessments would need to examine the prospects and costs of mechanising all aspects of production and processing.

There is also, bearing in mind new research targets especially concerned with influences on the physiological states of the human body, an opportunity to bring to light new properties of ramie. This may help to find new applications in the apparel sector of the textile industry. Also, the growing interest in the use of natural fibres as reinforcement in composite materials may also provide a new application for ramie.

5.10 Appendices

Appendix A: Degumming, recipe and process

1. Treat the decorticated ribbons for one hour under 6 kg/square cm. pressure at 160 ºC with a liquor to dry fibre weight ratio of 6 : 1. Composition of liquor:
   - 6% sodium hydroxide
   - 3% sodium sulphite
   - 3% sodium tripolyphosphate
   - 3% organo-phosphate wetting agent.
2. Wash with water.
3. Repeat 1. above with a fresh supply of liquor.
4. Wash with water.
5. If required, bleach for one hour with hydrogen peroxide 1% at 83 ºC, pH9.
6. Rinse in a dilute solution of acetic acid in water.
7. Apply an oil emulsion such as sulphonated hydrocarbon, between 3% and 4% on dry fibre weight.
8. Remove excess emulsion (by calendering).

(Source: M. Petruszka. FAO Rome May 1977 ref w/K6485.)

Appendix B: Non-textile uses of ramie

The fibre is also used for making paper.[27] The leaves are removed from the stems, the stems are steamed and the fibres stripped off. The fibres are cooked for two hours with lye, fresh material might require longer cooking, and they are then beaten in a Hollander beater before being made into paper. Short fibres from processing wastes are used for the production of high quality papers, such as banknotes and cigarette papers. Pulping trials conducted in the USA rated ramie as among the best of the potential pulp sources.

Medicinal uses: antiphlogistic, astringent, demulcent, diuretic, febrifuge, haemostatic, resolvent, vulnerary and women's complaints. Used to prevent miscarriages and promote the drainage of pus.[28,29] The leaves are astringent and resolvent,[30,31] They are used in the treatment of fluxes and wounds. The root is antiabortifacient, cooling, demulcent, diuretic, resolvent and uterosedative.

Other uses: the ramie plant, grown mainly as a fibre crop, is also a source of nutritious green feed. The leaves and tops, unlike the stems, have low fibre content and are rich in protein, minerals, lysine and carotene. The nutritive value of ramie has been described as similar to that of lucerne, which it can, however, greatly outyield. When ramie is grown for fodder up to fourteen cuttings a year can be taken from established crops, yielding as much as 300 t of fresh material (42 t dry matter) per hectare per year.

The foliage is palatable and has proved to be of value not only to stock but also to pigs and poultry. Ramie can be grazed, used for silage, ensiled together with molasses or artificially dried for leaf meal. Ramie is palatable to all classes of domestic livestock and is an excellent feed for cattle. As long as satisfactory mineral levels are achieved, ramie can be fed to pigs of all ages and acceptable production obtained. Ramie meal has proved valuable to poultry as a source of carotenoids and riboflavin. The only problem associated with feeding ramie is its high mineral uptake, especially molybdenum on soils rich in this element; this can be corrected by adding appropriate levels of copper sulphate to the diet. When root-peeled and boiled it has a pleasant and sweet taste.[32] One can detect very little flavour, but the root has a very strange mucilaginous texture that does not appeal to most people who have tried it.[33] Once in the mouth it takes a lot of chewing before it is ready to be swallowed. Ramie takes up phosphorus, so it is potentially useful for use in cleaning up the Everglades, as this region suffers from a nutrient overload from the sugar industry.

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5.13 Glossary of terms

Boehmeria nivea Latin name for ramie. *See* China-grass.

China-grass White ramie – *Boehmeria nivea*, of Chinese origin as opposed to ramie, or green ramie – *Boehmeria nivea, var tenaccissima*, of Malay origin.

Crocking Dye rubbing off a fabric, usually due to inadequate dyeing.

Decortification Removing non-fibrous material from retted stalks or from ribbons or strips of bast or leaf fibres.

Green ramie *See* China-grass.

Noil The shorter fibres separated from the longer fibres in combing during the preparatory process before spinning.

Ribbonning Separating the outer bark/epidermis from the rest of the stalk.

Stripping Removing strips of bast fibres from the stalks of the plants.

White ramie *See China-grass.*

6
Sisal

C YU

6.1 Introduction: the plant and its anatomy

Sisal (*Agave sisalana*) is a monocotyledon, one of the 300 species of the *Agave* genus, which is one of the 21 genera of the *Agavacea* family. They are all tropical or sub-tropical plants, originally from Central and South America. At present sisal and several other species are cultivated for their fibres in about 24 countries in Central and South America, East Africa, Madagascar and Asia (see Table 6.10 on page 241). Agaves are large plants which have a central bole from which the leaves grow; these are dark green, pointed, straight and can reach a length of 3 m and a width of 15 cm. They have a spine at their end; many species also have spines on the edges of their leaves. The cross-section of the leaf resembles a flattened triangle whose apex is on the underside of the leaf.

Apart from sisal, which is grown in South China, East Africa, the Indian sub-continent and South-East Asia, the two other important cultivated species are henequen (*A. fourcroydes*), which is mostly grown in Mexico; maguey, also called cantala, (*A. cantala* and *A. americana*), grown in the Philippines, Indonesia and India. *A. letonae* is also cultivated commercially in El Salvador[1,2] but its production is small. In the FAO statistics it is grouped with 'Agave fibres not elsewhere specified', (in other words, not sisal or henequen) and its production is probably of the order of 2,000 to 3,000 tonnes. Two other species, *A. lecheguilla* and *A. funkiana* produce fibres that are used only to make brushes and therefore not being strictly textile fibres, are not covered in this book.[1]

Agaves flower only once, towards the end of their lives. The top of the bole grows into a long 'pole' which has branches bearing clusters of white or pale green flowers. Despite these flowers the plants' principal means of propagation is by 'bulbils' that develop in the axil of the flower pole. These grow into small plants whilst still on the parent plant, drop off onto the ground and if conditions permit, take root and develop into new plants. In commercial plantations the bulbils are generally removed to nurseries before being planted out.[1] Although, as stated above, reproduction is generally through bulbils, some viable seeds are produced and this permits the development of hybrids.[1]

Figure 6.1 Sisal plants in the field. Courtesy of Chuck Bargeron, www.invasive.org.

Sisal is a xerophytic plant that can grow in the poor soil and sloping terrains which do not suit other plants. The field management of the plant is easy and the harvest period is not fixed, which means that the farmers can cut the leaves at their convenience, bearing in mind that the interval between cuttings should be approximately one year. Although the supply of hard fibres that is required to meet world demand is obtained from several kinds of plant, including, for example, abaca and coir, by far the most important is sisal with its annual production of around 300,000 tonnes.

As with other bast and leaf fibres agave fibres occur in bundles which run the length of the leaves. In the bundles on the sides of the leaves away from the boles there are usually small or intermediate sized bundles arranged in two rows, with a few larger bundles placed near these rows. The fibre bundles on the other sides of the leaves nearer the bole form a single irregular row which sometimes breaks into two rows.[3]

6.2 Chemical and physical fibre structure

6.2.1 Structure of the sisal fibres

Sisal fibres used for textile processing are multi-cell fibres, the fibre bundles containing about 100–200 single cells which are bonded together by natural gums. Figure 6.2(a) and (b) are scan electronic microscope (SEM) photos of the longitudinal appearance of the fibre bundles (Fig. 6.2(a)) and as can be seen, the fibre is straight, without crimp. There are many knots and stripes on the surface of the fibre, this shows that the fibre bundle is composed of many single cells

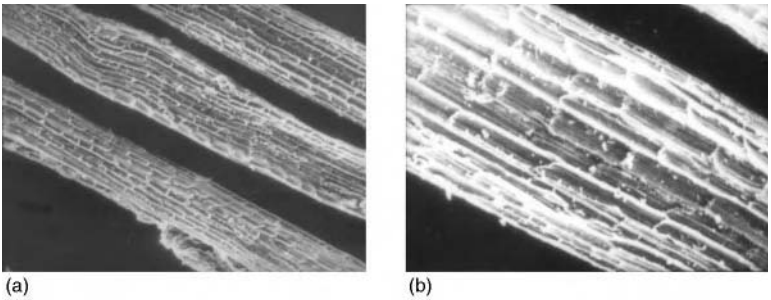

Figure 6.2 (a) and (b) longitudinal appearances of sisal fibre bundle.

Table 6.1 The microstructure data of sisal fibre[4]

Crystallinity (%)	Orientation f_x	Orientation α	Birefringens $n_{\parallel}$	Birefringens $n_{\perp}$	Birefringens $\Delta n = n_{\parallel} - n_{\perp}$
55–65	0.862	24.8	1.5980	1.5297	0.9620

* f_x: Hermans' orientation factor; α: mean orientation angle

which are arranged in straight parallel lines. Figure 6.2(b) shows a cross-section of fibre bundles. This consists of many single cells with thick walls with a central lumen. The shape of the single cell is polygonic.

As sisal fibres contain considerable amounts of non-cellulosic materials, such as pectins, hemi-cellulose and water soluble materials, and because these are not present in an ordered structure the crystallinity of the fibre is not high (Table

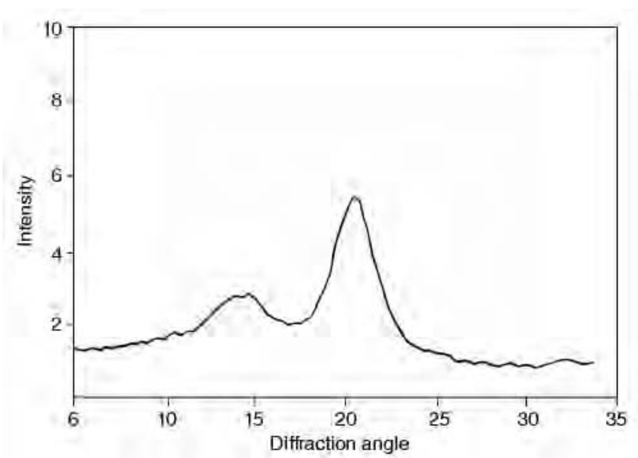

Figure 6.3 X-ray of sisal fibre.

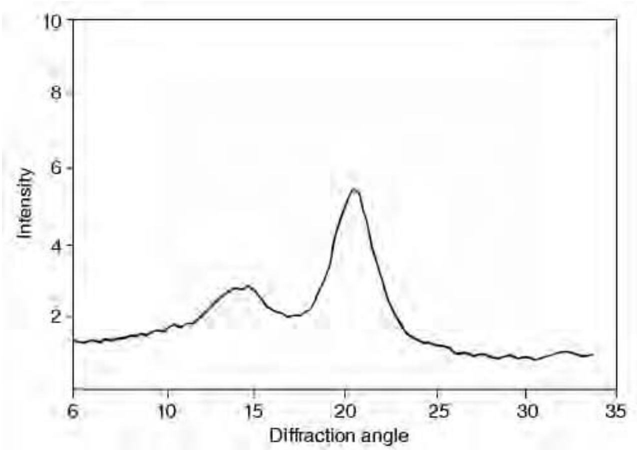

Figure 6.4 Infra-red spectrum of sisal fibre.

6.1). X-ray and infra-red spectrums of the sisal fibre are shown in Fig. 6.3 and Fig. 6.4, respectively. The degree of polymerisation is around 4500 (measured by the nitration method), greater than that of ramie, jute and kenaf.

6.2.2 Chemical constitution of the fibre

As mentioned above, sisal fibre is extracted from the leaf of the plant. It is an attribute of leaf fibres that they are harder than fibres extracted from the bast of plants, such as ramie, flax and hemp. In addition to cellulose there are many other components of sisal fibres as is shown in Table 6.2.

Compared to jute, kenaf and pineapple fibre, the cellulose content in sisal fibre is similar but the lignin content is a little higher. Based on the composition of the fibre it can be deduced that the sisal fibre is harder (has greater rigidity and lower flexibility) and coarser than other bast and leaf fibres because of the high lignin and pectin content.

Table 6.2 The components of sisal fibre (% by weight)

Cellulose	55–65
Hemi-cellulose	10–15
Pectin	2–4
Lignin	10–20
Water soluble materials	1–4
Fat and wax	0.15–0.3
Ash	0.7–1.5

6.2.3 Physical properties

The properties of single cells

According to the test results on the length and width of the hybrid *H11648*, which is the dominant sisal variety in China and which originated from East Africa, the size of the single cell is shown in Table 6.3, and the distribution of diameter and length are shown in Figs 6.5 and 6.6, respectively.

Table 6.3 Dimensions of single cells of sisal ultimate fibres (Hybrid 11648)

	Mean value	Maximum value	Minimum value	Average range	Coefficient variation (%)	Ratio of length to diameter
Length (mm)	2.282	4.75	0.995	1.46–2.785	25.08	
Width (μm)	20.32	31.6	8.0	15.6–22.8	25.81	113
Thickness of cell wall (μm)	4.6	8.4	2.4	4.0–5.6	–	

Adapted from: G. Guang, L. Haimin and Y. Zhili (1992), 'A fundamental study on sisal fibre', *Journal of South China University of Technology (Natural Science Edition)*, Vol. 20, No. 3.

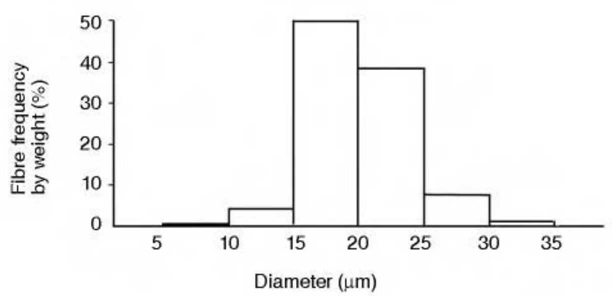

Figure 6.5 The distribution of width of single cells.

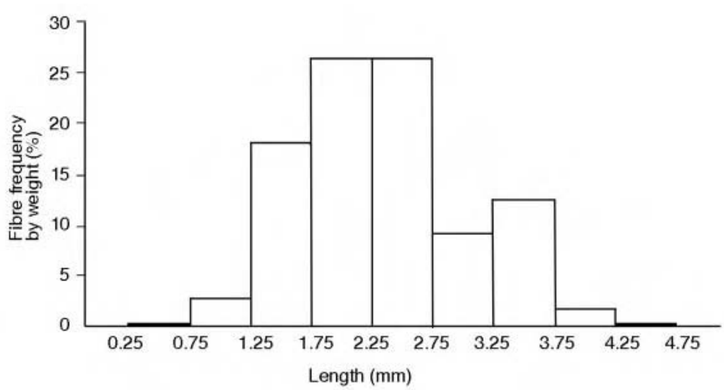

Figure 6.6 The distribution of length of single cells.

Table 6.4 Dimensions of single cells of other agave fibres

Name	Length (mm)	Diameter (μm)	Thickness of wall (μm)
Agave fourcroydes	2.88 ± 0.3	22.6 ± 1.8	7.7 ± 0.3
Agave americana	1.71 ± 0.1	28.7 ± 1.4	4.7 ± 0.3
Agave chrysantha	0.84 ± 0.1	25.7 ± 1.4	6.0 ± 0.4
Agave deserti	1.00 ± 0.1	28.0 ± 0.5	4.2 ± 0.2
Agave funkiana	0.97 ± 0.1	30.3 ± 1.1	9.0 ± 0.3
Agave lecheguilla	0.92 ± 0.1	27.0 ± 1.9	5.7 ± 0.5
Agave murpheyi	1.29 ± 0.1	21.5 ± 0.9	3.9 ± 0.3
Agave palmeri	1.22 ± 0.1	27.9 ± 0.7	4.1 ± 0.3

Source: Z. Wenrong, 'Prospecting sisal in China, based on the status of sisal products in the world', *Information on Tropical Crops in the World* 1996 (6).

Compared to other fibres, such as jute, reed, and sugar cane, the single cell of sisal fibre is longer and thinner than those of reed and sugar cane, which are usually used in papermaking. Sisal fibre would therefore be expected to provide better quality pulp for paper. But the single cell of sisal fibre is shorter and thicker than that of jute, and therefore, its textile processing abilities such as its spinability would be expected to be inferior to that of jute. Compared to other leaf fibres, such as pineapple, sisal fibres are much harder and coarser. The properties of fibres will vary between specimens. Some of the physical characteristics of other species of the *agave* genus are listed in Table 6.4.

The properties of fibre bundles

Sisal single cell fibres are too short to be suitable for spinning under normal textile yarn spinning conditions, the minimal practical length being 25 to 30 mm. As with most other bast and leaf fibres, single cell fibres cemented together by the naturally occurring gums are the raw material for textile processing. The length of the fibre bundles will depend of the length of the fresh leaves and on the conditions under which they are processed. Under good fibre extraction conditions the length of fibre bundles can be almost the same as the length of the leaves. The length of fresh leaves will, of course, vary with the species, cultivation and climate.

According to the test results of length shown in Fig. 6.7, it can be seen that the main lengths of sisal fibre bundles are in the 50–120 mm, range, which

Table 6.5 Dimensions of sisal fibre bundles[4]

	Length (mm)	Fineness (tex)	Moisture regain (%)	Density (g/m^3)
Mean	90.84	15–20	10.57	1.30
CV%	22.1	2.23	–	–

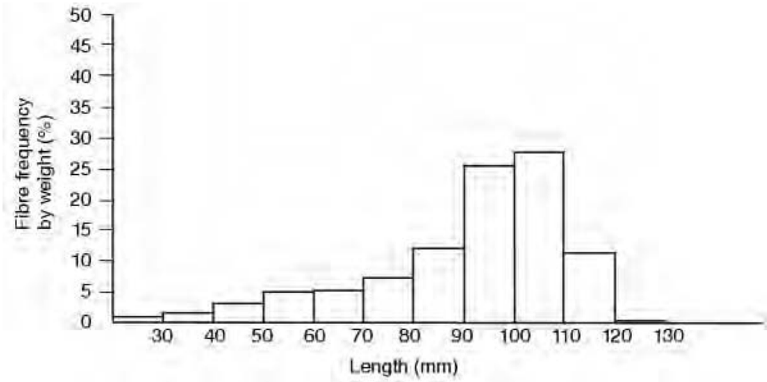

Figure 6.7 Distribution of length of fibre bundles.

account for more than 90% of total fibre weight. Over 50% of the fibre lengths are in the range of 90–110 mm.

The mechanical properties of sisal fibre bundles

Tensile properties

Because of the higher content of lignin in the fibre bundles, sisal fibre bundles are more rigid and have greater tenacity than other bast and leaf fibres. Compared to the jute and pineapple fibres, sisal fibre has the highest tension rigidity (modulus) and equivalent elongation (for method of testing see Appendix B).

Table 6.6 Tensile properties of sisal fibre[5]

	Tenacity (cN/tex)	Elongation (%)	Modulus (cN/tex)	Rupture work ($\times 10^2$ J)
Mean	57.2	3.02	1830.12	2.80
CV%	23.38	11.29	29.08	22.89

The compression properties of sisal fibre bundles

Compression property tests show that sisal fibres have the highest stiffness (measured by the twist method – Appendix B) and therefore the lowest compressibility when compared to other fibres. This is 30% lower than that of jute and 50–60% lower than that of acrylics and wool. Sisal's recovery from compression is lower than that of jute by about 15%, and is only about one-third that of acrylic and wool fibres.

Table 6.7 Compression properties of sisal fibre[5]

Compression (%)	Recovery from compression (%)	Compression work ($\times 10^2$ J)	Recovery work from compression ($\times 10^2$ J)
9.578	37.5	1.59	0.117

6.3 Chemical treatment of sisal fibre

6.3.1 Treatment with sodium hydroxide

Considerable research work has been carried out on the chemical treatment of sisal fibres to see how these can be modified in order to improve or change their properties. Most of these trials involve the use of sodium hydroxide. Although sodium hydroxide does not affect the cellulose component of the fibre it does dissolve and remove some of the non-cellulosic materials such as hemi-cellulose, pectins and water soluble substances. This 'purifies' the fibres and improves their performance. Of course this degumming needs to be carefully controlled as complete removal would reduce the fibres bundles to single cells which, as stated above, could not be processed on textile machinery.

Treatment with higher concentrations of sodium hydroxide will cause the fibres to swell and, to some extent, modify the crystallinity and orientation of the fibre components. The main objective of these treatments is to decrease the amount of lignin and gums in the fibres and modify or improve some of their characteristics and in particular improve their flexibility, fineness and elongation at break. This would improve the spinnability of the fibre and enable the production of finer and higher quality products than would be possible with untreated fibre. Certainly, the concentration and temperature of sodium hydroxide solution, the material-to-liquor ratio (M:L), the time of treatment and the use of some other agents will have obvious effects on the properties of the treated sisal fibre, as shown in Figs 6.8 and 6.9.

From the results shown in the figures, it is clear that treatment with sodium hydroxide will cause changes in the composition and on the tensile and compression properties of the fibres. In the case of low-concentration sodium hydroxide solutions, the fibre bundle is degummed, and would be expected to be finer and shorter. The higher the concentration of sodium hydroxide and the longer the time of degumming, the greater the loss of fibre tenacity. Higher concentrations of sodium hydroxide (of 200 g/l or more) also modify the microstructure of the fibre. When degumming with sodium hydroxide it is therefore necessary to find the required balance between the advantages of greater spinnability and the disadvantage of lower fibre tenacity.

[*Editor's note.* The sodium hydroxide treatment of sisal fibres also improves their properties for use in polyester/sisal composite materials by increasing

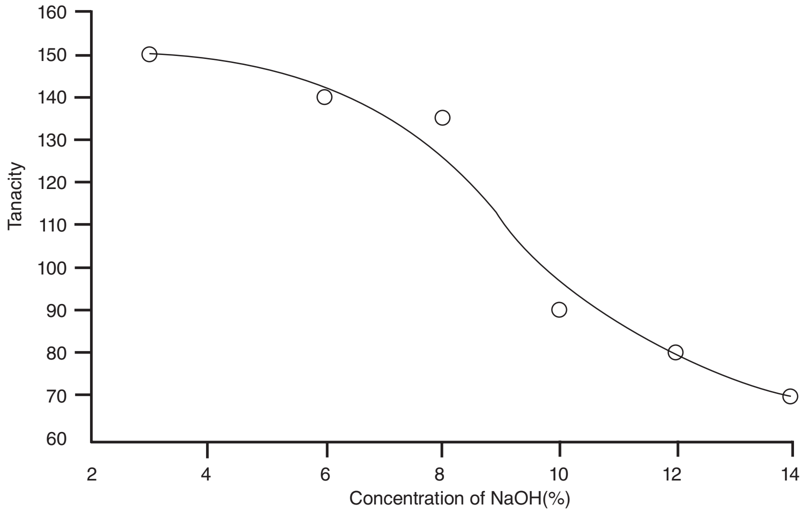

Figure 6.8 The influence of concentration of NaOH on tenacity.

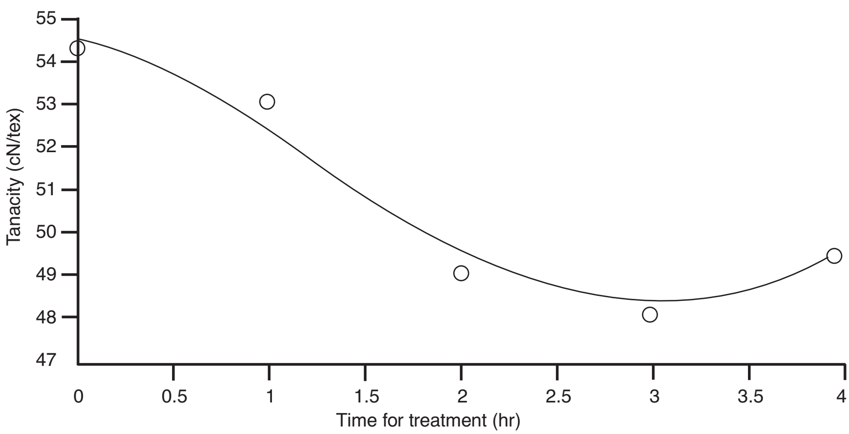

Figure 6.9 The influence of treatment time of NaOH on tenacity.

tenacity and debonding strength, and improving fibre dispersion in the polyester matrix.[6]

6.3.2 Sisal's resistance to temperature and certain chemicals[7]

In general sisal's resistance to temperature and chemicals is better than that of many other natural fibres. Resistance to temperature is shown in Fig. 6.10. Sisal fibre's tenacity decreases as temperatures increase.

Table 6.8 The influence of NaOH on the properties of sisal fibre (M:L = 1:20)[4]

	Raw sisal fibre (untreated)	NaOH: 100 g/l, 10 min. room temp.	NaOH: 180 g/l, 10 min. room temp.	NaOH: 180 g/l, 10 min. 80 °C	NaOH: 250 g/l, 240 min. 80 °C
Constitute					
Cellulose	55.86	61.29	67.01	69.71	79.47
Hemi-cellulose	14.38	10.27	8.20	6.20	5.20
Lignin	21.16	18.72	14.28	13.57	10.60
Pectin	3.02	4.03	4.63	3.67	2.78
Microstructure					
Crystallinity (%)	0.614	0.586	–	0.566	0.556
Orientation factor	0.883	0.871	–	0.862	0.849
Tensile properties					
Tenacity (cN/tex)	0.572	0.261	0.280	0.214	0.231
CV (%)	23.38	21.74	23.37	22.17	21.48
Elongation (%)	3.02	3.24	5.98	4.84	7.08
Modulus (cN/tex)	1830.17	763.06	466.53	432.53	303.39
Work ($\times 10^2$ J)	2.80	1.25	2.53	1.11	2.25
Compression properties					
Compression (%)	71.2	70.4	73.3	74.8	73.1
Recovery (%)	9.58	10.54	9.07	9.86	10.26
Compression work ($\times 10^2$ J)	1.59	1.56	1.26	0.96	0.92
Recovery work ($\times 10^2$ J)	0.117	0.112	0.116	0.10	0.09

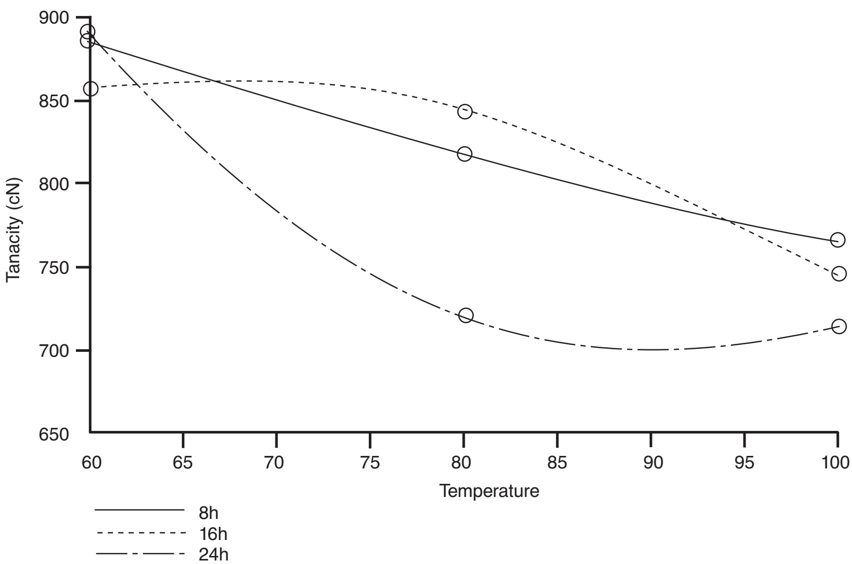

Figure 6.10 Resistance to temperatures (°C).

Resistance to salt

To evaluate sisal fibre's resistance to salt, the fibres are immersed in a solution of sodium chloride for 20 days at various concentrations and temperatures (with M:L=1:20). The results are shown in Fig. 6.11.

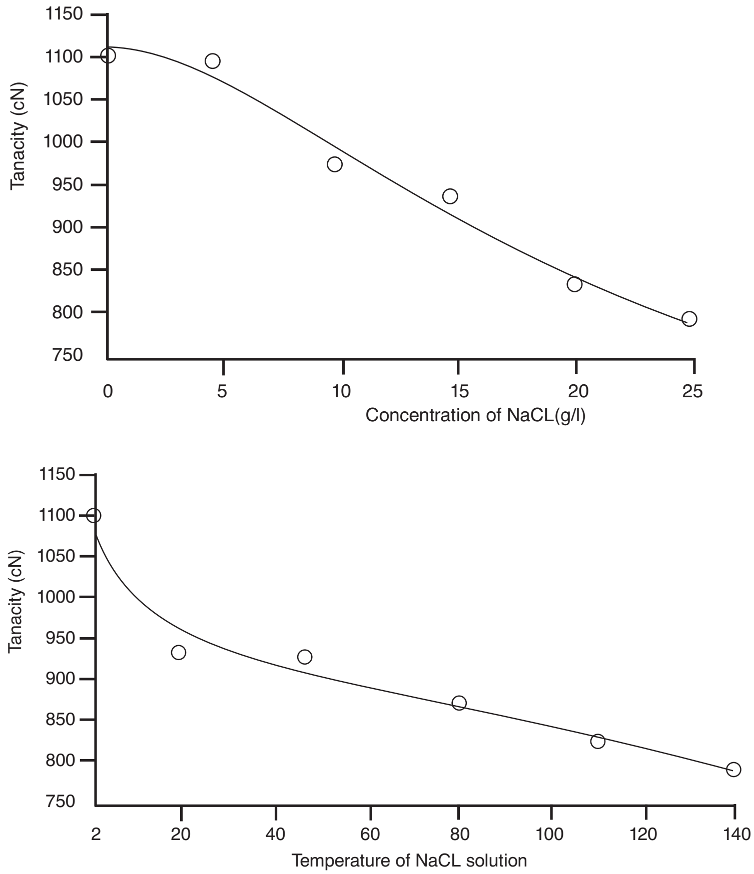

Figure 6.11 Resistance to salt (a) concentration (b) temperature.

Resistance to sulphuric acid

To evaluate the resistance of sisal fibre to acid the fibres are immersed in sulphuric acid solution at a temperature of 20 ºC with a M:L=1:50. The results are shown in Fig. 6.12. Obviously, like other vegetable fibres, sisal fibre will also decompose in acid solutions.

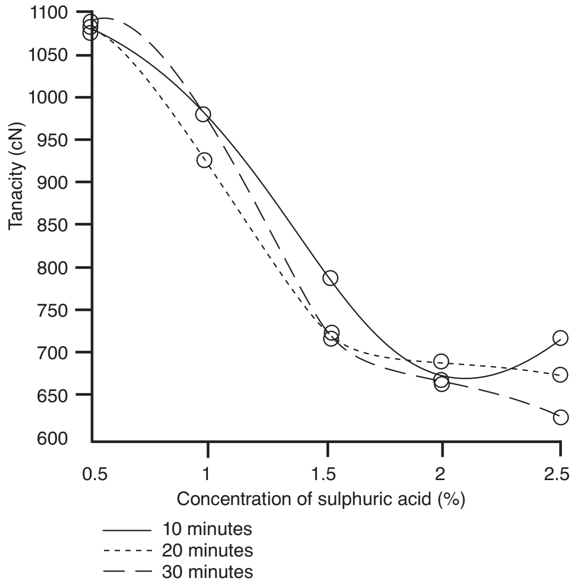

Figure 6.12 Resistance to sulphuric acid.

Resistance to water

The fibres are immersed in fresh and seawater, respectively, for several days, and the tenacity of the immersed fibre in each solution is measured. The results are shown Table 6.9. The table shows that the resistance of sisal fibre to seawater is higher than that to fresh water. It is considered that this is because when immersed in water, micro-organisms breed on the fibres and preferentially attack the gums which bind the single cell fibres to each other. Inter-fibre cohesion is therefore reduced with the consequential decrease in the tenacity of the fibre bundles. In seawater however, the salt retards the growth of the micro-organisms and therefore delays the decrease in fibre tenacity.

Table 6.9 The strength* (N/g) of sisal fibre immersed in water

	Immersed in sea water	Immersed in fresh water
Un-immersed	793.8	793.8
After 10 days	788.5	754.1
After 41 days	785.6	706.1
After 74 days	689.8	620.8
After 247 days	595.6	409.9

* The fibre bundle tested for the strength is 1 g, length of 300 mm and gripped length of 200 mm.

6.4 Production and early processing

6.4.1 Production

Agave sisalana is a xerophytic plant and can therefore grow in dry climates but it will not grow well in poorly drained soil. On the other hand, it is in the wet season that the plant produces new leaves so it does need a certain rainfall if it is to be cultivated. *Agave sisalana* can also grow in poor soil, the rate of growth of the plant and its life span are changed by the climatic conditions, cultivation and species. For example, in Kenya, particularly at high altitudes of up to 1,500 metres, sisal grows more slowly and has a shorter life than in its native environment where a plant might live for 20 years. In addition, higher annual production will also shorten the life of the plant. In China, because of higher production of up to almost 4,500 kg per hectare, which is almost two to three times that of the average world production yield, the life of sisal plants is usually only 15 to 18 years.

Sisal is usually harvested once a year but if soil and climate permit it can be harvested three times in two years. The leaves grow in circles around the bole of the plant and farmers harvest four or five circles at each harvest. Each circle consists of about 13 leaves, the total crop from each harvest is therefore from 52 to 65 leaves. The time of harvesting is not critical and this therefore allows

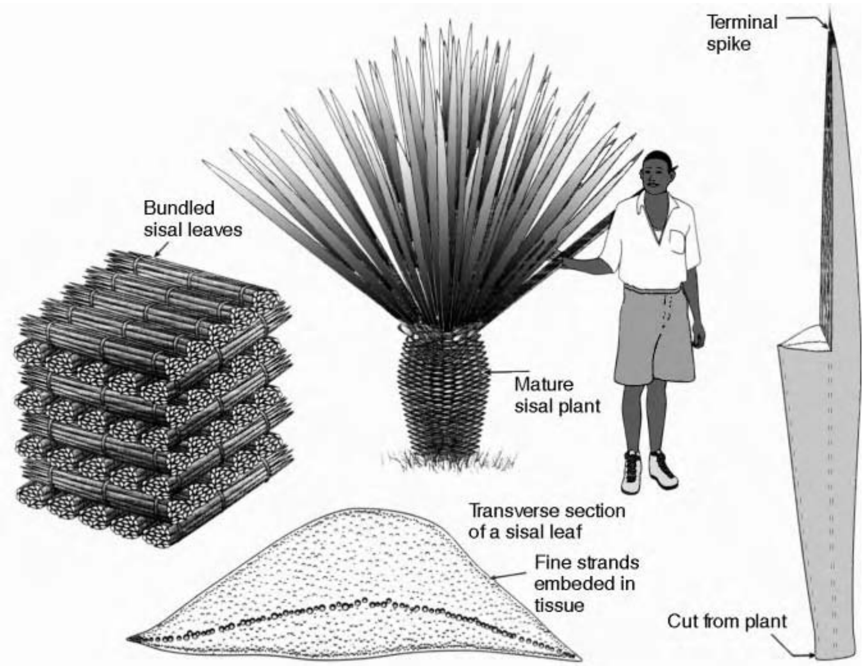

Figure 6.13 Harvesting sisal leaves. Source: C. Jarman, *Plant fibre and processing: A handbook*. Courtesy: ITDG Publishing, UK.

farmers considerable flexibility in fitting this in with their other activities. The length of sisal plant leaf is usually 1.5–2 m, the longest reaches up to 3 m. The weight of each leaf is in the range of 0.5–1.5 kg, and the ratio (by weight) of fibre extracted from the fresh leaf is 4%–7%.

Fibre yield per hectare will depend on the number of plants per hectare. The total annual production of sisal fibre varies, depending on demand, climatic conditions and cultivation. Productivity has been raised from 0.7 tonne/ha in the

Table 6.10 Average annual production (1,000 tonnes) areas (1,000 ha) of sisal fibre

(a) Main producing countries 1948–1997

	1948–1952	1961–1965	1974–1976	1989–1991	1995	1996	1997
Brazil							
Area	67	255.6	290	273	153	153	153
Production	43.6	176.7	257	213	118	133	132
Tanzania							
Area	211	220	161	59	53	53	53
Production	136.8	219.3	130	34	30	32	30
Kenya							
Area	93	121	47	34	26	26	26
Production	37.6	65.1	55	39	28	28	29
Mexico							
Area	141	1864	187	55	55	56	56
Production	110	171	165	34	37	37	37
Madagascar							
Area	13	24.2	25	20	14	14	14
Production	6	25.5	29	18	13	10	10
Haiti							
Area	31	48.8	23	18	13	10	10
Production	28.3	26.3	12	10	7	6	6
China							
Area	3	8	8	14	15	15	15
Production	1.5	9.8	10	26	42	42	42

(b) World production 1999–2003 (m tonnes)

1999	2000	2001	2002	2003
353,891	413,050	305,177	287,142	295,425

Source: C. Donghong (1999), 'History review and looking ahead on the production of sisal worldwide and China', *Fujian Science and Technology of Tropical Crops*, Vol. 24, No. 1 and FAO.

1950s to approximately 1 tonne/ha by the end of the last century. In recent years annual production in the world has been about 200,000–300,000 tonnes. The main producers are Brazil, Tanzania, Mexico, Kenya, Madagascar, Haiti and the tropical provinces of China (Guandong, Guangxi, Hainan, Yunan, Fujian and Guizhou). Table 6.10(a) shows the production and areas cultivated in the main producer countries in recent years and (b) shows world production 1999–2003.

6.4.2 Early processing

The purpose of the early processing of sisal is to extract the fibres from the fresh leaves. Once the fresh leaves are harvested from the plants the workers cut 10 mm in length from the tip of the leaf, to avoid any injury from the hard sharp tip. This tip contains only a small amount of hard fibres and therefore poor quality fibres. The order of the work of fibre extraction is as follows: fresh leaves without tip – decorticating – washing (with water) – binding – cleaning – drying – cleaning. This produces the principal product, long fibre. The process also produces by-products; short fibre, 'dregs' and liquid waste. After decorticating the long fibres are removed by the operator and dried. The short fibres are further processed to produce 'kinked' fibre which is used for non-wovens, moulded composites and various other purposes.

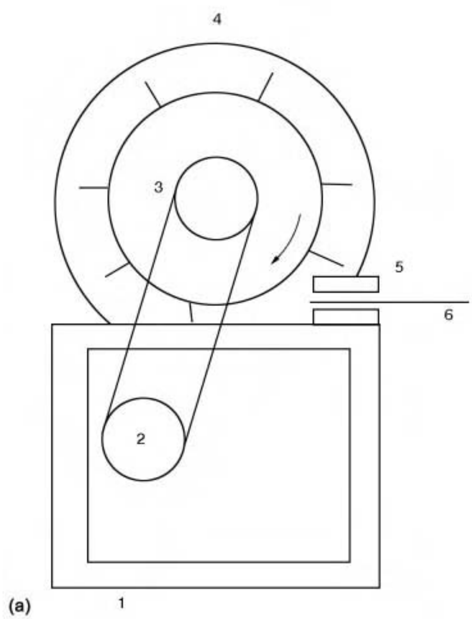

Figure 6.14 Decorticating machines for sisal fibre (a) sisal fibre decorticator (b) sisal raspador (c) crane decorticator. Source: C. Jarman, *Plant fibre and processing: A handbook*. Courtesy: ITDG Publishing, UK.

Whilst decorticating is taking place water is sprayed over the leaves and fibres being processed. This washes away the broken fibres and pulp (called dregs) which are used as natural fertilisers or animal fodder and the liquid as a source of saponin from which certain hormones, such as hecogenin and tigoenin can be extracted. These are important raw materials for the production of cortisone and prophylactic medical products.

The decorticating machines used for extracting the fibres from fresh leaves are shown in Fig. 6.14. The longer machine (a) can decorticate sisal fibre

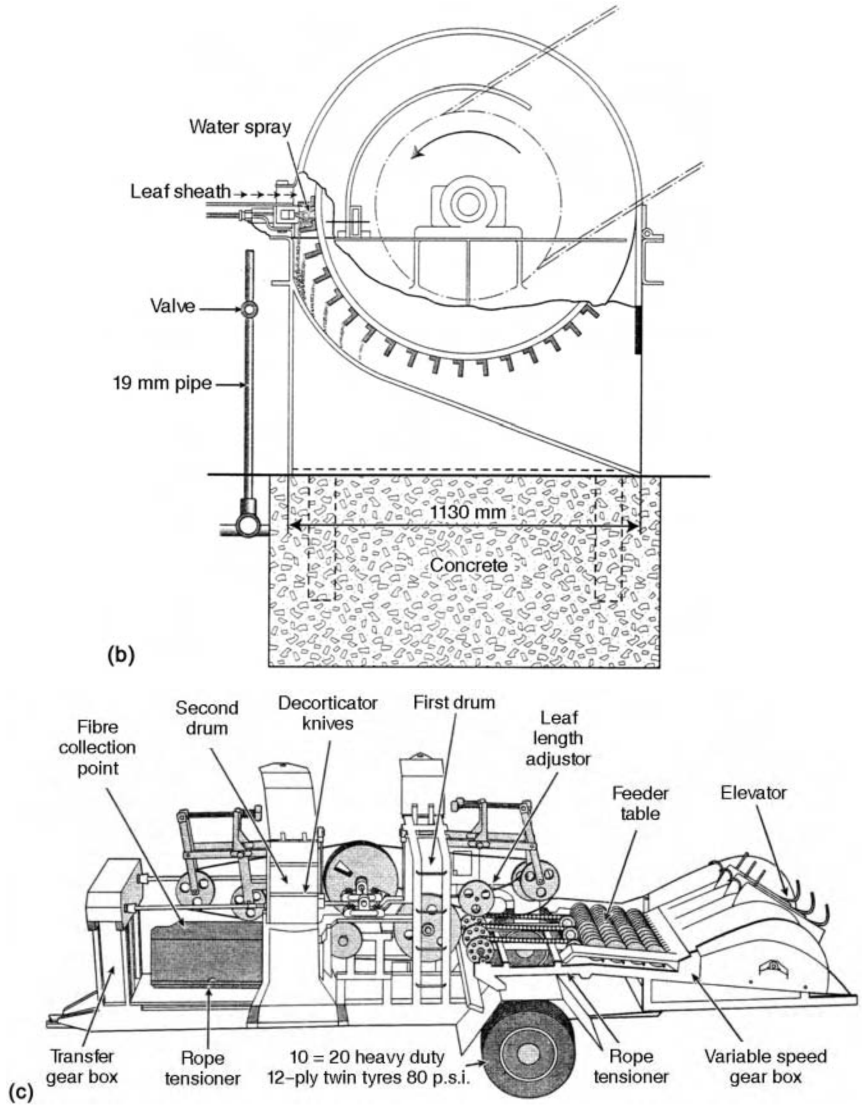

Figure 6.14 contd.

Table 6.11 Quality standards of sisal long fibre

	Excellent	First grade	Qualified grade
Length (cm)	≥ 95	≥ 85	≥ 70
Bundle strength* (N/g)	≥ 880	≥ 830	≥ 780
Trash content (%)	≤ 2.5	≤ 3.5	≤ 5.0
Colour	White or milky white with lustre	White	Yellow or yellowish-brown
Spot	Nil	Very few	Very few

* See Table 6.9.

automatically at a processing rate of 200 tonnes of fresh leaves per shift. This machine needs 8–10 workers to use it. The smaller decorticating machine (c) can be moved from place to place if necessary, and has a higher extraction rate than the longer machine. About five operators are needed to run this decorticator which processes ten tonnes of fresh leaves per shift.

Figure 6.14(a) shows the way in which decorticators work. The roller with blades (3) is mounted on the base frame (1), covered by the hood (4) and is driven by the motor (2). The fresh leaves (6) are hand fed into the machine by the operator through the clippers (5), beaten by the rotating blade roller, the dregs and liquid from the leaves are decorticated away and the remaining fibre is removed from the machine by the operator. To summarise: The product of early processing is long fibre with good lustre, and waste – kinked fibres. Quality standards for long fibre include appearance and physical properties and are set out in Table 6.11.

6.5 Production and machinery

Sisal fibres extracted from fresh leaves are transported to mills to be converted into yarns, twines, ropes and fabrics, and then can be further processed into end-products according to requirements.

6.5.1 Yarn production

The procedure for yarn production is generally oiling and ageing, drafting and doubling, spinning.

Oiling and ageing

The objectives of oiling are to improve the performance of downstream processing and the resulting products. For example, to make the fibres softer, stronger, smoother, with better anti-static properties and higher resistance to abrasion and other kinds of wear. The most effective oil for sisal is a special oil refined from petroleum. In some cases, other mineral oils are used as substitutes. The fibre can be oiled both before drawing and doubling (manually) or at the delivery of the first draw frame (automatically, by the machine). The latter is used only in special cases for high quality fibres. After being oiled the fibres need to be aged for several days to allow the oil to penetrate the fibres. The results of the effects of oiling and ageing on sisal fibre can be seen from Figs 6.15–6.18.

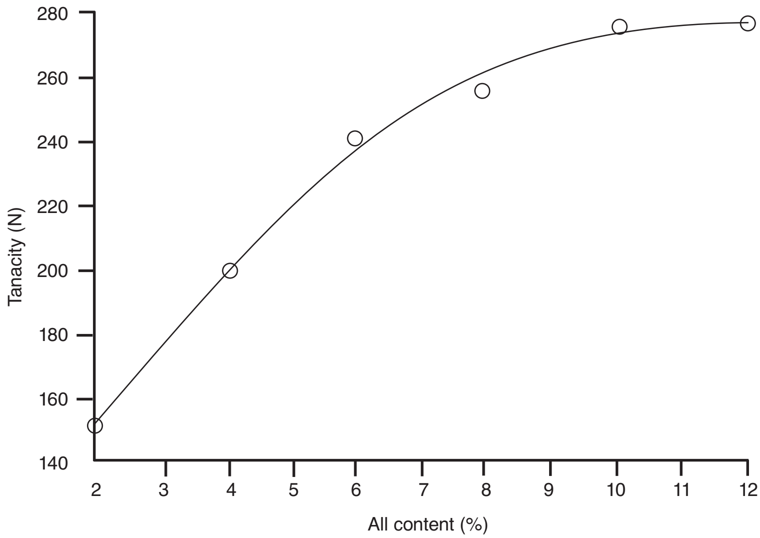

Figure 6.15 Yarn tenacity (N) vs oil content (%).

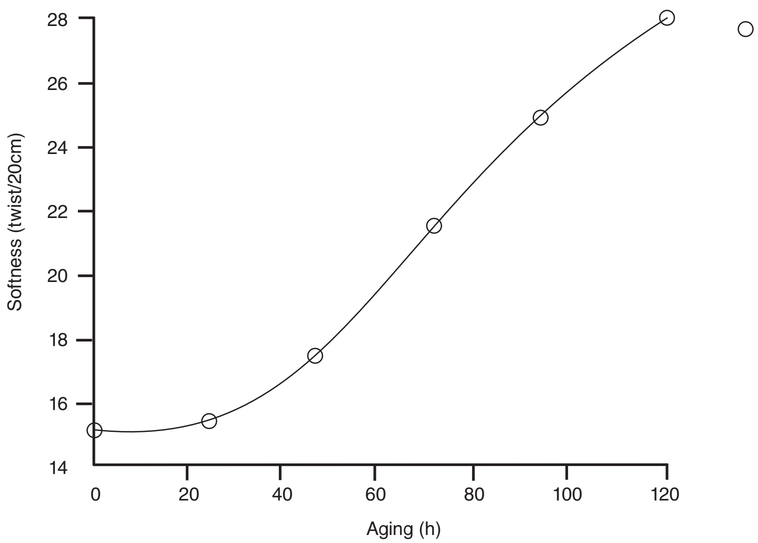

Figure 6.16 Softness (torsion-ability) of fibre vs ageing time (days).

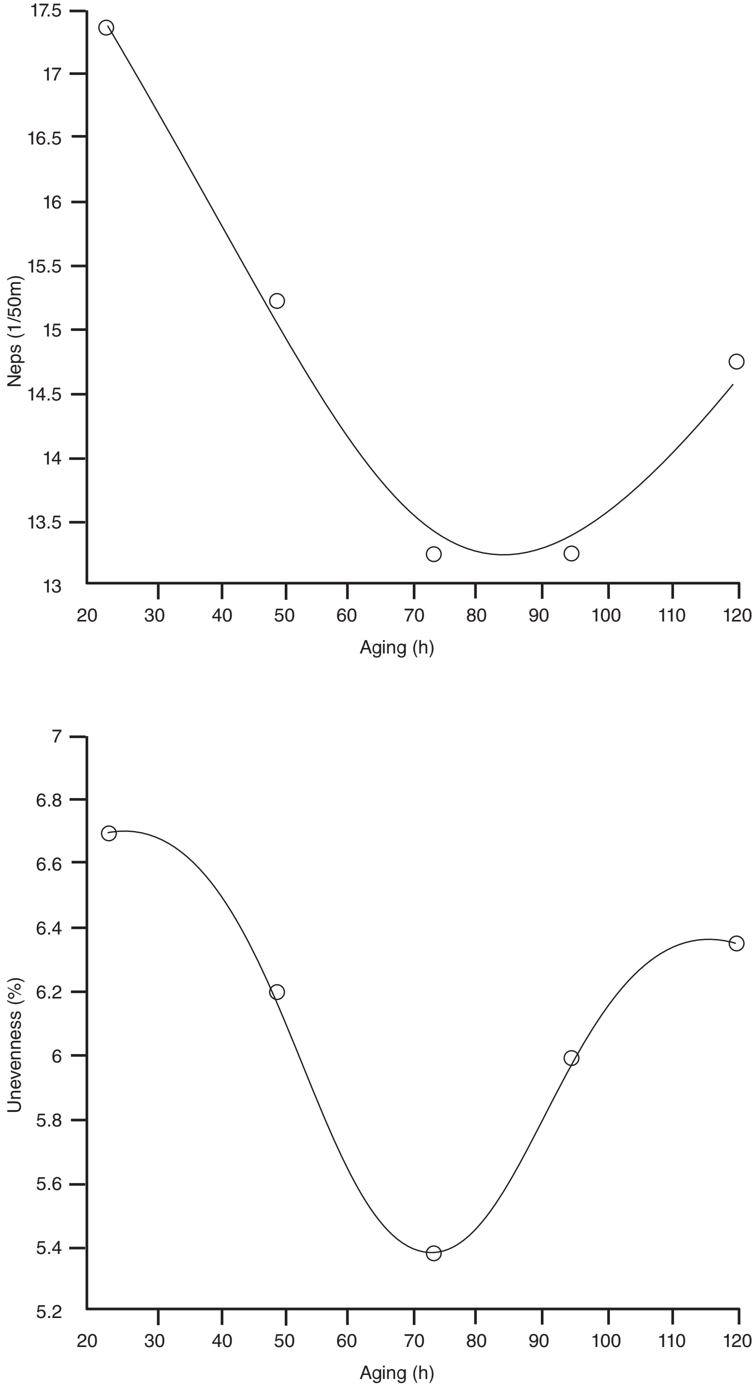

Figure 6.17 Yarn quality of sisal vs ageing time (a) and (b).

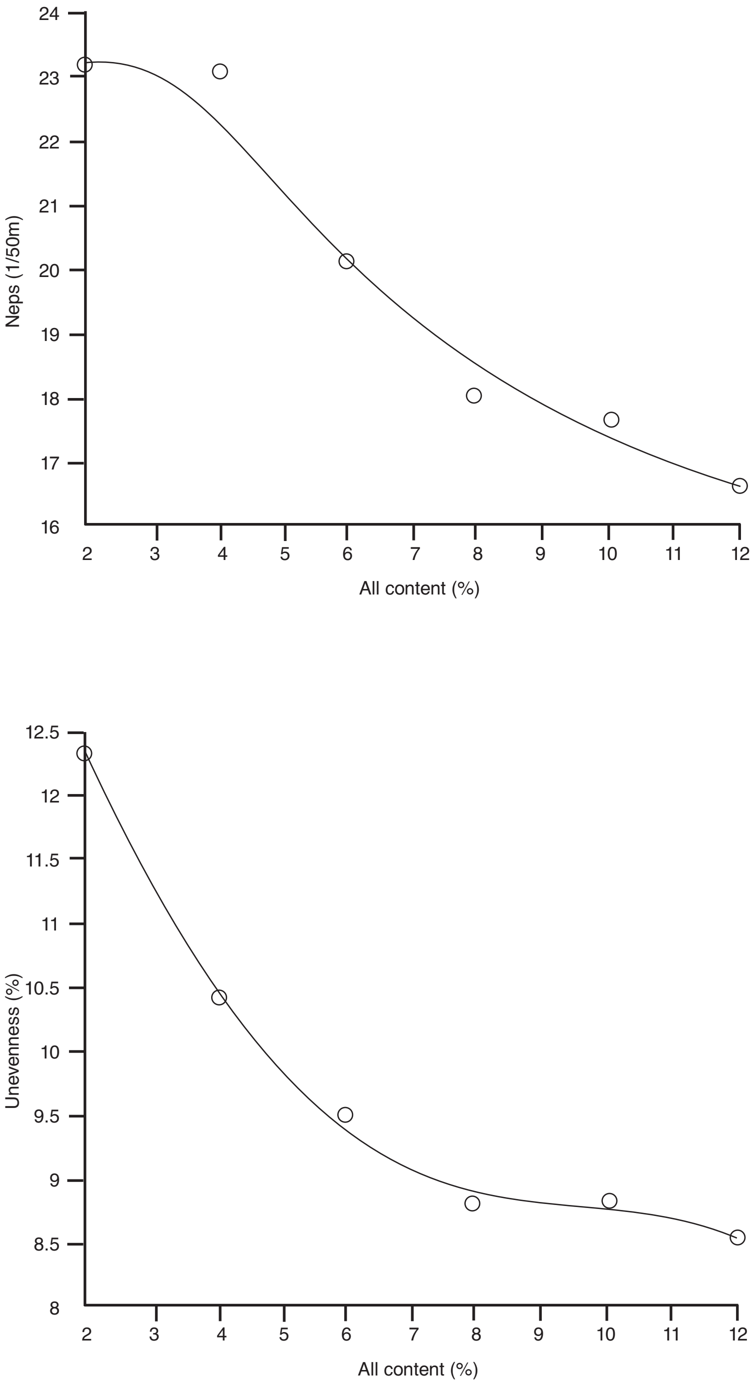

Figure 6.18 Yarn quality of sisal vs oil content (a) and (b).

The degree of the fibres' improvement in performance depends on three factors: oil content, time of ageing and fibre density during ageing.

The quantity of oil used is about 10% of the weight of fibre, ageing time is usually 2–4 days, and the fibre density during ageing should be 180–220 kg/m^3. It is better to add water whilst oiling so as to keep a certain degree of about 10% of moisture regain. This will improve the processability of the fibres.

Drafting and doubling

The fibres, after having been oiled and aged, are then drafted and doubled (usually 4–5 passages) before spinning. For the first and second passages the fibres are only drafted. In the following passages the slivers are doubled as well as drafted. The schematic drawing of these processes is shown in Fig. 6.20.

The fibres are fed into the machine through the feed plate (1) and feed rollers (2), are then gilled by the slow lattice (3) and fast lattice (4) with pins, between which the draft is usually 1.1–1.8. The output rollers (5) then pull the fibres from the fast lattice with a draft of about 15–20. Led by the delivery rollers (7), the drafted and doubled slivers are coiled by the rotating plate (9) under the pressure of the weight of the cone (10). The main parameters for yarn preparation processing are as follows:

- draft: 6–12
- weight of output sliver: 100–350 g/m
- output speed: 40–70 m/min.

Figure 6.19 Drafting frame.

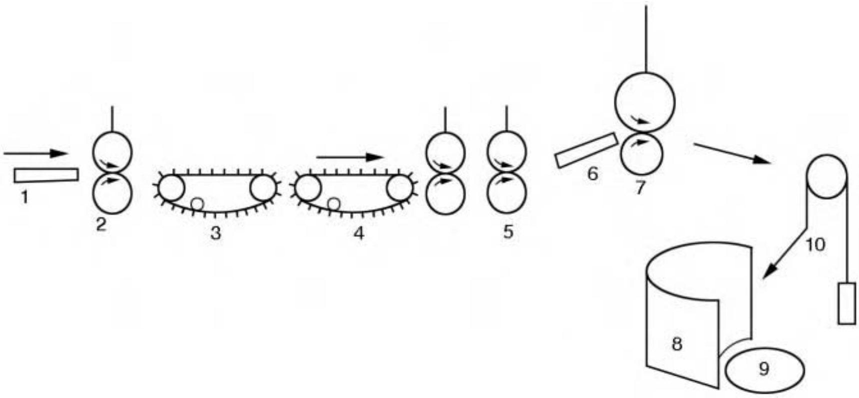

Figure 6.20 Schematic drawing of drafting line.

After two passages through the drafting frames the slivers are drafted by the doubling machines, between the back roller and front roller, then further drafted and doubled on the next two or three passages.

As shown in Fig. 6.22, slivers are fed into the doubling machine through feed rollers (1) and back rollers (2), gilled by the pins (3), then drafted by the front rollers (4) output through delivery rollers (5), and coiled into cans. The main processing parameters of doubling machines are as follows:

- number of fed slivers: 6–12
- draft: 6–12
- weight of output sliver: 10–30 g/m

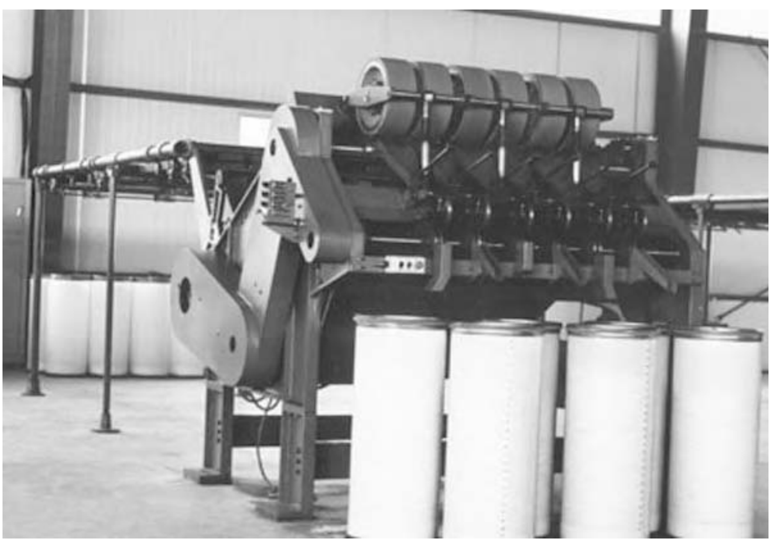

Figure 6.21 Doubling machine.

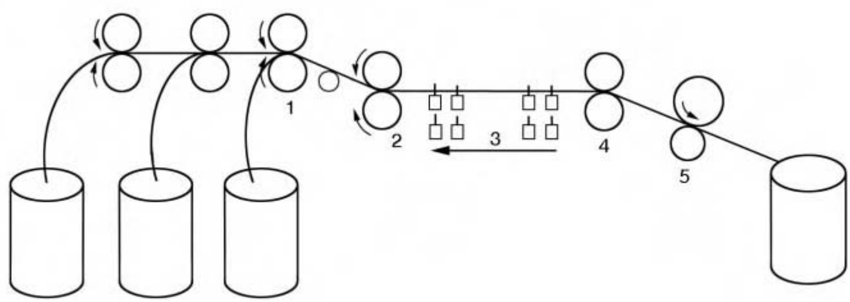

Figure 6.22 Schematic drawing of doubling line.

- output speed: 50–90 m/min;
- number of output slivers: 2–6.

Spinning

Because of the coarseness of the fibres the counts of sisal yarns are also coarse, usually in the range of 0.1–1.2 metric count (N). Yarns with counts higher than 0.4 N are usually called finer yarns, whilst yarns with counts lower than 0.4 N are usually called coarser yarns. Yarn diameters are also used to indicate the fineness of sisal yarns, twine and rope, and the relationship between the diameter (*d*) and metric count (*N*) of sisal yarn is shown as follows:

$$d = \sqrt{\frac{(1-y)}{\frac{\pi}{4}\rho \cdot N \cdot a}} = \sqrt{\frac{G(1-y)}{\frac{\pi}{4}\rho \cdot a}}$$

where

ρ = the density of sisal bundle fibre, which usually is in the range of 1.30–1.32 g/cm^3

y = the oil content in the yarn (%)

G = fineness of yarn (ktex);

a = experience coefficient (usually 0.68).

As with yarns spun from other fibres sisal yarns have twist factors (critical twists) which will produce yarns of maximum strength. The twist factors (metric) for sisal are usually in the range of 80–110. The finer the yarn, the higher the twist factor. Examples of the twists and twist factors employed for various yarns are shown in Table 6.12.

Both horizontal and vertical spinning frames are used for spinning sisal fibre, The vertical machines are almost the same as those used for jute except that they are shorter. In some cases jute spinning frames are used to process short sisal fibre, Fig. 6.23 shows the vertical ring frame. The main parameters used in spinning are:

Table 6.12 Yarn twist

Fineness of yarn (metric count, m/g) N	Diameter of yarn (mm)	Twist factor α	Twists (turns/m) T
0.2	2.55	80–94	36–42
0.25	2.28	84–96	42–48
0.33	1.98	97–97	50–56

$T = \alpha N^{1/2}$ (as for wool or cotton uarns)

Figure 6.23 Vertical ring frame for sisal spinning.

- draft: 10–15
- twists: 40–100 turns/m
- speed of flyer: 300–1800 rpm (depending on the fineness of the yarn).

6.5.2 Twine

Twines are composed of several yarns twisted together. For twine processing, the metric twist factor k is expressed as:

$$k = \frac{1000}{TD}$$

where

T = the twists in twine (turns/m)

D = diameter of twine (mm).

Table 6.13 Twine: relationship between the diameter and coefficient of experience

Diameter of twine (mm)	6–10	12–24	26–96
Coefficient of experience, *C*	0.0092–0.0080	0.00075–0.00071	0.00070

Adapted from: X. Lianrong (1991), 'Bleaching and dying of sisal fibre', *Research of Tropical Crops*, No. 2.

Twist factors for common twines of 3-ply or 4-ply are usually in the range of 2.0–4.0. Diameter is also commonly used to represent the fineness of twine, the relationship of the diameter and metric count is:

$$G = C \cdot D^2[1 + (y_s - y_b)].$$

where
G = the fineness of the twine (kg/km, or ktex)
N = $1/G$ (m/g, metric count)
D = diameter of the twine (mm)
y_s = the actual oil content in twine (%)
y_b = nominal oil content in twine (%)
C = coefficient of experience.

The coefficient C varies with the different diameters of twines as shown in Table 6.13.

6.5.3 Rope

Ropes are composed of several twines twisted together. For a certain diameter of rope, the component twines needed depend on the diameter and number of the twines. The number of twines in a rope can be calculated by the formula:

$$n = b \cdot \frac{D^2}{d^2}$$

where
D = diameter of the rope
d = diameter of the twine
b = coefficient of experience.

Table 6.14 Ropes: relationship between the diameter and the coefficient of experience

Diameter of rope *D* (mm)	6–8	10–16	18–44	48–96
Coefficient of experience	1.2	1.1	1.0	0.95

Adapted from: X. Lianrong (1991), 'Bleaching and dying of sisal fibre', *Research of Tropical Crops*, No. 2.

Because of distortion caused by the compression of the twines in the rope, the result needs to be modified by the experience coefficient which varies with the diameter of ropes.

The twist factor used for rope is usually decided by the twist factor of the twines:

$$k' = 0.893k$$

where
k' = the twist factor of the twine
k = the twist factor of the rope.

Also because of the distortion caused by the twist, the length of the resultant rope decreases. It is therefore necessary to allow for this shrinkage and the following formula is used to describe the relationship between the length of twine and the resultant rope:

$$L = L' \cdot \frac{\sqrt{\frac{\pi^2}{3} + k^2}}{k}$$

where
L' = the length of twine
L = the length of the resultant rope
k = the twist factor of the rope.

There are two kinds of rope manufacturing machine, horizontal and vertical. The diagram of the vertical rope making machine is shown in Fig. 6.24.

Several packages of twine are placed on individual supports mounted on a rotatory plate. The twines are pulled off their packages, through the controller, by the tension rollers. As they are pulled off, the individual packages of twine rotate in the opposite direction to that of the rotating plate. The rope is formed in the controller by twisting the twines together. The newly formed rope then passes through the tension rollers and is wound into a package.

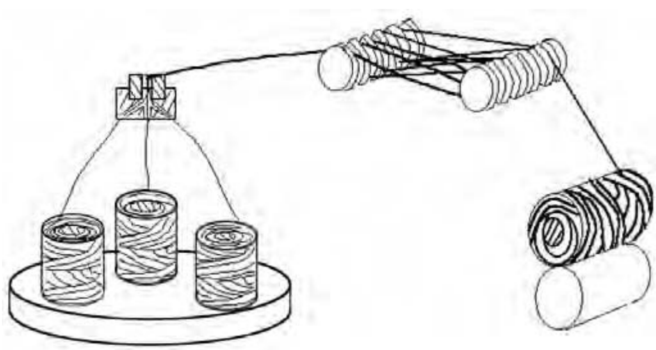

Figure 6.24 Vertical rope making machine.

6.5.4 Fabric

The weaving of sisal is similar to that of jute and kenaf. The yarns used as warp (or end) are coarse and strong enough to be woven without sizing. The flowchart for the production of sisal fabrics is:

Yarns → Beam warping → Weaving fabric
Yarns → Weft winding → Weaving fabric

In some cases beam warping can be dispensed with; the warp yarn packages, placed on a creel, feed the yarn directly into the loom (see Fig. 6.25). The main specification of weaving machines used for sisal fabrics is:

- width (m): 1.5–14
- speed (picks per minute): 50–120
- range of weft density (picks per 10 cm): 6–90.

6.5.5 Bleaching and dyeing of sisal fibre

In the past, because sisal products such as cordage and twine were used by industry, there was no need to dye the fibres of manufactured products. However, since the 1980s the development of the use of sisal yarns for products such as carpets, tapestry and other decorative fabrics, has led to an increasing demand for dyeing. Although sisal is a vegetable fibre, because of its relatively high gum content its dyeability is much poorer than that of cotton, ramie or flax.

Figure 6.25 Weaving machine.

Figure 6.26 Carpet-weaving machine.

Bleaching fibre

It is usually necessary to bleach sisal before dyeing. Depending on requirement sisal can be bleached as fibre or yarn, the former being more common. Normal procedure for fibre bleaching is drafting or doubling (finishing the fibre before dyeing) – boiling (bleaching) – washing off – water extraction – drying. The parameters employed in boiling are ratio of material to liquid (M:L) 1:10–20, time: 30–50 min., temperature: 90–100 ºC, pH value: 8. The effects of various bleaching agents on the fibre are shown in Table 6.15.

Table 6.15 The effects of bleaching agents (the raw whiteness of unbleached sisal fibre is 59.0)

Agents in boiling solution	Whiteness
Na_2CO_3	60.0
NaOH	48.0
NaClO	64.0
H_2O_2	69.0
H_2O_2 Na_2CO_3	66.0
H_2O_2 NaOH	70.2
H_2O_2 Na_2SiO_3	72.0
H_2O_2 Na_2CO_3 NaOH	72.6
H_2O_2 Na_2SiO_3 Na_2CO_3	73.6
H_2O_2 Na_2SiO_3 NaOH	74.5

Adapted from: X. Lianrong (1991), 'Bleaching and dying of sisal fibre', *Research of Tropical Crops*, No. 2.

The results show that hydrogen peroxide performs better than other bleaching agents and combinations of hydrogen peroxide with sodium silicate and sodium hydroxide result in the highest degree of whiteness. Therefore and although the cost is a little higher, sisal is usually bleached using hydrogen peroxide instead of sodium hypochlorite. Sodium hypchlorite also has the disadvantages of damaging the strength of the fibres and pollution by the irritant chlorine.

Dyeing fibre

The dyes used for cotton and other bast fibres can also be used for sisal fibre, for example, direct dyes and reactive dyes. Of course, reactive dyes usually perform better than direct dyes but at a higher cost. In some cases, selected disperse dyes are also used. The effects of dye on sisal with direct dyes is shown in Table 6.16.

The procedures for dyeing sisal (bleached or unbleached) with direct dyes are drafting and doubling – boiling – water extraction – dip dyeing – washing off – water extraction – drying. The parameters and formulae used for direct dyes are: dyeing depth, 1–2% (o.w.f.); liquor ratio, 20–30:1; pH value for the liquid, 8; liquid temperature, 95–100 °C; dyeing time, 20–40 minutes; composition of the liquor dyes, 1–2% (weight ratio to fibre); strengths of solutions of sodium hydroxide or sodium sulphate 20%; distilled water 150–250 ml and of sodium carbonate 5% (for adjustment of pH value of liquid).

Table 6.16 The colour fastness of direct dyes

Dyes	Wet fastness		Washing fastness		Rubbing fastness		Light fastness
	Discoloration	Staining	Discoloration	Staining	Dry	Wet	Discoloration
Direct yellow brown TND3G	3–4	4	3–4	3	4	2	3
Direct red brown	3	4	2–3	3	4	3	4
Direct green GN	3–4	4	3	4	4	2–3	2
C.I. direct blue 151	3–4	4	3	3	4	2	3
C.I. direct red 23	3–4	3–4	3–4	3	3–4	3	3–4
C.I. direct blue 81	4	4	3	3–4	4	3–4	3–4
C.I. direct black 103	4	4	2–3	4	4	3–4	3

Adapted from: X. Lianrong (1991), 'Bleaching and dying of sisal fibre', *Research of Tropical Crops*, No. 2.

Table 6.17 The parameters and formulae for dyeing with reactive dyes

	Type of reactive dyes Dichlorotrizine	Monochlorotrizine	Vinylsulphone
Parameters employed in dyeing			
Dyeing depth (%)	2	2	2
Liquid ratio	1:20–30	1:20	1:30
Time of pre-dyeing (min.)	10	10	10
Temperature of pre-dyeing (°C)	30	50	50
Time of dyeing with salt (min.)	15	20	30
Temperature of dyeing with salt (°C)	30	60	60
Fixing time (min.)	30	20	40
Fixing temperature (°C)	30	90	60
Formulae of dyeing			
Dyes (o.w.f.) (%)	2	2	3
Salt (g/l)	30	40	60
Sodium (g/l)	15	15	12
Detergent (g/l)	4	4	4

Source: W. Jianfeng, L. Qing and C. Song (2000), 'Preliminary study on degumming and dyeing of sisal', *Sichuan Textile Science and Technology*, No. 2.

Table 6.18 The colourfastness of reactive dyes

Dyes	Wet fastness		Washing fastness		Rubbing fastness		Light fastness
	Discoloration	Staining	Discoloration	Staining	Dry	Wet	Discoloration
C.I. reactive yellow I	4	4	3	3–4	3–4	3	3
C.I. reactive blue 4	4	3–4	3	3–4	4	2–3	3
Reactive brill. orange X-GN	3–4	3–4	3	3–4	4	2–3	4
C.I. reactive yellow 4	3–4	3–4	3	3–4	4	2–3	4
Reactive brill. yellow brown K-GR	3–4	3	3	3–4	4	3	4
C.I. reactive violet 2	3–4	3	2–3	3–4	4	3	4
C.I. reactive red 24	3–4	3	3	3–4	4	2–3	4
Reactive light yellow K-6G	4	3–4	3	4	4	3	2–3
Reactive brill. orange K-GN	4	3	3–4	3–4	4	3	4
C.I. reactive blue 19	3–4	3	3	3	4	2–3	4

Table 6.19 The affinity of different reactive dyes on sisal fibre

	Dye uptake (%)	Fixation yield (%)
C.I. reactive yellow 1	52.1	45.94
C.I. reactive red 2	63.4	48.79
C.I. reactive blue 4	37.2	22.51
C.I. reactive red 15	14.34	9.65
Reactive light yellow K-4G	31.08	16.62
Cibacron brill. blue BR-P	69.86	50.81
Reactive brill. red M-8B	63.14	46.25
Reactive light yellow M-7G	60.67	43.24

For dyeing with reactive dyes, the dyeing procedure is: drafting and doubling – boiling – water extraction – dip dyeing – fixing – washing off – soap boiling – washing off – water extraction – drying. The parameters and formulae employed in dyeing with reactive dyes are shown in Table 6.17. Some results of dyeing with reactive dyes on sisal fibre are shown in Tables 6.18 and 6.19.

As the relatively poor dyeability of sisal is due to the high content of gums in the fibres, dye uptake is increased by degumming before dyeing. Results of 75% uptake or more have been reported. High gum content also leads to uneven dyeing, it is therefore preferable to dye fibre rather than dyeing end products. This not only has the advantages that it is easier to dye the fibres but also, even if the fibre dyeing is uneven, fibre mixing during subsequent processing will remove, or at least greatly reduce, colour variation. The dyeing of sisal fibre is usually carried out by loose-stock dyeing in kiers.

6.6 Products and applications

Because of the hardness and coarseness of sisal fibre the end products are usually used in industry or for decorative and household products. The typical sisal product, the agave rope, (now also called sisal rope) was originally mainly used in naval vessels because of its excellent resistance to sea water and other chemical agents. At present yarns, fabrics and especially ropes are widely used in industrial fields such as shipping, transportation, oil, mining, forestry, agriculture and construction. With the development of man-made fibres some of these traditional applications of sisal have declined. However, new applications are being developed, such as sisal buff which is used for polishing metal and other materials, carpets, and other floor coverings which perform well because of sisal's exceptional resistance to wear and its ability to absorb and release water (sisal's velocity of water release is 2–3 times of that of jute and composite products).

6.6.1 Sisal yarn

An important outlet for sisal yarns is as weft, sometimes as warp, for carpets and in craft products. The fineness of the yarns is usually in the range of 0.1–1.2 metric count. Sisal single yarns are also used for making twine and rope, for binding twines, and as the core of steel cables. Some applications require a smooth and clean appearance. This is obtained by cutting the protruding fibres from the yarns, these yarns are called sheared yarns.

Generally, the unevenness (CV%) of the yarn is expected to be less than 8%, the deviation of the yarn count is expected to be less than 12%, and the tenacity is expected to be higher than 11 cN/tex. Because of the coarseness of the yarns the strength of commonly used sisal yarn is usually of the order of 300–700 N.

6.6.2 Twine

Sisal twines as well as single yarns are also widely used as binding and for weft in carpets. Twines are also further processed into rope. The specifications of twines, with or without grease oil, sheared or ordinary, vary according to the requirements of the product. The most popular twines are 2-ply to 4-ply single yarns. The quality of twines is mainly evaluated by

1. fineness, of which the deviation should be less than about 10%;
2. strength, it is usually in the range of 400-1000 N according to the fineness of twine;
3. oil content in the twine, this is usually required to be less than 10–15%, according to the requirements of the product.

The market for sisal twines is decreasing due to competition from cheaper synthetic fibres.

6.6.3 Sisal rope (cordage)

Sisal ropes are made of twisted twines. They are characterised by high strength, good anti-slippage properties, good resistance to cold, good resistance to abrasion, and better resistance to some chemical agents than other natural fibres. They are used in the industrial fields mentioned below (section 6.8). The main kinds of sisal ropes are 3- and 4-twines. Like sisal yarns and twines, sisal rope is also used as a core for steel wire rope to improve the flexibility of the wire rope, which can facilitate its use and maintenance and to absorb the grease, which decreases the abrasion between the wire rope and moving or fixed parts of suspension or retaining systems, thus prolonging their life span.

The quality of sisal cordage is evaluated by the deviation of their fineness (less than 10%), and strength (usually in the range of 3,000–200,000N depending on the diameter of the rope. Rope diameters range from 3–60 mm.

As with twines, the market for sisal ropes is decreasing and for the same reasons.

6.6.4 Sisal fabrics

Sisal fabrics are woven from single yarns. Bags are woven from low density fabric constructions. Medium densities are used for polishing buffs and high densities, with high weights per square metre, for polishing buffs and wrapping fabrics. Quality requirements for sisal cloths include the weight per unit area, and strength in both warp and weft directions. Examples of sisal cloths with their specifications are shown in Table 6.20.

Table 6.20 Some sisal fabrics with their specifications

Code of fabrics	Structure of fabrics	Count of fabric (1/10 cm)		Strength (N)		Weight (g/m^2)
		Warp	Weft	Warp	Weft	
No. 1	Plain	32	30	2585	2420	1175
No. 2	with	32	28	2585	2260	1140
No. 3	single	28	32	2260	2565	1135
No. 4	ends	22	23	1775	2260	945
No. 5		22	24	1770	1940	870

6.6.5 Sisal buffs

This is a new development. Sisal buffing cloths are used to polish materials, both metallic and non-metallic. Sisal buffs can be processed to various shapes according to the requirements of the product to be polished. They offer better performance than the traditional cotton buff, as can be seen from the data shown in Table 6.21. As shown in the table, compared to cotton buff, and while polishing the same blank, a sisal buff has the advantages of saving energy,

Table 6.21 Comparison between sisal buff and cotton buff (for the polishing of tap made of brass)

	Cotton buff	Sisal buff
Polishing efficiency (%)*	100	122.75
Abrasion of buff (mm)	14.5	5.5
Consumption of power	100	75.3
Smooth finish after polishing (for the same raw material)	V7–V8	V8–V9
Powder suspended in mill (mg/m^3)	4.0	1.97

* Number of articles polished by a single buff expressed as a percentage of 100 articles polished by a cotton buff.

longer life span, smoother finish and the powder pollution in the mill is only half that produced when using cotton buffs. This better performance is probably due to sisal's greater stiffness and resistance to abrasion.

6.6.6 Mattress

Short or kinked fibres are processed on non-woven systems, punched or bonded, to be converted into mattresses. The sisal mattress, with better permeability of water and air, performs excellently when used both for mattresses and upholstery. Some specifications of mattresses made from sisal fibres are shown in Table 6.22.

Table 6.22 Specifications of some sisal mattress materials

Nominal thickness (mm)	Lining cloth	Weight of mattress (g/m^2)	Sheared strength (N)	
			Warp direction	Weft direction
6	With	1050	100	100
	Without		10	20
8	With	1400	120	120
	Without		20	30
10	With	1750	150	150
	Without		30	50
12	With	2100	180	180
	Without		50	70

6.6.7 Floor coverings

Floor coverings are also a new product developed during the recent decade and which are expected partially to take the place of traditional sisal products – ropes and twines, which are in considerable decline because of the challenge from cheaper man-made fibres. Compared to floor coverings made from wool and man-made fibres, sisal has the advantages of anti-static properties (compared to synthetic fibre products), is insect-proof, is more durable even under difficult conditions, has faster absorption and release of water and moisture, and is biodegradable without causing pollution. Sisal floor coverings are gaining more favour with consumers in speciality applications such as, for example, bathrooms, living rooms, outdoors and shipping.

6.6.8 Other products and applications

Other products and applications using sisal include papermaking, enzyme production and saponin and hormones extracted from fresh leaves (see Appendix A).

6.7 Economic and cost considerations

Compared to other crops which can grow on the same land as sisal, such as sugarcane, pineapple and banana, sisal produces higher profits. A comparison between the profits for sisal and sugarcane is shown in Table 6.23.

Table 6.23 The profit (RMB) gained from one hectare per year of sisal and sugarcane planting

	Output value	Cost of planting	Cost of prcessing	Net profit
Sisal	18,000	4,500	4,500	9,000
Sugarcane	11,250	4,500	0	6,750

The lifespan of sisal is usually 16–18 years, of which there is an initial 3–4 year loss in production before the first harvest. From there on the leaves can be cut at least once every year, and as the product is used in industry (as opposed to fashion) demand is relatively stable. Sisal fibre prices from 1900 to 1995, from Uganda and Brazil, averaged US$622 and 445 per tonne, respectively

6.8 Marketing and consumption

The consumption of sisal fibre and products peaked during the early 1960s to the middle 1970s, when production and exports reached 800,000 tonnes and 650,000 tonnes, respectively. Recently, production and exports have decreased because of the challenge from man-made fibres and their products, but sisal fibre and its products still retain certain traditional markets. In recent years the total annual demand for sisal products in the world has been in the range of 300,000–400,000 tonnes. Its use for packing and binding materials for agriculture is approximately 150,000–200,000 tonnes per year; consumption in the mining, forestry and metallurgical industries is around 100,000–150,000 tonnes per year; its use in floor covering crafts, for buffs and building materials is about 100,000–150,000 tonnes annually, and another 100,000 tonnes of sisal are used for high quality papermaking, and composite materials.

As a country, the United States is the second largest consumer of sisal by weight. Almost 60,000–70,000 tonnes of sisal products are imported annually, and by value it is the largest importer. As a continent, Europe is the largest consumer by weight with annual imports of sisal fibre and products averaging in 40,000 tonnes and 50,000 tonnes respectively. By value Europe follows the US. France, Italy and England are the major fibre importing countries while Canada, France, Germany and Belgium are the major product importing countries. However, the UK re-exports a substantial proportion of its fibre imports.

Table 6.24 The export of sisal fibre and products in the world

	1991	1992	1993	1994	1995	1996	1997
Brazil							
Fibres	4.40	3.10	4.70	4.20	2.60	2.90	3.80
Products	7.70	7.00	5.70	7.60	6.10	3.80	4.40
Haiti							
Fibres	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Products	0.70	0.70	0.60	0.40	0.40	0.40	
Kenya							
Fibres	2.40	3.10	2.70	2.60	2.30	2.50	
Products	0.10	0.20	0.37	0.39	0.52	0.45	
Madagascar							
Fibres	0.87	0.79	1.15	1.05	1.12	1.12	
Products	0.15	0.19	0.20	0.20	0.20	0.20	
Mexico							
Fibres							
Products	1.10	0.82	0.82	0.82	0.82	0.82	
Mozambique							
Fibres	0.05	0.05	0.05	0.05	0.05	0.05	
Products	0.05	0.05	0.05	0.05	0.05	–	
Tanzania							
Fibres	0.38	0.52	0.40	0.65	0.30	0.30	
Products	1.72	1.30	1.70	1.72	1.70	1.58	
Others							
Fibres	0.35	0.35	0.35	0.35	0.35	0.35	
Products	0.80	0.80	0.80	0.80	0.80	0.80	
Total world							
Finres	8.60	8.00	9.40	9.00	6.90	7.40	
Products	12.30	11.20	10.50	12.10	10.70	8.10	

Source: C. Donghong (1999), 'History review and looking ahead on the sisal production of worldwide and China', *Fujian Science and Technology of Tropical Crops*, Vol. 24, No. 1.

As man-made fibres take over more and more of the twine and rope markets the development of new markets for sisal, such as floor coverings, buffing fabrics, mattresses, upholstery and composite products has enabled the global production of sisal to be maintained at a reasonable level.

[*Editor's note*: I am indebted to Mr Gordon Mackie who supplied me with the graphs (Figs 6.27–6.34) and to Mr Vivian Landon, who sent me the tables (Tables 6.25–6.28) that they originally presented to conferences organised by the FAO on hard fibres. These confirm clearly the points made by Professor Yu in his chapter, not only concerning the overall decline in sisal consumption, and therefore production, but also that this decline was, and still is, caused by the decrease in consumption of sisal twine (Fig. 6.27 and Table 6.25). Mr Mackie's graph (Fig 6.27) also shows the effect that the competition of polypropylene twine has had on the price of Brazilian sisal; and this despite the fact that the

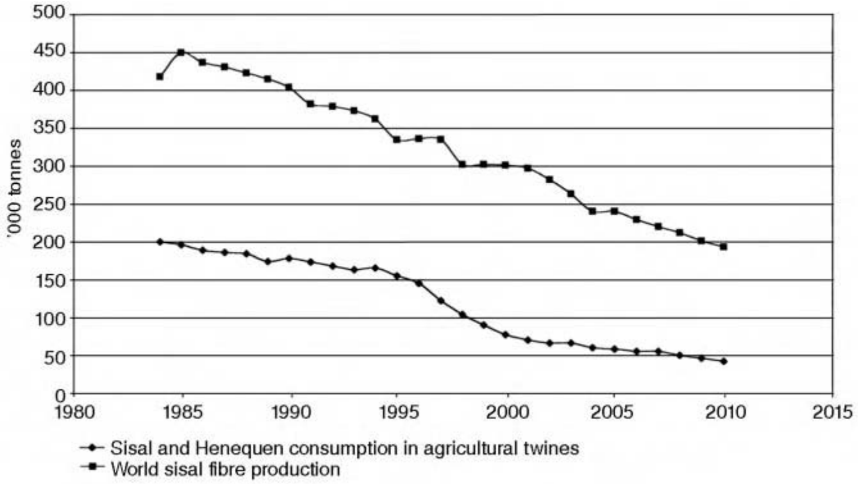

Figure 6.27 World sisal production and consumption 1985–2010. Courtesy: Gordon Mackie.

world's total consumption of all types of twine has increased by 400% since 1900.[4]

Whilst the figures given in the graph and tables are not identical they are sufficiently close to reinforce each other and present a coherent overall view of the present market for sisal (2004) and its likely situation in 2010 by two authorities on the fibre, its marketing and its end-uses.

Figures 6.30–6.34 and Tables 6.27–6.28 fill in some of the detail. As can be seen from most of these figures and tables the consumption of sisal in nearly all its end-uses is expected to continue to decrease, with perhaps two exceptions,

Table 6.25 Sisal baler and binder twine consumption by country

	1973/74 (tonnes)	1978/79 (tonnes)	1990 (tonnes)	2000 (tonnes)
USA	130,000	82,000–87,000	78,000	62,000
Canada	39,000	20,000–22,000	13,000	
EC	139,000	105,000–110,000	42,000	15,000
Other western Europe[1]	18,000	12,000–14,000	10,000	
Other developed[2]	32,000	14,000–17,000	12,000	7,000
Eastern bloc[3]	42,000	25,000–28,000	25,000	
Total world	400,000	258,000–278,000	180,000	84,000

1. Includes Israel, Greece, Spain, Portugal, Austria, Sweden, Finland, Switzerland, Norway, etc.
2. Includes Australia, New Zealand, Japan, South Africa, Argentina, etc.
3. Includes Poland, USSR, Hungary, Yugoslavia, Romania, Czechoslovakia, etc.
Source: 'A review of the Market in Traditional Sisal and Henequen Product (Especially Agricultural Twines and General Cordage) and an Assessment of Future Potential'
http://www.fao.org/DOCREP/004/Y1873E/y1873e07.htm#fn9
Courtesy: V. J. Landon, Ex-Chairman Wigglesworth & Co. Limited, London.

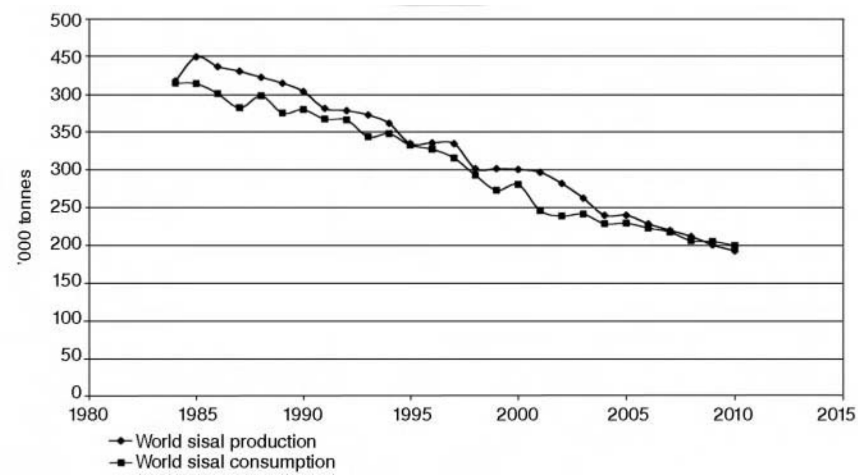

Figure 6.28 World sisal production 1900–2020. Courtesy: Gordon Mackie.

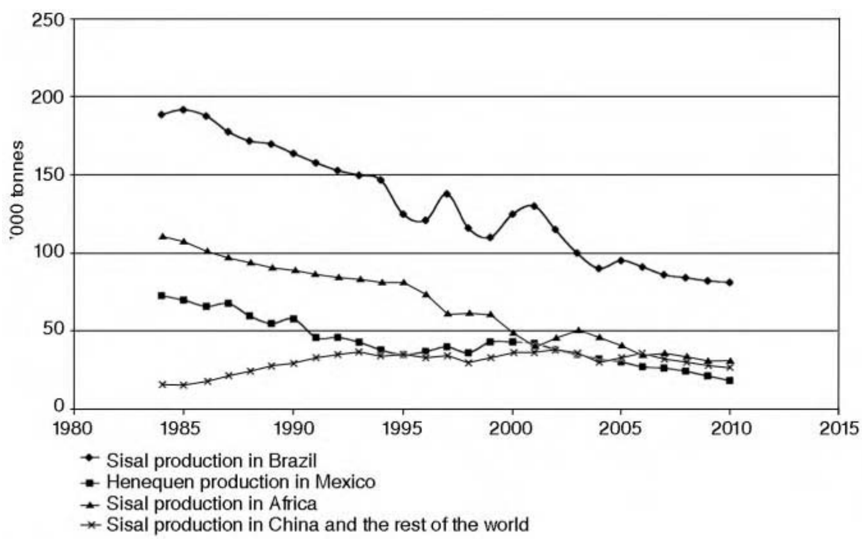

Figure 6.29 World sisal production by country. Courtesy: Gordon Mackie.

buffing cloths and composites. Although its use for buffing cloths will continue to increase it is a fairly small market and will not materially help to replace the expected substantial fall in consumption. Composites, on the other hand, could in the not-too-distant future develop into an interesting market. Although only small quantities of sisal are used in composite manufacture at present, this could increase as the overall market for vegetable fibre composites develops beyond their present use in pressure moulded panels for the automobile industry. Should

Table 6.26 Possible sisal consumption in 2010

Application	2000 projection (tonnes)
Agricultural twines	20,000
Other twines, ropes and cables, sacks and bags	32,000
Padding	8,000
Carpets, matting	18,000
Paper	30,000
Other (including automobile, buffing cloth, dartboards, geotextiles, handicrafts, etc.)	47,000
Total	155,000

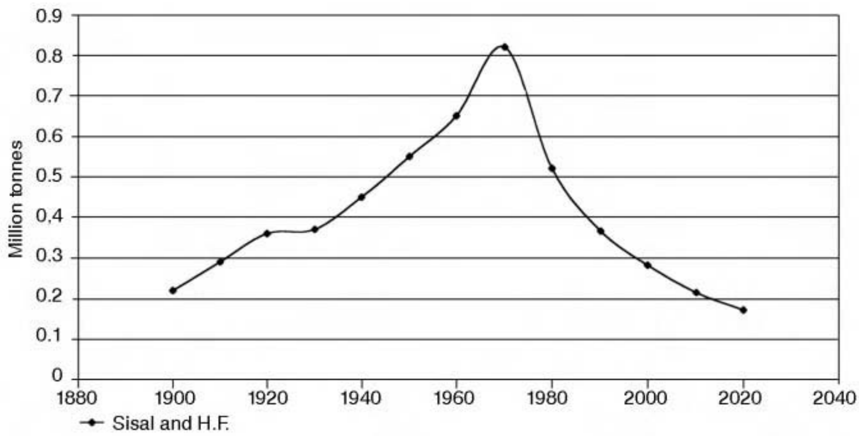

Figure 6.30 Sisal production and twine output. Courtesy: Gordon Mackie.

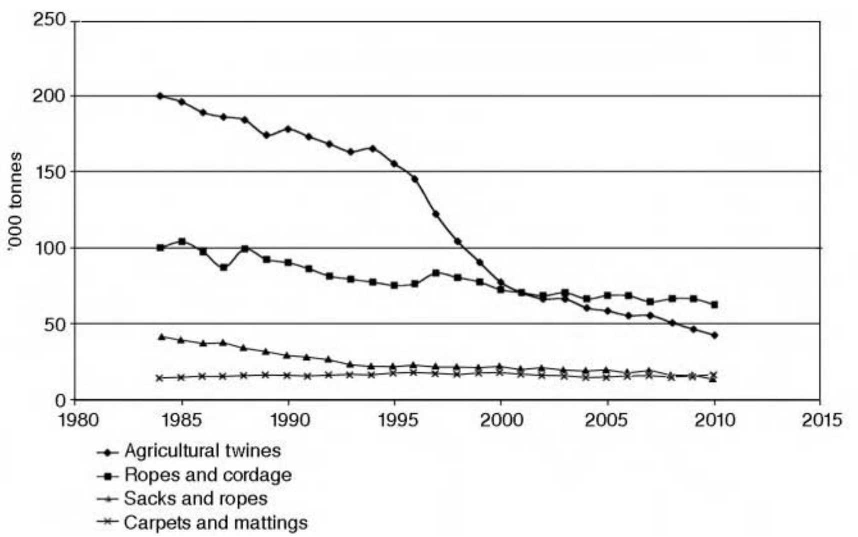

Figure 6.31 Major end uses of sisal and hard fibres. Courtesy: Gordon Mackie.

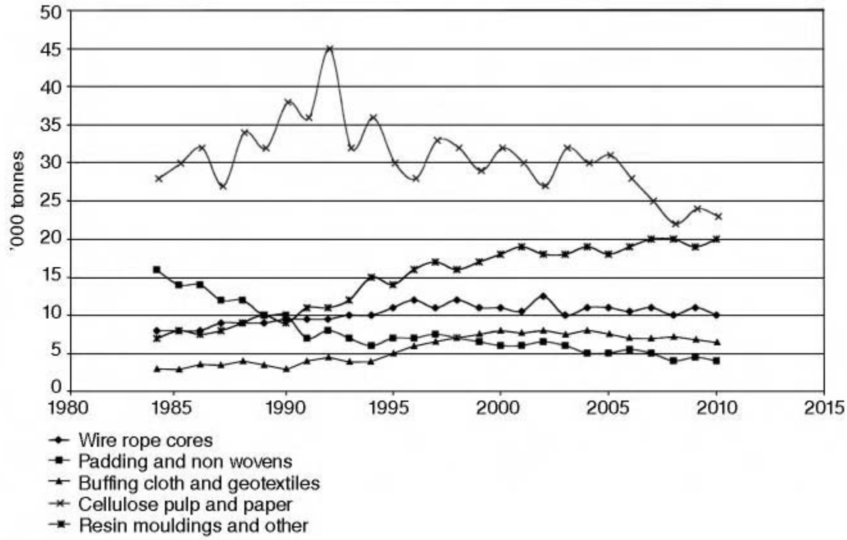

Figure 6.32 Minor end uses of sisal and hard fibres, excluding abaca. Courtesy: Gordon Mackie.

this happen, as seems likely, sisal would take its share of the market. This new market for bast and leaf fibres is more fully discussed in Chapter 10.

The use of sisal in the paper industry is something of an enigma. Its consumption of sisal in 2000 was estimated by Mr Landon at 70,000 tonnes but at only 30,000 tonnes by Mr Mackie. However, both believe that the figure will continue to fall in the near future (Fig. 6.32 and Table 6.28) but the use of sisal

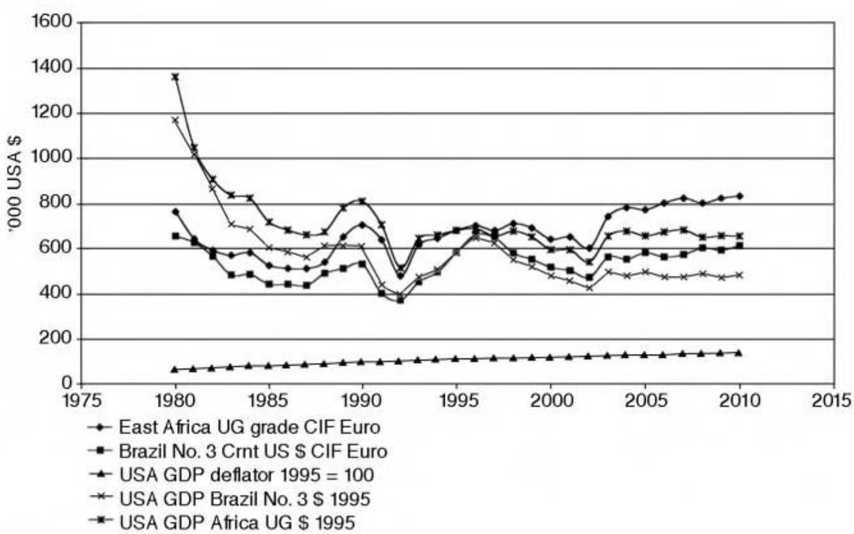

Figure 6.33 Sisal prices in current and constant 1995 US$ values. Courtesy: Gordon Mackie.

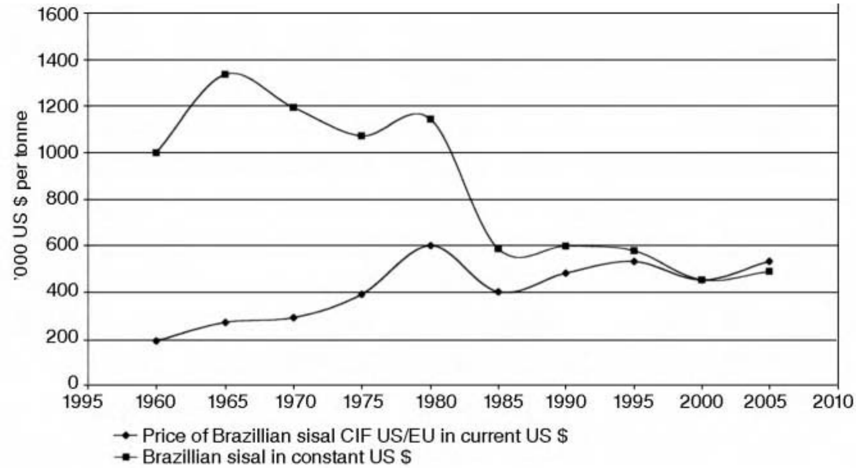

Figure 6.34 Long term sisal prices in current and constant US$ (2000 = 100%). Courtesy: Gordon Mackie.

in paper manufacturing is difficult to quantify, as these two very different estimates of consumption in 2000 show. This is because in paper manufacture it is mixed with other vegetable fibres and with wood pulp and whether a particular fibre is used or not will very often depend on the relative prices of the possible different constituents of the blend, and these prices can, at times, be volatile.]

Table 6.27 End uses of sisal and henequen (1973/4, 1990 and 2000)

	1973/74		1990		2000	
	Quantity (tonnes)	Share (%)	Quantity (tonnes)	Share (%)	Quantity (tonnes)	Share (%)
Harvest twines	400,000	53.3	180,000	45.0	84,000	32.3
Packing/tying twines	82,000	10.9	88,000	22.0	72,000	27.7
Ropes, general cordage	80,000	10.7	n.a.	n.a.	n.a.	n.a.
Padding, sacking, chopping	110,000	14.7	70,000	17.5	12,000	4.6
Total traditional uses	672,000	90.0	338,000	85.0	103,000	40.0
Carpets, wall coverings	38,000	5.1	12,000	3.0	20,000	7.7
Paper, including kraft, and other	40,000	5.3	50,000	12.5	72,000	27.7
Total world use	750,000	100.0	400,000	100.0	260,000	100.0

n.a. = not available.
Source: 'A review of the Market in Traditional Sisal and Henequen Product (Especially Agricultural Twines and General Cordage) and an Assessment of Future Potential'
http://www.fao.org/DOCREP/004/Y1873E/y1873e07.htm#fn9
Courtesy: V. J. Landon, Ex-Chairman Wigglesworth & Co. Limited, London.

Table 6.28 1993 projections to 2000 and estimated actual consumption 2000

	1993 projections to 2000		Estimated actual consumption in 2000	
	tonnes	%	tonnes	%
Agricultural twines	120,000	32.4	84,000	32.3
Other twines, ropes and cables	50,000	13.5	72,000	27.7
Sacks, bags and padding	50,000	13.5	12,000	4.6
Carpets, mats and matting	5,000	9.5	20,000	7.7
Paper	90,000	24.3	72,000	27.7
Other	25,000	6.8		
Total	340,000	100.0	260,000	100.0

Source: 'A review of the Market in Traditional Sisal and Henequen Product (Especially Agricultural Twines and General Cordage) and an Assessment of Future Potential'
http://www.fao.org/DOCREP/004/Y1873E/y1873e07.htm#fn9
Courtesy: V. J. Landon, Ex-Chairman Wigglesworth & Co. Limited, London.

6.9 Acknowledgements

I am very appreciative of the grateful help of Dongfang Sisal Group Co. Ltd of Guandong Province (China), Guanxi Sisal Group Co. Ltd (China) and the authors of the references cited directly and indirectly in the preparation of this chapter.

6.10 Appendices

Appendix A: Non-textile applications of sisal

Papermaking

Some researchers have suggested that sisal production and processing may change in the future if its production is geared more toward paper applications rather than of the traditional applications of twines and cordage. To a certain extent this is true and it is already happening. Research results show that paper made from sisal pulp has superior breaking properties and burst index. However, it is more expensive than wood pulp and is therefore restricted to speciality papers such as teabags, certain filter papers, sausage skins, printed currency notes, electrolyte capacity paper, etc. Sisal can be pulped by the kraft, soda or sulphite processes, as can some other natural non-wood plants, such as abaca, reeds, cotton lints, etc., and these are expected, to some extent, to become substitutes for wood pulp.

Vegetable protease

Another by-product of sisal fibre is the Agavain–SH, which is a vegetable protein extracted from fresh sisal leaves. Like papain and the vegetable proteins extracted from pineapple, etc., Agavain–SH finds its applications in the food and medical industries. Agavain–SH can also be used as a shedding agent for removing animal hair from leather. It has been reported that the production of the protease agent is approximately 1.5 tonnes enzyme from 500 sisal plants per hectare, which increases the profits of cultivating sisal by 18%. In comparison with the use of a micro-organism enzyme agent the use of the protease agent in depilating leather reduces the cost of removing hair by 63%. Compared to the traditional method of depilating by alkali these agents reduce pollution considerably.

Saponin

Saponin and hormones, such as hecogenin and tigoenin, can be extracted from the waste liquid of the fibre extraction process. They are the important materials for prophylactics and other steroid hormone medicines. The molecular formulae of hecogenin and tigoenin are $C_{21}H_{42}O_4$ and $C_{27}H_{44}O_3$, respectively. The structures of the molecules are shown in Figs 6.35 and 6.36. It is interesting to note that the fibre content of the leaves of *A. americana* is lower than that of *A. sisalana* and *A. fourcroydes* and that their saponin content is higher. Some

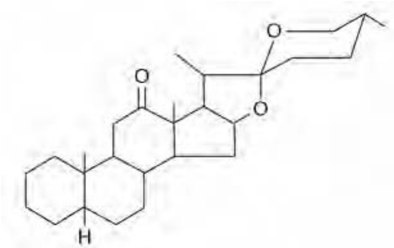

Figure 6.35 Hecogenin ($C_{21}H_{42}O_4$).

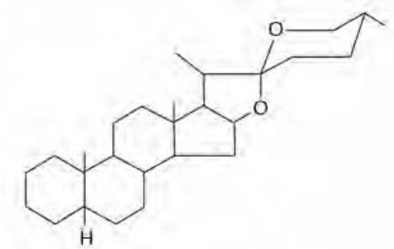

Figure 6.36 Tigoenin ($C_{27}H_{44}O_3$).

Table 6.29 The specification of hecogenin

	Excellent	First grade	Second grade
Content of hecogenin (%) $\geq$	88.0	85.0	80.0
Content of tigoenin (%) $<$	5.0	5.0	8.0
Melting point (°C)	250–265	248–265	245–265
Content of water (%) $\leq$	4	4	4
Ash (%) $\leq$	0.2	0.2	0.2

Table 6.30 The specification of tigoenin

	Excellent	First grade	Second grade	Third grade
Content of tigoenin (%) $\geq$	93.0	90.0	85.0	80.0
Content of hecogenin (%) $<$	5	6	7	10
Melting point (°C)	190–206	188–206	186–206	184–206
Content of water (%) $\leq$	4	4	4	4
Ash (%) $\leq$	0.2	0.2	0.2	0.2

specifications of the hecogenin and tigoenin extracted from sisal leaves are shown in Tables 6.29 and 6.30.

Fertiliser and animal fodder

Aside from the waste liquid, another waste product is produced during decortication. These dregs can be used as a natural fertiliser or for animal fodder.

Craft products, composite materials and sun helmets

Sisal fibre is also used for making sun helmets, friction towels and tapestry products. With more and more attention being paid to sisal's cost, stiffness and strength, its fibre is used as reinforcement in some composite materials.

Appendix B: Testing sisal fibres for stiffness and compression

Testing for fibre stiffness (or softness)

This test referred to on page 234 is used for testing the rigidity of jute and kenaf fibres. A given amount of fibre of appropriate length is placed in the clips at the two ends of the twist testing machine. The fibres are twisted until they break. The higher the twist inserted the softer the fibre.

Testing for compression

A given quantity of fibre is placed into a box or cup-like container. Compression is applied by placing a plate of a certain weight on top of the fibre. Compression is measured by noting the height of the plate after 30 seconds. Recovery is measured by noting the height the fibres attain after the plate has been removed.

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6.12 Glossary of terms

Agave sisalana Latin name of sisal.
Agave fourcroydes Latin name of henequen.
Agave americana Latin name of maguey.
Dregs Waste liquid produced during the decortication of sisal.
Kiers A container used to boil and refine (clean) fabrics before dyeing.
Kinked Short fibre produced during the decortication of sisal.

7
Coir

P M MATHAI

7.1 Introduction and history

7.1.1 Introduction

Kerala, the land of 'Kera' (which means coconut tree) is a small state in the southern part of India and the state is, in fact, named after its coconut trees which grow in abundance all over the state. Coir, one of the industrial hard fibres, enjoys a unique position. Kerala is the main producer and supplier of coir to the world market and 'Coir' from Kerala is known for its quality and exquisiteness all over the world.

7.1.2 History

Coir is the fibre extracted from the fibrous outer covering of the fruit of the coconut palm, botanically known as *Cocos nucifera* (Linn) and is a native of the tropics. Botanists are of varying opinions regarding the origin of this tree. Whilst this crop is considered to be of pre-historic origin in the Philippine Islands, its known cultivation dates back to 300 BC in Sri Lanka and available evidence also confirms its existence in India 3,000 years ago. Coconut is one of the most important sources of vegetable oil in the world as its kernel contains up to 60% oil.

The spinning of coir yarn from coir fibre was practised several centuries ago but the industrial manufacture of coir products developed in the middle of the 19th century. James Darrah, an Irish-born American entrepreneur who came to India in 1850, set up a factory in Alleppey in 1859 and this marked the beginning of the organised world coir industry. This factory grew to become a very large firm under the name Darrah Smail & Co. and was of considerable renown in Alleppey. Within fifteen to twenty years of Darrah Smail & Co.'s establishment more than a dozen other such factories were set up in the town, most of these managed and owned by Europeans. After India gained independence in 1947 most of the coir factories were either closed down or handed over to Indian nationals. From the centralised production system that prevailed up to that time production began slowly to migrate to the suburbs and grow as a cottage industry. Thousands of small-scale coir product manufacturing units were gradually set up within a few kilometres of the town of Alleppey. The products manufactured by these small units were bought in semi-finished condition by exporters, were further processed under their supervision and then exported after value addition. Recently some exporters have begun to set up large-scale manufacturing units of their own as centralised production has been found to help ensure better-quality products.

7.2 Chemical and physical fibre structure

7.2.1 Chemical structure

The tables in the Appendix to Chapter 1 compare the physical and chemical characteristics of coir to those of other fibres. Natural fibres can be grouped mainly into three groups

1. vegetable fibres (cellulosic or lignocellulosic)
2. animal fibres (protein fibres)
3. mineral fibres.

Cellulosic fibres are formed by the polymerisation of glucopyranosyl units and protein fibres are formed by the polymerisation of amino acids. Lignocellulosic fibres are formed by the incrustation of three basic polymers cellulose, hemicellulose and lignin.

The building unit for a cellulose molecule is glucose. A cellulose molecule is formed by the polymerisation of glucose units by glucopyranosyl linkages. This polymeric molecule, containing around 1,500 glucose units, forms the primary structure of cellulose. For fibre formation these long chain molecules lie side by side in bundles held together by hydrogen bonds between the numerous neighbouring hydroxyl groups. Whilst forming the hydrogen bonds, the bundles are twisted to form rope-like structures which join together and deposit to form the fibres. In a similar way, the polymerisation of mainly xylose (a pentose of sugar) forms a xylan chain. Xylan chains along with some other molecules are commonly known as hemicellulose. Lignin is a polymer of a set of aromatic compounds.

During the formation of lignocellulosic fibres, the cellulose bundles, before twisting together, are embedded in lignin, which cements them to each other, producing a structure that can be compared to a composite product or reinforced concrete, of which the cellulose and hemicellulose chains are integral parts. Because lignin plays an important role in the physical characteristics of the fibres and because these fibres are formed by the mechanism described above they are relatively harder and stiffer than pure cellulosic fibres such as cotton and also harder and stiffer than other lignocellulosic fibres such as pineapple, ramie and sisal. The chemical composition of coir is given in Table 7.1.

Table 7.1 Chemical composition of coir fibre

1.	Water soluble	5.25%
2.	Pectin and related compounds	3.00%
3.	Hemicellulose	0.25%
4.	Lignin	45.84%
5.	Cellulose	43.44%
6.	Ash	2.22%

The Appendix to Chapter 1 of this book also provides largely similar figures for the composition of coir fibres (Table 1.9). Jarman, interestingly, also provides figures for both young and old nuts (see Appendix B on page 305).

7.2.2 Physical structure

The individual textile fibres of all hard fibres are made up of a number of minute cells and these cells have distinguishing features that help in their identification. Like the fibre bundles themselves some cells of similar shape and dimensions occur in all the hard fibres but the averages and extreme values differ appreciably. The wall of each cell is made up of several layers of cellulose micro-fibrils laid in spirals about a common axis. One particular cell layer, commonly known as the S2 layer of the secondary wall, makes up most of the cell substance and the average spiral angle of the micro-fibrils of this layer dominates the combined effects of the other layers. As a result this angle is known as the spiral angle of that particular fibre cell (see Table 7.5 on page 295).

A cross-sectional outline shows that the cells of coir fibre have an oval shape. They have small air cavities near the centre of the filaments and roughly one-third of the bulk of the fibres is filled by air. This entrapped air gives rise to the pronounced springiness (resilience) of the fibres, their buoyancy in water and increases the time water takes to penetrate them. When soaked in water for some time the filaments swell laterally, but there is little or no longitudinal swelling. After 24 hours of immersion in water coir swells less in comparison to other hard fibres. Thus the properties of coir are less affected under wet conditions than are other hard fibres, and coir is particularly resistant to the effects of bacteria and salt water. Average values of the physical properties of coir fibre are given in Table 7.2. The enlarged views of the cross-sections of coir cells are given in Fig. 7.1(a) and longitudinal section through a coconut in Fig. 7.1(b). Other, sometimes slightly different, results for the physical characteristics of coir fibres are given in tables in the appendix to the Introduction of this book. The colour of coir fibre varies from golden yellow to dark brown depending on the method of fibre extraction.

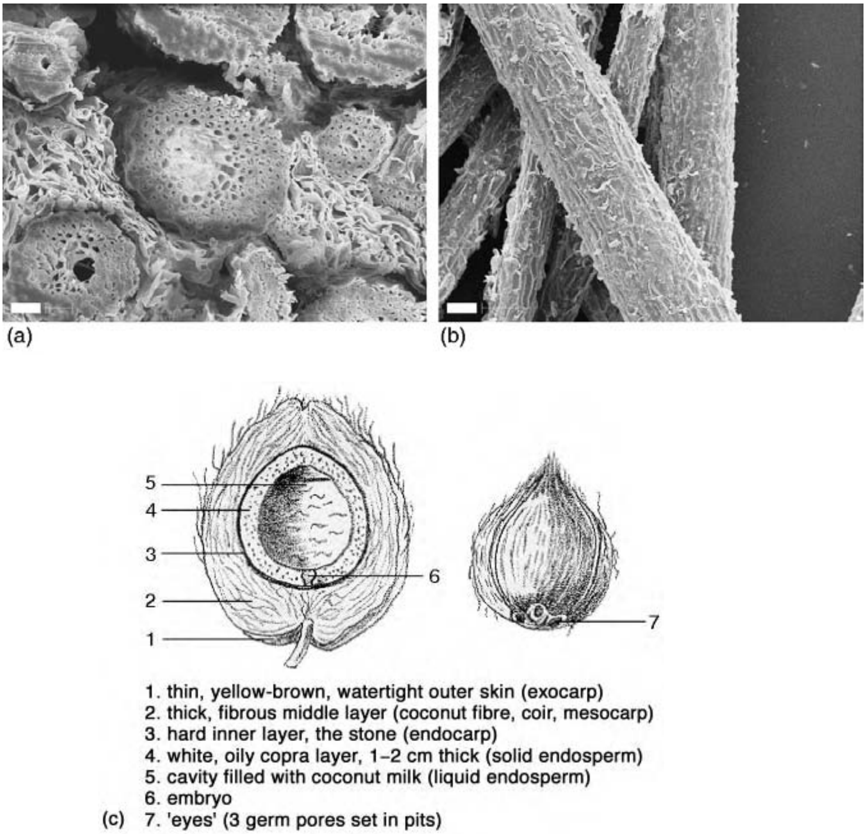

Figure 7.1 (a) and (b) Photomicrographs of coir stalk cross and longitudinal sections. Source: DeMontfort University, 2004; (c) longitudinal section through a coconut (left) and plan view of stone (right). Source: Gesamtverband der Deutschen Versicherungswirtschaft. Courtesy: www.tis-gdv.de.

7.3 Fibre production and early processing

Coir fibre can be extracted from the fibrous coconut husks either after natural retting or without retting.

7.3.1 Natural retting and fibre extraction

The ripe coconut is dehusked for the removal of the nut. This is done by impaling the coconut on a sharp iron spike (Fig. 7.2). The removal of the husk is a skilful operation as it requires both cutting and twisting the coconut as it is impaled.[1]

1. Textile Consultant, 228 Ballylesson Rd, Drumbo, Lisburn, UK.

Table 7.2 Properties of coir fibre

Physical properties of coir fibre		
1. Gravimetric fineness (tex)		40.00
2. Breaking load (kg)		0.45
3. Tenacity (g/tex)		10.00
4. Extension at break (%)		29.13
5. Flexural rigidity (dynes/cm^2)		200.00
6. Modulus of torsional rigidity ($\times 10^{10}$ dynes/cm^2)		1.89
7. Density (g/cc)		1.40
8. Porosity (%)		40.00
9. Moisture regain at 65%R.H (%)		10.50
10. Transverse swelling in water (%)		5.00
Dimensions and other physical characteristics of ultimate cells of coir fibres:		
1. Length (mm)	Average	0.60
	Maximum	1.00
	Minimum	0.30
2. Width (micron)	Average	259.00
	Maximum	277.00
	Minimum	229.00
3. Cell shape	Oval	
4. Lumen shape and size	Elliptic, large to medium	
5. Wall thickness	Medium to thin	

In natural retting the husks are immersed in water soon after dehusking. Husks that are exposed to the sun or allowed to dry become brittle and do not yield superior quality fibre because some of the water-extractable components such as tannin are decomposed by air and sunlight into insoluble compounds.

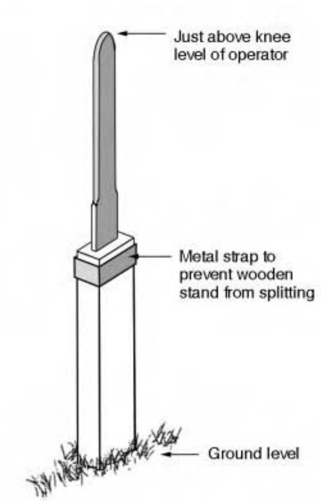

Figure 7.2 Coconut dehusking spike. Source: C. Jarman, *Plant fibre and processing: A handbook*. Courtesy: ITDG Publishing, UK.

Traditionally, retting is done by immersing the husk in water, preferably brackish, for six to nine months. The husks are placed in coir nets or dumped into pits near lagoons or by the side of backwaters where the water flows in and out with the rise and fall of the tide. During retting the pith binding the fibres together decays and the water soluble tannic substances are washed away. Retting improves the tenacity, flexibility and extensionability of the fibre and helps to obtain a whitish golden colour. Retting is decisive to the final quality of the fibre. Modern research has helped to reduce retting time by crushing the husks before retting and the Coir Board has also developed an effective bacterial culture (trade name 'Coirret') which both reduces retting time to as little as three months and improves fibre quality.

When retted the husks are taken out of the water and their outer skins, the exocarp, are peeled off. Traditionally, they are then placed on wooden blocks and beaten manually with wooden mallets in order to separate the fibres but now this is also done mechanically by using beater drums. The fibre is then cleaned by using a 'willowing' machine. The fibres are then dried under shade and bundled for further use. This fibre is called retted fibre and is mainly used for spinning coir yarn. It is also used for the manufacture of fibre mats.

7.3.2 Mechanical fibre extraction

There are two methods adopted in the coir industry for the non-retted mechanical extraction of fibre. The first method uses decorticators and the second method uses combing drums.

Fibre extraction by decorticator

The husk is first crushed with spiked or fluted rollers in order to break the exocarp and to let water enter the husk. After crushing the husks are soaked for different periods, up to a maximum of two weeks, depending on whether the husks are green or dry. The soaked husks are then fed into the beater (decorticator) by hand.

The beater is a set of 25–40 one foot (30.5 cm) long steel beater arms fitted on the periphery of a shaft in a helical path and rotated at about 300 rpm with 30–40 HP motors. The beater mechanism is contained in a grilled circular casing of sifter rods which is generally 5/6 ft (1.52/1.83 m) long and 2.5 ft (76 cm) in diameter. The husks are fed through a hole on one side of the beater, and beaten. This process also partially sifts the fibres which then come out at the other end. At this stage the fibres are not completely opened and they are fed into a turbo cleaner, (which is a mini-beater) to complete the opening operation. They are then fed into a sifter to remove dust, pith, etc., and dried in the shade and bundled. The main defect of extraction of fibre by decorticator is that the mattress (shorter) and bristle (longer) fibres are mixed.

Fibre extraction by combing machines

In this method the husks are also first crushed and soaked before being fed into the combing machine. This machine is equipped with two picker drums which comb alternate halves of the husks as they are moved past them by the rims of two eccentric revolving wheels or a conveyor belt system. Combing removes the shorter fibres and pith from the husk and separates the longer fibres. After combing the shorter fibres and pith are taken on to a revolving screener, drop through the screener and are discharged at the other end of the machine. Fibres from the screener are then further cleaned in a turbo cleaner. If the fibre is to be used for spinning the longer and shorter fibres have to be mixed and that is done at this stage. If the bristle and mattress fibres are not to be mixed, the fibres are then dried and bundled separately.

The fibres obtained in this way from unretted husks are lower in quality than retted fibres in that the colour is not as good, and their tenacity, extension, flexibility and yield are also inferior. This is because greater force is required to extract unretted fibres and therefore they suffer greater damage during processing. Coirret, developed by the Coir Board, mentioned above, does improve the quality of unretted fibres to that of retted fibres and to obtain this result the fibre is treated in tanks for 72 hours. However it should also be noted that of the two types of fibre, unretted fibre has better resilience which makes it more suitable for use in the manufacture of rubberised coir (see below section 7.7.10).

7.4 Yarn production and machinery

7.4.1 Yarn production – traditional method

Coir yarn production is perhaps the only field of the coir industry in which mechanisation has hardly penetrated. Spinning coir is mainly done by the traditional method of using manually rotated wheels called ratts. The conventional ratt is a set of two wheels, one fitted to a stationary stand and the other to a movable stand. In a simple unit the stationary stand contains two spindles connected to the wheel by a belt and the movable ratt contains one spindle. The wheels are fitted with handles so that they can be rotated. A minimum of three people is required to operate the unit, one for rotating the stationary ratt (the 'rotator') and the other two to draw the two single strands which make up the two-ply yarn. The number of people required to operate the unit may increase to four depending on the variety of yarn spun, number of spindles available, etc. The wheel on the stationary ratt is rotated in an anti-clockwise direction by one of the workers whilst the other two feed the fibre onto the rotating spindle and move backward drawing the single strands to the required thickness. When the required length of single strand is attained, the free ends of the strands are joined together and hooked onto the spindle on the movable ratt. A triangular yarn guide is then held between the two strands so as to control the evenness of twist by one worker whilst the third worker rotates the movable ratt in a clockwise direction along with the rotation of the stationary ratt in an anti-clockwise direction. While rotating the movable ratt, the worker will also push it forward in order to adjust for the loss of length while doubling the yarn. The speed of rotation of the wheels, the movement of the yarn guide and the forward movement of the movable ratt have to be regulated in the desired manner to obtain different varieties of yarn. Although fibre quality is important the main factor that will control yarn quality is the regularity of twist levels in the single and doubled yarns. The count of the yarn is decided by the quantity of fibre used when spinning the single strands.

Nowadays the above method of yarn production has been mechanised to a certain extent by incorporating a motor to rotate the stationary ratt in place of the rotator. This type of ratt is called a 'Motorised Traditional Ratt'. This method also helps to improve the quality of yarn as the motor provides an even speed of rotation. Also this method improves productivity since the rotator is substituted by a motor. It is also worth mentioning in this context that a portion of some varieties of coir yarns such as Quilandy yarn, Beach yarn, etc., are still hand spun. These yarns are of uniform thickness and have a smooth texture without any hairiness, but production costs are higher.

7.4.2 Mechanical spinning

Up to now the efforts of different organisations aimed at developing effective spinning machinery for coir have not been fully successful, mainly due to the non-mesh-forming and lack of cohesiveness characteristics of the fibres which cause problems during drafting, although another mechanism called the 'Motorised Ratt' has been developed. In these, twisting, doubling, etc., are mechanised but the feeding of the fibre is manual and yarn quality still depends on the expertise of the worker. Also their production capacity is limited.

7.4.3 Automatic spinning

Automatic spinning machines are also available. These have been developed following research by the Coir Board of India, and they continue to be improved by further R & D. They are based on the principle of DREF III core spinning, the core yarns used are generally fine cotton or nylon. There are no statistics available which would indicate the quantity of coir yarn which is machine spun but it is probably less than 10% of total yarn production.

7.4.4 Specifications of coir yarns

The Bureau of Indian Standards has approved 23 varieties of coir yarn spun from retted fibre and three varieties spun from unretted brown fibre but the number of

Table 7.3 Specifications of important varieties of coir yarn

S. no.	Variety	Type of fibre	Colour (natural)	Twisting and spinning	Approx. runnage	General characteristics
1.	Anjengo	Long and medium stapled well cleaned fibre from well retted husks.	Bright golden, reddish brown to bluish grey	Wheel-spun hard twisted and hard spun	180/360	Less hairy and smooth texture
2.	Alapat	Long and medium stapled combed fibre from retted or under-retted husks spun	Bright golden to bright brown or grey	Hand or wheel spun soft twisted soft or medium spun	170/230	Less hairy smooth texture and regular in spinning
3.	Aratory	Long and medium stapled, less combed fibre from retted husks	Reddish brown to bluish grey	Wheel-spun soft twisted and hard spun	200/260	Hairy, less regular in spinning and slightly pithy
4.	Vycome	Medium and short stapled combed* fibre lumpy with pith from retted husks	Bright cream reddish brown to dark grey	Hand or wheel spun, soft twisted and soft spun	200/300	Hairy, less regular in spinning and rough texture
5.	Beach	Medium and short stapled uncombed fibre from under-retted husks	Reddish brown	Hand spun very soft twisted and soft spun	240/260	Less hairy, smooth texture, regular in spinning and very pithy

6.	Quilandy	Medium stapled, less combed fibre from well retted husks	Bright golden to greyish	Hand spun, medium twisted and medium spun	110/130	Slightly hairy regular in spinning and with little pith
7.	Roping	Medium and short stapled uncombed fibre from under-retted husks.	Brown to grey	Hand spun, soft twisted and soft spun	50/60	Extraordinarily thick, unclean in appearance, very less hairy and pithy
8.	Beypore	Medium and short stapled less combed fibre from under-retted husks	Bluish-brown	Hand spun soft twisted and soft spun	70/90	Very thick, less hairy, containing a little pith
9.	3-ply	Medium and short stapled, less combed fibre from under-retted husks	Brown to grey	Wheel spun in 3-ply hard twisted and hard spun	55	Extraordinarily thick, hairy with varying amounts of pith, hard and rough texture
10.	Parur	Long and medium staple clean fibre from well retted husks	Golden, reddish brown to bluish grey	Wheel spun, very hard twisted and very hard spun	85/115	Fairly hairy and rought texture with little pith

* In this context 'combing' does not denote the normal textile process but is a manual cleaning operation carried out as the fibres are removed from the retted husks. Wheel spinning is spinning using traditinal hand ratts. Hand spinning is spinning by hand without the use of ratts. This produces soft twisted and level yarns but production is much lower. 'Hard spun' applies to single yarns. 'Hard twist' applies to plied yarns.

yarns actually produced at present is lower and are listed in Table 7.3. The important varieties of coir yarn spun from retted fibre have been named after the places where they were traditionally spun. Thus the best yarn, called Anjengo, is spun in the Anjengo area of the Trivandrum District of Kerala State. Aratory yarn, Vycome, Parur, etc., are similar names derived from the names of the places connected with the production of these yarns. They can broadly be classified into three types, hard twisted, medium twisted and soft twisted. Among the important varieties of yarn, Anjengo and Aratory are hard twisted, Alapat and Quilandy are medium twisted and Vycome and Beach are soft twisted. The hard twisted yarns are mainly used for the production of coir matting and carpets, and soft twisted yarns for the production of coir mats as these produce good brush (pile). Generally soft twist yarns are used only for the brush of mats whilst for other end-uses hard twisted yarns are usually preferred. In Table 7.3 'hand spinning' indicates that no equipment is used, wheel spinning that traditional ratts are used. Hand spinning produces soft twist yarns of uniform thickness but, of course, production is much lower than spinning with ratts.

7.4.5 Yarn thickness measurement systems

The fineness of coir yarn is denoted by the term 'scorage' which is 1/20th of the number of windings of coir yarn which could be wound close to each other without overlapping in a span of 36 inches (91.5 cm). In other words, the term scorage represents the number of strings or yarns that could be held close to each other without overlapping, in a span of 1.8 inches (4.57 cm).

Runnage is another term which is generally accepted by the trade to denote the fineness of coir yarn. The runnage of a yarn is the length in metres of one kilogram of that yarn. For example, if one kilogramme weight of a particular yarn measures 240 metres, the runnage of that yarn is expressed as 240 m/kg. Table 7.3 shows specifications of some of the important varieties of coir yarn.

7.5 Bleaching, dyeing, printing and finishing

The changing tastes of consumers have also affected the coir industry. For example, it has become essential to make increasingly ornate products. Dyeing has been used in the industry for quite a long time in order to impart design into products, but in recent years bleaching has also been developed as a means of ornamentation.

7.5.1 Bleaching

It is estimated that about 20% of coir fibre and yarn used for the manufacture of various coir products is now bleached. Due to the bulky nature of the products they are not easy to bleach and therefore this is generally done at the yarn stage. Various bleaching agents are used for bleaching textile materials. This is effected either by oxidation or reduction under appropriate conditions. Bleaching may include oxidation by hypochlorites, chlorites, peroxides or eracids and reducing agents such as sulphites, bisulphites, borohydrides, etc. The quality of water used in bleaching plays a very important role and it is therefore useful to incorporate water softening agents such as Calgon, zeolites, ETDA, etc., in the bleaching recipes. The coir industry generally uses hydrogen peroxide, and the process may be either hot or cold.

In cold processing the bleaching is done in cement tanks constructed for the purpose. The material to be bleached is kept in the solution having a material to liquor ratio of 1:10 for yarn and 1:12 for fibre with a treatment time of 16 hours at room temperature. In hot processing the material and liquor are kept at 80–90 °C for one hour in a stainless steel tank with frequent agitation. In both processes the material is taken out after bleaching, washed in cold water and dried under shade. The following materials are used for bleaching coir.

1. Hydrogen peroxide
2. Sodium silicate
3. Soda ash
4. Lisapol D
5. Trisodium phosphate
6. Calidon – L1
7. Bleaching powder
8. Alum
9. Caustic soda

Typical bleaching recipes are as follows:

Hot bleaching. Hydrogen peroxide, 35%-10cc per litre of water or 7 to 8% by weight, sodium silicate 6% by weight.

Cold bleaching. Hydrogen peroxide, 10% by weight, sodium silicate, 7% by weight, wetting agent or soap solution, 1% by weight.

Hot bleaching is more expensive than cold bleaching as heat is required but fewer chemicals are needed, productivity is higher and quality is improved.

7.5.2 Dyeing

Applying different colours to products so as to make them attractive from the point of view of the consumer is a basic principle adopted in many industries and coir is no exception to this worldwide phenomenon. Although a wide range of dyes capable of yielding bright shades of good to excellent fastness is used in textiles, quite a large number of these are not suitable for dyeing coir, mainly for two reasons. Some of them require special pre-treatments of the material which are not practical for coir due to its bulky nature whilst others are too expensive from the point of view of the coir industry.

The evenness of dyeing depends upon the power of absorption of the coir fibre, the nature of the dyestuff and the dyeing conditions. Taking into account such aspects as penetration, brilliance of shade, fastness properties, costs, etc., dyestuffs belonging to the basic, acid and direct classes are generally used. In order to achieve better results dye bath assistants such as acetic acid, sulphuric acid, formic acid, common salt, etc., are also used under appropriate conditions of temperature and for specified periods depending on the dyestuff being used.

Basic dyes have high tinctorial value and affinity to coir but are susceptible to light and rubbing. Acid dyes have better fastness to light but are not as bright as basic dyes. Direct dyes could produce shades having better fastness properties than acid dyes but they produce dull shades and require longer processing times. The coir industry also uses azo-free dyes as well as natural dyes.

7.5.3 Printing

Due to the uneven surface of coir products stencil printing has to be used. The designs are first cut out on galvanised iron sheets, the number of sheets required for printing a particular design depending on the number of colours present in the design. The dyes used are mainly basic, though selected acid and direct dyes are also sometimes used. After printing the materials are dried in the air at room temperature. Usual after-treatments, such as steaming, which form an essential part of processing printed apparel textiles are impractical for coir because of the bulky nature of the products, and therefore printing with these categories of dyes produces colours with practically no fastness to water or rubbing. As an alternative to these dyes plastic emulsions, synthetic enamel paints and reactive dyestuffs are used to achieve prints of better light fastness and deeper penetration.

For printing, the ready mixed paint or dyestuff solution is sprayed onto the coir mats or matting manually, using a compressor and spray guns. Experiments show that products printed with plastic emulsion or paint, when tested (by xenotest) for light fastness, show a slight initial dulling after six to eight hours of exposure followed by no further change in the colour tone. Regarding the behaviour of products under service conditions synthetic enamel paints abrade or wear off slowly from the surface resulting in the loss of the gloss or lustre of the film. With plastic emulsion paint the colour is rather subdued, but offers greater resistance to abrasion or wear. Both types of paint show excellent fastness to water.

In the case of reactive dyes the penetration is deeper, coupled with brilliant hues. It has been reported that 10% fading occurred when subjecting mats dyed with this class of dye to direct sunlight for 15 days.

7.5.4 Bleaching and dyeing machinery

Two methods are used to bleach and dye coir: manual and mechanised.

Manual bleaching and dyeing

This is the most popularly used method for dyeing and bleaching coir. The material to be dyed is placed in the dye solution in copper or stainless steel tubs and heated from below. The material is manually stirred regularly for specified periods. After dyeing is complete the products are washed with clean water and dried under shade.

Mechanised dyeing

The mechanised system of dyeing consists of a forced circulation of liquor in both directions through uniformly arranged materials. The temperature is controlled as required by regulating the flow of the heating system. After dyeing, hydro-extractors are used to remove the major part of the mechanically held water and finally these materials are dried on an endless conveyer drier. This system helps to improve penetration, shade consistency and levelness by the action of temperature, efficient and forced circulation of dye liquor and the period of processing. It also enables the processing of large quantities of material at a time. This method of dyeing and bleaching has been adopted by the major exporters of the coir industry. The machinery is manufactured in India.

7.6 Fabric production

Fabric production in the coir industry can be broadly classified as woven and non-woven. The greater part of India's exports of coir consists of woven products. Although non-woven products, mainly tufted products, are mainly manufactured in Europe their production is increasing in India. Details of the various methods of fabric production are set out below.

7.6.1 Woven production

The major portion of woven coir products are manufactured by using the simple method of the interlacement of warp and weft. The woven products are broadly classified into three groups: mats, matting and carpets.

Mats

Coir mats are mainly classified into two categories, brush mats and non-brush mats. In brush mats, warp and weft are interlaced with simple weaving

Table 7.4 Standard mat sizes

Size number	Dimensions in mm
0	550 × 330
1	600 × 350
2	700 × 400
3	750 × 450
4	850 × 500
5	900 × 550
6	1000 × 600
7	1050 × 650
8	1150 × 700
9	1200 × 750

techniques, using two to three shafts, to form the base fabric into which the brush is interlaced using various suitable techniques and in this way producing different types of mats. The brush may be cut or uncut yarns or fibre. Brush mats are manufactured usually up to six feet (183 cm) in width, in required lengths. If the brush is yarn, this is interlaced with the lease fabric and cut on the loom by inserting a knife through a grooved iron rod over which the warp passes. The rod is then removed and the weft beaten up to the fell by the slay to secure the cut pile yarns. If the brush is fibre, small bunches (tufts) are inserted by hand on alternate warp yarns. After completing a row of tufts across the warp a pick of weft will be passed and pushed by the reed against the fell of the cloth, thus anchoring the tufts onto the warp yarns. The top portions of the tufts are then cut with scissors to the required height of the pile. The standard sizes for mats are set out in Table 7.4. Mats are also produced to required sizes.

In non-brush mats only warp and weft interlacement is used. These are comparatively thinner when compared to brush mats and are generally manufactured in small sizes for use as doormats only. Patterns can be woven into these mats by using different coloured yarns or fibres. Details of the different types of coir mats and their end uses are described in the section on matting below.

Machinery

Coir mats are generally manufactured on traditional wooden or iron hand looms. The weaving technique is also very simple. The only exception to hand-weaving is one particular variety of mats, creel mats, which are also manufactured on power looms, but the quantity produced in this way is very small. For hand weaving on these looms the weft is hand wound onto flat wooden pieces specially made for the purpose. Non-brush mats are manufactured on various types of wooden frame. In the case of the most important variety, called corridor mats, a number of iron rods equal to the number of warp ends required are arranged on the frame. The weft yarn is then wound over and under alternate rods. After winding the required number of weft yarns the rods bearing the weft yarns are removed from the frame, placed in a hand press and pressed to the required width of the mat. The rods are then pulled out, one by one, and the warp yarn inserted with the help of an iron rod similar to a needle. The rods are about 60 cm long.

Matting

Coir matting is brushless and is produced by using simple two- to four-shaft weaves as well as more complicated designs. In the simple weaves the variety of designs produced are bicoloured, striped, checked and other designs. These mattings are reversible. Three-shaft weaves are used in order to get sturdier mattings than ordinary two-shaft weaves but this also enables the production of twills, herringbones (known as VV designs) and other weaves. The main defect in using a three-shaft weave is that the matting is not reversible.

Four-shaft weaves are another common type of weave used in coir industry. These produce a more compact fabric than does the use of two- or three-treadle weaves mentioned above. Design effects produced include twills, herringbones, diamonds, stripes, solid colours and others; these mattings are beautiful and reversible. Only relatively simple designs can be produced by using the above weaves. If more complicated designs are to be produced Jacquard weaving mechanisms are required. Coir matting is produced in rolls of different widths ranging from 30 cm up to 5 m and in lengths from 25–50 m per roll.

Machinery

The machinery used for manufacturing matting is mainly of two types, traditional handlooms and power looms. For handloom weaving yarn preparation includes sorting, splicing, spooling, warping and beaming. Sectional warping is used because single-beam warping is not practical due to the bulky nature of the fibre. All this preparation is done on wooden equipment. If the yarn is to be woven on ‘improved’ handlooms, called bobbin looms, the warp yarns are not wound onto a weaving beam but onto bobbins, using bobbin winders. These are then arranged on a creel which holds as many bobbins as the number of warp ends required to weave the particular matting to be produced. The yarns are then drawn between tension beams fitted with emery fillet and fed through the heddle frames. This system avoids warping.

In handloom weaving production per worker per shift of eight hours is around 12 to 15 sq. yards (10 to 12.5 m^2). The number of workers working on a handloom will be in proportion to the width of the loom, one weaver controlling up to one metre in width. To a certain extent power looms are also used to weave matting of 1–5 m width. In these looms the yarns are drawn directly from creels as in the case of bobbin handlooms. In this case the weft yarn is wound onto cops by cop winders. One weaver is required per machine to replace empty cops and to attend to yarn breakages.

The Coir Board of India has developed a semi-automatic loom for manufacturing coir matting. In this loom the picking is manual but all other operations are done mechanically. The main benefit of this loom is that it produces material of more consistent quality than that produced on handlooms. However, handlooms require much less investment than power looms, but their production is lower.

In ordinary power and semi-automatic looms only simple weaving techniques using two-, three- and four-shaft mechanisms are used and therefore the designs formed on these will be of limited complexity. For more complicated designs dobby and jacquard mechanisms are used.

Carpets

Coir carpets, also known as Mourzouk Carpets, are one of the most attractive coir products. A particular type of weave known as Mourzouk weave is used and the peculiarity of this product is that the weft is predominant and the designs are formed by using different coloured weft threads. To produce the design weft threads are individually dyed and woven into the warp in the appropriate order to make up the design. The warp threads are concealed. In ordinary coir matting the warp is equally or more predominant than the weft and the designs are formed by both warp and weft. By using the Mourzouk weave any type of intricate and attractive design of regular or irregular shape can be manufactured. This product is available in rug sizes.

Machinery

Mourzouk carpets are manufactured on slightly modified traditional handlooms only.

7.6.2 Non-woven products

Coir non-woven products are manufactured using bonding and needling techniques with easily curable products, for example polyvinyl chloride (PVC), or rubber. These are used as bonding agents in standard curing processes. Coir pile fabrics, apart from brush mats, are generally made in this way. On the other hand, in the production of needle-punched non-wovens, simple needling is sufficient; no bonding agent is required and other fibres, such as jute or wool for example, can be mixed with coir to form the final product. When producing blended non-wovens the fibres may either be mixed or used as separate layers in the fabric. Non-woven fabrics are mostly produced in roll form.

Another important non-woven product is rubberised coir. The coir fibre, extracted from dry coconut husk, is fed into a heavy-duty curling machine which twists the fibre into a fairly thick yarn. Twist continues to be added to the yarn until it curls up on itself into a single-ply rope. This is kept for three to four months so as to set the curl in the fibres. This rope is then de-twisted which, as it is single ply, will free the individual fibres which take the form of small springs. These 'spring' fibres are spread to form thin layers and sprayed with latex (plus suitable chemicals). and passed into a vulcanising chamber. After vulcanisation the sheets will be about 1.25 cm thick and these individual sheets are then pasted again with rubber latex and vulcanised again to form the required thickness of the final product.

Machinery

Unlike most other coir products, coir non-wovens are mainly machine manufactured. The most important coir non-wovens, PVC tufted products, are manufactured on a production line consisting of a creel with a tensioning device which holds the yarn in position, a yarn cutting head, a PVC layer spreader, the tufting mechanism, the curing chamber, a shearer for cutting the brush and arrangements for cutting the rolls to size along with the required conveyor systems. The investment required is considerable, approximately US$220,000, and the productivity of the machinery is high, about 800 m^2 per eight-hour shift. Machinery for tufting into a rubber base as is done with PVC has yet to be developed. However, the manual tufting of coir to a rubber base to make small-sized mats is currently practised These machines are locally manufactured but due to their low productivity are not in large-scale use.

In the case of rubberised coir a series of machines is also required. They are the machine for de-twisting the curled coir, a sheet-forming machine with arrangements to spray rubber latex on both sides of the sheet, a vulcanising chamber, cutting machines and arrangements for stitching the cotton cover. The most important of these is the sheet-forming machine. This machinery is made indigenously.

7.7 Products and applications

As already mentioned, Coir gives a variety of eco-friendly products suitable for industrial, commercial and domestic uses. The main items are coir fibre, yarn, mats, matting, geotextiles, garden articles, coir ropes, and fenders. These products and their main applications are described below.

7.7.1 Coir fibre

Coir fibre is the basic raw material for spinning coir yarn. Over and above this basic use it is the main constituent of a recently developed wood substitute. Fibre is also used in the manufacture of certain varieties of mats. Baby fibre (fibre cut into small pieces) is used as pot filling material in horticulture; it is also a good packaging material. Coir fibre is also used, at present only to a small extent, in the manufacture of composite panels for the interior trim of automobiles.

7.7.2 Coir yarn

Coir yarn is the main product used for manufacturing other coir products such as mats, matting, ropes, etc. It also has several other uses. It has been, and still is, the main binding material used in the construction of wooden ships. As these yarns give good grip to climbing plants and are eco-friendly they are widely used in the cultivation of hops. Due to its resistance to slippage it also is used as a good binding (tying) material. Coir yarn is also used in greenhouses as an 'air-cooler. For this, the sides of the greenhouses are covered by strings of two-ply yarn hanging close to each other. These are then soaked with water. When air penetrates into the greenhouse through these wet strings, the water evaporates and by doing so cools the air inside the greenhouse. The specifications of the important varieties of yarn used for the above purposes are given in Table 7.3 above.

7.7.3 Coir mats

There are a number of Coir mats manufactured as described in section 7.6.1. They are required for different occasions and uses. Details are described below. Indian quality codes and specifications of important varieties of these mats and mattings are set out in Appendix F.

Fibre mats

This is the most important variety of coir brush mats. The presence of individual fibres in the brush provides a good brushing effect and hence they serve as very effective doormats. These mats are very good examples of fine craftsmanship and a wide variety of designs can be woven into them using dyed or bleached fibre. As stated above in section 7.6 very attractive and complicated designs can also be printed onto the mats on natural or bleached grounds, using dyestuffs or enamel paints. These mats are excellent examples of 'fitness for purpose' and in addition are aesthetically attractive. In some areas coir fibre mats are used for polishing glass bangles. The quality code of the most common item is FM2.

Creel mats

This variety is a brush mat with warp cut pile. This is comparatively cheaper with less pile height, woven both on hand looms and power looms. Beach creel mats, made from cheaper beach yarn, are cheaper than vycome creel mats, made out of vycome yarn. Both are available in natural or bleached colour or with printed designs. Their main use is as doormats for short-term uses. The quality codes are BC, VC, etc.

Rod mats

This is a type of brush mat with higher pile height. This is also manufactured with beach and vycome yarns and generally exported in natural colour. This variety is used for doormats and dumping mats, for example. The cheapest quality, with thin pile, is also used as a medium for seed germination as coir has good water-holding capacity which provides sustained moisture during growth. The quality codes are BR, VR, etc.

Gymnasium mats

This is a special type of mat used in gymnasia. They are available in different thicknesses starting from 6 cm. They can be manufactured with cordage handles for easy handling and are available in different sizes, the standard size being 6×6 ft (183×183 cm). Cheaper varieties are used as dumping mats. The quality codes are BG, VG, etc.

Non-brush mats

Coir mats without brush are generally manufactured on frames. Corridor mats which are the most important non-brush mats are also known as Hollander or Dutch mats. Other types are Sinnet mats (also known as chain mats or braid mats), Mesh mats, Rope mats (also known as lovers' knot mats). They are generally used as doormats. Rope mats, made out of coir rope, are sturdier in construction and are also suitable for outdoor uses. The way in which these are made is described in Appendix D.

7.7.4 Coir matting

Coir matting manufactured as described in section 7.6.1 is put to many uses; for example wall-to-wall floor covering, wall panelling, echo controlling. Coir matting, cut to required rug sizes with four sides stitched and with or without different types of webbing serve as good decorative items for living rooms. Since coir has an inherent ability to control excess heat and cold it serves as an excellent floor covering, especially under cold conditions. The echo-controlling quality of coir makes it a good material for furnishing large auditoriums, for both floor and wall coverings. Its capacity to resist dampness makes it a good rug for temporary uses on lawns and other open areas.

Coir matting mats

Coir matting cut to small mat sizes in different dimensions and with rubber backing and edging serves as very good doormats in the cheaper price ranges. This matting is also made into square tiles with rubber backing and edging for floor coverings and into moulded car mats.

7.7.5 Coir carpets

Coir carpets, also known as Mourzouk Carpets, are a beautiful range of furnishing materials in rug sizes. With the possibility of incorporating any complicated design by weaving, this variety is extensively used as decorative floor coverings for domestic and commercial use, especially where they may be subjected to heavy use.

7.7.6 PVC-backed coir mats

Manufactured as described in section 7.6.2, PVC-backed coir mats are a kind of pile mat. This item is easily cut to any size and shape and used without any further finishing. They are widely used as doormats, runners, carpets, different shaped products such as show pieces etc. They are available in different pile heights starting from 14 mm.

7.7.7 Coir geotextiles

In the present world scenario, given the great importance of preserving nature, geotextiles are becoming increasingly important. Coir finds a major place in this market as it is 100% natural, can be completely absorbed by the soil within a period ranging from several months to several years, as required, and is an excellent replacement for synthetic fibres which are extensively used at present. Due to its long-lasting qualities, coir provides better performance when compared to other natural geotextile materials such as jute; in soil erosion control, soil stabilisation and river embankment protection, for example. The different coir geotextile items are described below.

Coir mesh matting

Woven mesh coir matting is the most important coir geotextile. Mesh matting is made with different varieties of coir yarn in fairly open constructions with

Table 7.5 Specifications of popularly used coir mesh matting

Designation code (1)	Type of warp yarn (2)	Approximate scorage of warp yarn (3)	Ends per dm (4)	Type of weft yarn (5)	Picks per dm (6)	Mass kg/m^2 (7)
MMA3 (H2M8)	Anjengo	12	11	Aratory	7	0.700
MMA4 (H2M9)	Anjengo	11	13	Aratory	7	0.900
MMV1 (H2M5)	Vycome	13	9	Vycome	8	0.740
MMV2 (H2M6)	Vycome	12	4.6	Vycome	4	0.400

dm: decimetre (10 cm).

varying strengths and mesh sizes. The item required for a particular use is selected on the basis of several criteria; the slope of the ground, the type of soil, climatic conditions and possibly others. The specifications of the most popularly used coir mesh matting are described in Table 7.5. Although these are open fabrics their construction remains stable during handling because the roughness of the fibres and yarns provide sufficient friction to prevent yarn slippage.

These mesh mattings are also available in the form of loop fabric, where loops of coir yarn are formed on the surface of the matting by using rods during weaving. These loops give extra grip for the plants growing through the mesh and thus give added strength to the combination of matting and plants.

Coir (coco) logs

Coir log is manufactured by filling tubular nets made out of coir (or if necessary synthetic) twine with coir fibre or coir needle felt. The resulting shape is that of wooden logs. These logs are used for controlling soil erosion on river banks and other places subject to heavy water flow and when fixed in position they allow the water to drain away whilst retaining the soil. In order to help the easy growth of vegetation around the logs, layers of wood charcoal are also placed in the nets with the coir to serve as manure for the plants. These logs are available in a range of sizes, but the most used are 12–18 ins diameter and 10–20 ft. long (30–45 cm diameter and 3–6 m long).

Coir bed

Coir bed is manufactured by filling bags made from mesh matting with coir fibre. These can also be used to control soil erosion. Beds with portions cut out at specific distances so as to enable the placing of plant saplings are also available on the market. Another use of coir bed is for seed germination in nurseries. After germination, the whole coir bed, with the saplings, is taken to the final site of cultivation.

Coir needled felt blanket

Coir needled felt is manufactured as described in section 7.6.2 and is available in different densities. When applied in blanket form it is a good soil erosion control material and will encourage vegetation growth. It can also be cut to required sizes and shapes and used as basket liners, mulch material, seed germination pots, moulded pots, soil conditioners, coco poles, etc. It is also an excellent packaging material.

7.7.8 Coir rope

Coir rope is spun from coir yarn and available in shroud laid (three-strand) and hawser laid (four-strand) constructions. Due to the peculiarity of the fibre, coir rope has better 'grip' when compared to synthetic ropes and is therefore easier to handle for ordinary uses. Coir rope is available in different thicknesses starting from half to five inch (1.25–12.5 cm) diameter. In addition to its conventional uses coir rope is now being used on a large scale for growing mussels. For this, ropes of approximately one inch diameter in continuous length of 200–250 m are used. European Countries, especially France, are the main users of coir rope for this purpose.

7.7.9 Coir fenders

Coir fenders are manufactured by knotting coir rope in a particular way over an inner core made to the required shape from coir yarn or fibre. They are available in spherical and cylindrical shapes with handles made from coir rope. In addition to their marine use to prevent damage to ships during berthing they are also used as decorative pieces in hotels and other public places.

7.7.10 Coir garden articles

There are a number of garden articles manufactured from coir. These include coir poles used as climbers for creeper type plants (grow sticks). These are made by covering wooden poles with fibre or rubberised sheets and winding coir yarn tightly round the poles. These are generally three feet (approximately 90 cm) long and PVC tubes are sometimes used instead of wood. Other gardening articles include small coir pots used for growing seedlings, larger pots used as inner liners, husk chips and baby fibre used for pot filling, etc. Birdnests made from coir are yet another item; these are made by hand stitching thin varieties of two-ply yarn.

7.7.11 Rubberised coir products

The rubberised coir sector offers a range of products suitable for modern comfortable living. The soft but stiff nature of rubberised mattresses (rubberised coir sheets covered and stitched with thick cotton fabric) are recognised as providing comfort with good back support and are accepted as being amongst the best products available on this market. Cushions, pillows, bolsters, etc., made from rubberised coir are also available. The bare sheets (without cotton fabric covers) are used as packing material for sophisticated engineering products.

7.8 Handle and wear characteristics

Coming under the group of industrial fibres, coir fibre is well known for its stiffness and resilience. It can withstand large amounts of pressure and abrasion and recovers as soon as the pressure is removed. Coir fibre is categorised as a wood fibre having a lignin content of about 45%. Due to this, the floor coverings made from coir are very much more durable (but not as soft) than jute or wool. Comparative figures of the properties of coir with some other natural fibres are given in Table 7.6.

Unlike the soft vegetable fibres coir is devoid of any mesh structure. Coir's extension at break is far greater than that of these fibres and therefore it is better able to withstand sudden loading. Coir density is low due to its porosity. About one-third of the fibres are filled by air, which imparts its springiness. Efforts are being made to soften coir fibre. Experiments conducted at the Central Coir Research Institute by the Coir Board reveal that softening using a vegetable oil and water emulsion with added urea is effective in softening coir fibres. Further work in this area continues.

7.9 Economic and cost considerations

In the present world of stiff competition, the marketing of products of good quality at reasonable prices is very important. Coir being a natural product manufactured mainly by small 'cottage industry' operations is well placed to benefit from this situation. Coir products should not be compared to similar

Table 7.6 Comparative properties of a few natural fibres

Property	Jute	Sisal	Coir
Width or Diameter (mm)	–	50–200	100–450
Density (g/cc)	1.3	1.45	1.40
Micro-fibrillar angle (degree)	8.1	10.22	30–49
Cellulose/lignin content (%)	61/12	67/12	43/45
Elastic modulus (GN/m^2)	–	9–16	4–6
Tenacity (MN/m^2)	440–533	568–640	131–175
Elongation (%)	1–1.2	3–7	15–40
Aspect ratio (L/D) (mm)	152–365	–	35

Table 7.7 Prices of comparable qualities of floor coverings made from coir, jute and sisal (prices in US$/m^2 FOB)

	Coir	Jute	Sisal
1. Panama matting – natural colour (latex backed)	2.5	3.00	7.00
2. Panama matting – bleached (latex backed)	3.0	3.50	–
3. Boucle matting – natural (latex backed)	3.80	4.25	8.00
4. Boucle matting – bleached (latex backed)	4.6	5.00	–

products made from synthetic fibres as their characteristics are very different; however, they can be compared to products made from jute, sisal and other bast and leaf fibres. The half million artisans engaged in the production of coir throughout India can provide coir at a reasonably low price when compared to jute and sisal products also manufactured in India. Examples of the FOB prices of comparable qualities of coir, jute and sisal products are given as Table 7.7.

Coir is a bulky material when compared to jute and sisal and therefore freight costs will be higher. Hence the delivered cost in distant markets may be comparable to those of jute or sisal. However, coir has specific qualities which give it advantages over other natural fibres, and due to this the world demand for coir is increasing year by year. Some comparative prices are illustrated in Table 7.8.

7.10 Marketing

Marketing occupies an important position in the organisation of a business unit and, in fact, it is the essence of all business. It is the function of a business concerned with the creation of a customer. The creation of a customer entails the identification of customer needs and organising the business to meet these needs. Marketing is also defined as the delivery of customer satisfaction at a profit. Sound marketing is critical for the success of any organisation. Exporters of India's coir industry have always accepted these points.

Table 7.8 Comparison of prices and other characteristics of coir and other fibres

	Coir	Sisal	Jute	Hemp
Price per tonne $US Sept. 2003	600–650	1900–2000	550–600	550–600
Density g/cc	1.4	1.45	1.3	NA
Resilience (modulus)	4.6	9–16	NA	NA

Table 7.9 Import tariffs of major importing countries (May 2003)

1.	USA	0–4.6%
2.	UK	0–10.4%
3.	Australia	0–10.8%
4.	Germany	0–6%
5.	Denmark	0–5.8%
6.	Sweden	Nil
7.	Portugal	4–9.6%
8.	Greece	0–9.6%
9.	Canada	Nil
10.	Pakistan	15–35%

After India's independence in 1947 and the subsequent closure of the European companies the individual exporters maintained existing relations with the broad sales network covering overseas importers and agents.. Exports of coir products from India are now handled by about 250 exporters; these include large, medium and small companies, public and private limited companies, proprietary (single-owner) concerns, government undertakings and workers' co-operative societies; all of which compete fairly with each other. Most of these exporters are capable of supplying all types of product including PVC tufted products, and they export to about 80 countries in the world.

The marketing of coir has a special nature. Coir is generally a buyers' market. Hence the importers and agents, and not the producers, decide on the type, quality, design and other specifications of the product to be marketed in a particular season. Based on these estimated requirements they then place firm orders with the exporters. Generally exporters only manufacture products after receiving firm orders. The lead time from receipt of order to despatch is about one month but this may vary slightly according to circumstances. In exceptional cases exporters will keep a stock of manufactured goods if they are sure to receive specific orders for them. A list of exporters representing all sections mentioned above and of the three exporters associations is given in Appendix E.

Some importing countries levy import duty on coir products. These tariffs vary from product to product and country to country and Table 7.9 gives the range of tariffs levied by some of the major importing countries. These tariffs are liable to be waived or reduced on production of country of origin certificates under the Generalised System of Preferences Scheme. Various agencies in India including the Coir Board are authorised to issue such GSP certificates.

7.11 Production and consumption

7.11.1 Production and exports

Coir is produced in about ten countries. However India and Sri Lanka account for the major portion of world production. Details are given in Table 7.10.

Table 7.10 Estimated production of coir products in India and Sri Lanka (tonnes)

	India		Sri Lanka	
	1999–2000	2000–01	1999	2000
White fibre	120,000	120,000	55,242	55,100
Brown Fibre	236,000	244,000		
Bristle fibre	–	–	4,081	5,103
Mattress fibre	–	–	23,222	28,919
Twisted fibre	–	–	19,512	21,078
Coir yarn	222,300	233,400	–	–
Coir Products	64,900	71,500	–	–
Coir rope	48,900	51,300	–	–
Curled coir	29,800	31,000	–	–
Rubberised coir	46,300	51,000	–	–
TOTAL	768,200	802,200	102,057	110,200

Table 7.11 World exports of coir and coir products (1996–2000) (tonnes)

Country	1996	1997	1998	1999	2000
APCC Countries*	**102,283**	**104,810**	**112,337**	**110,002**	**117,394**
India	*44,660*	*46,223*	*51,139*	*50,697*	*56,046*
Coir yarn	13,631	14,238	17,845	13,095	14,817
Coir matting	7,136	7,392	6,769	6,932	8,288
Coir mats	20,962	21,450	20,560	25,344	28,944
Coir rope	108	87	183	243	298
Rugs & carpets	2,190	1,895	3,183	3,285	2,603
Rubberised coir	209	227	431	650	402
Others	424	934	2,168	1,148	694
Indonesia	*866*	*595*	*30*	*59*	*102*
Malaysia	*110*	*225*	*139*	*65*	*52*
Philippines	*927*	*1,001*	*1,818*	*1,504*	*1,509*
Sri Lanka	*52,402*	*51,973*	*54,106*	*50,787*	*52,430*
Mattress fibre	24,384	26,072	20,083	23,222	24,508
Bristle fibre	5,515	5,696	5,014	4,081	4,325
Coir yarn	849	945	780	486	768
Twisted fibre	18,635	18,086	25,761	19,512	17,863
Coir twine	3,019	1,174	2,468	3,486	4,966
Thailand	*3,318*	*4,793*	*5,105*	*6,890*	*7,255*
Other countries	**300**	**300**	**300**	**300**	**300**
TOTAL	**102,583**	**105,110**	**112,637**	**110,302**	**117,694**

* APCC: Asian and Pacific Coconut Community.

Production of the other countries is nominal. According to the Asian Pacific Coconut Community (APCC), world exports of coir and coir products in 2000 totalled 117,694 tonnes. India accounted for 56,046 tonnes and Sri Lanka for 52,430 tonnes. India having been in the industry for quite a long time, exports more value added products than Sri Lanka, whose main export is still coir mattress fibre. Table 7.11 shows the world exports of coir and coir products during the years 1996 to 2000.

[*Editor's note*: (a) Set out in Appendix C on page 305 are the annual world coir production statistics, by country; for each year between 1999 and 2003, and for every five years between 1964 and 1999. These show that the total production over this period increased by over 50%, the increase starting in the early 1980s. However, during this period Sri Lankan production decreased, as did Malaysia's, whilst India's more than doubled. In percentage terms Thailand increased production by 800%, but from a very low base of 2,500 tonnes and a 120% increase took place in one year, from 2002 to 2003. Also in Appendix C is a graph, prepared by Mr Gordon Mackie[1] which forecasts an encouraging future for coir (see page 306).

(b) There is, of course, in Tables 7.10 and 7.12, what could be called a certain amount of double counting in that fibre is present in these tables as fibre, yarn and products and whilst their totals are interesting as a measure of economic activity, they must not be considered as a total weight of fibre produced or consumed. Production tonnages are clearly set out in Appendix C.]

7.11.2 Domestic consumption (India)

As mentioned above, India and Sri Lanka are the main producers of coir in the world. The majority of India's production, amounting to 80% (by weight), is consumed in the domestic market and only 20% is exported. Table 7.12 gives the details of domestic consumption of various items of coir in India during 1999–2000 and 2000–2001. The domestic consumption of Sri Lanka is negligible.

Table 7.12 Indian domestic consumption of coir (tonnes)

Item	1999–2000	2000–01
Coir fibre	35,800	37,000
Coir yarn	109,000	110,000
Coir products	18,000	24,000
Coir rope	50,700	51,000
Curled coir	1,720	1,900
Rubberised coir	45,600	48,500

Table 7.13 Major importing countries of coir products in 2000 ('000 tonnes)

Country	Coir fibre	Coir yarn	Coir mats, matting & rugs
1. USA	4.1	1.7	13.3
2. UK	6.5	0.1	4.9
3. Netherlands	2.6	2.1	2.9
4. Germany	10.1	1.6	2.6
5. Japan	5.7	–	0.7
6. South Africa	1.7	–	–
7. Australia	0.6	–	1.5
8. France	0.5	1.8	1.3
9. Portugal	1.8	0.4	0.1
10. Belgium	0.3	1.1	2.2
11. Greece	1.3	–	0.2
12. Italy	0.6	3.6	1.2
13. Spain	0.7	0.5	0.9
14. Pakistan	1.2	0.5	–

7.11.3 Imports

The USA is the biggest importer of coir products in the world. In 2000 they imported 19,000 tonnes of coir; the other major importers are Germany, the Netherlands, the UK, Japan, Italy, Belgium, France and Australia. The USA imports mainly coir mats, matting and ropes along with coir fibre whereas Germany, the UK, Japan, etc., import more coir fibre than products. Italy and Netherlands are the main importers of coir yarn. The imports of coir by the major importing countries during 2000 are given in Table 7.13.

7.12 Environmental and health and safety issues

7.12.1 Introduction

Coir, being a 100% natural fibre extracted under natural conditions, has few problems with the environmental, health and safety aspects of its production. Even though it is claimed that the manual extraction of coir fibre after retting is harmful to the labourers engaged, as they sit for hours at a time, this has yet to be scientifically proved. Moreover, with the introduction of the mechanical extraction of fibres, this conventional method is now limited to one or two districts in Kerala State and even in these districts manual fibre extraction is falling and is expected to cease within a short period of time.

7.12.2 Natural retting

Traditionally, coir fibre was extracted from coconut husks after natural retting. In this process the effluents were carried away by tidal waters. These effluents are 100% natural and highly diluted with a low degree of toxicity and only the foul smell of this natural retting sites invites attention. Apart from this there are no serious pollution problems, and even this pollution is diminishing as the trend, due to economic and social changes, is towards a considerable reduction in the quantity of coir obtained by natural retting. Moreover, the Coir Board has developed a technology by which the retting can be done in concrete tanks and the rett liquor treated so as to neutralise the polluting ingredients.

7.12.3 Dyeing

Among the environmental problems arising from coir production, pollution by the effluents of coir dyeing is important because these contain residual dyestuffs. Even though, to some extent and where continuous dyeing is adopted, these residual dyestuffs will be utilised by the standing-bath method of dyeing, some liquor will inevitably be left at the end of the process. However, modern production practices employ approved non-azo dyestuffs and these are now increasingly used. Also several agencies are now establishing 'Common Facility Centres' for the use of small-scale manufacturers and this will also facilitate pollution control. The Indian Government's Pollution Control Board is extremely strict in implementing non-polluting methods of dyeing.

7.12.4 Sulphur smoking

Coir yarns and products are subjected to sulphur smoking before shipment. This is done both in order to disinfect them and to obtain a brighter colour. Sulphur smoking is done in airtight smoking chambers for about 12 hours. After completion and when the chambers are opened there is a possibility of the sulphur dioxide and other gases escaping. In order to overcome this difficulty the smoking chambers are fitted with the necessary equipment for collection and treatment of the sulphur dioxide gas, which is the main constituent, and which is converted to sulphuric acid. The Pollution Control Department ensures strict observation of these norms.

7.12.5 Accumulation of coir pith

Coir pith is a by-product of coir fibre extraction. In former days the pith was stored in heaps near the fibre extraction units and dust particles would spread over neighbouring areas. The Coir Board of India has developed a mechanism by which the coir pith can be converted into organic manure and used for agricultural purposes. As discussed in Appendix A on page 304 pith is now increasingly used in organic farming and horticulture, and its accumulation is being rapidly reduced.

7.13 Conclusion

Coir provides a livelihood to 500,000 poor people in India alone with low levels of atmospheric pollution. Being an ecofriendly, natural product from renewable sources, coir products serve mankind in several ways as a substitute for many synthetic products which are extensively used but are harmful to nature. Coir wood substitute will help to protect valuable forests. It is the duty of all nature lovers to give maximum encouragement to this industry.

7.14 Appendices

Appendix A: Non-textile coir products

Pith

Coir pith is the binding material which is the main constituent of the coconut husk. For each kilogram of coir fibre extracted about two kilograms of pith are produced. The accumulation of this pith in the coir fibre manufacturing units used to create pollution problems due to dust being blown all over the area by the wind. In addition large areas were required to store it. However, in recent years research by the Coir Board of India has demonstrated that pith has very good applications in various agricultural and horticultural fields. It has excellent moisture-retention capacity of 500–600%, high potassium content and low bulk and particle density. It is also reported that the high cation exchange capacity (CEC) enables it to retain large amounts of nutrients and the adsorption complex has high contents of exchangeable potassium, sodium, calcium and manganese.

Composted coir pith resembles peat and is commercially known as cocopeat. It is used for seed germination, raising seedlings, rooting cuttings and other forms of plant propagation, the hardening of plant tissue and for embryo cultured plants. It is also used in hydroponic systems of plant cultivation, glasshouse cultivation, soil conditioning, lawn making, etc. With the increased emphasis on organic farming and horticulture, coir pith is gaining in importance and relevance all over the world. It is exported in the form of briquettes and blocks; the Netherlands are one of the main importers.

Coir ply

Coir ply is a product developed by the Coir Board of India as a wood substitute. The product is made by bonding coir with phenolic resins, the coir content being approximately 65–70%. Since coir fibre is extracted from the fruit of coconut trees, which grow in abundance in several parts of the world, coir ply could make a material contribution to reducing the consumption of wood and thus save natural forests. The technology now developed is capable of producing products used, for example, for surfacing, panelling, furniture manufacture, and partitions. Further research is under way to produce coir ply grades suitable for shuttering and similar uses.

Appendix B: Chemical composition of new and old coconut fibres

	Water solubles	Pectins	Hemicellulose	Lignin	Cellulose
Young nut	16.00	2.70	0.15	40.50	32.9
Old nut	0.2	3.00	0.25	45.80	43.30

Source: Philippine Coconut Authority 1978, quoted by Jarman, C. *Plant Fibre Processing*, Intermediate Technology Publications, Rugby, UK, 1998.

Appendix C: World coir production 1964–2003

Table 7.14 World coir production 1964--2003 (tonnes).

	1964	1969	1974	1979	1984	1989
World	393,157	411,818	389,211	395,488	425,422	543,499
Bangladesh	8,057	10,618	7,911	9,188	10,622	10,699
India	187,400	217,700	224,000	209,400	256,800	347,700
Malaysia	41,200	47,500	43,300	43,900	48,000	45,300
Sri Lanka	154,000	135,500	109,000	127,000	103,000	132,000
Thailand	2,500	1,000	5,000	6,000	7,000	7,800
	1994	1999	2000	2001	2002	2003
World	695,800	654,190	682,790	658,390	632,290	636,640
Bangladesh	12,000	11,390	11,390	11,390	11,390	11,390
India	494,100	454,000	468,000	450,000	450,000	450,000
Malaysia	40,700	29,800	29,400	28,000	28,900	28,000
Sri Lanka	140,000	150,000	165,000	155,000	133,000	127,250
Thailand	9,000	9,000	9,000	14,000	9,000	20,000

Source: FAOstat.
Courtesy: Food and Agriculture Organization of the United Nations.

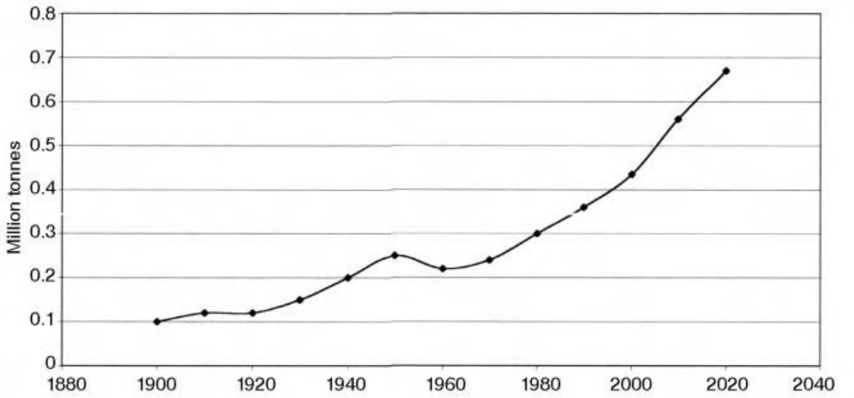

Figure 7.3 World coir production 1900–2003 and forecast to 2020. Courtesy: Gordon Mackie.

Appendix D: The manufacture of coir mats

The manufacture of corridor mats is covered above, in section 7.6.2.

Sinnet mats

A wooden frame is prepared onto which are fixed headless nails according to the design of the mat. Then coir yarn is braided to form flat braids; the number of yarns in the braid is generally 9 or 11, depending on the required quality of the mat. The braid is then guided through the nails in a zigzag path, leaving inner spaces and so producing the pattern; both the placing of the nails and the way in which the braid is guided through them will affect the quality of the mat. This is then followed by stitching, after which the mat is taken out of the frame and final finishing work done to produce the end-product.

Rope mats

A wooden frame is prepared in the same way as for sinnet mats. The coir yarn is plied into ropes of the required thickness and guided through the nails following a particular path. After completing one round, the process is repeated so that a minimum of four layers are formed. The number of layers will depend on the size of the mat. When this has been done the mat will be removed from the frame, the layers will be stitched and both ends of the rope will be merged into the body of the mat so that they are not noticeable

Mesh mats

A wooden rectangular frame is made to the size of the mat. Headless nails are fixed to all four sides of the frame. The warp and weft yarns are guided in between and around the nails along the length and width of the frame so as to be perpendicular to each other. Four layers, two of warp and two of weft, are laid alternately in this way and the mat will be made by tying them together where they intersect with a special knot. The mat is then removed from the frame an finished, using a suitable knotting technique.

Appendix E: Indian coir manufacturers and exporters trade associations

Travancore Coir Mats and Matting Manufacturers Association, Allepey, Kerala
Coir Shippers Council, Cherthala, Allepey, Kerala
Indian Coir Association, Kochi, Kerala.

Indian coir exporters

M/s. D C Mills (P) Ltd.,
P.B. No. 169, Alleppey,
Kerala – 688 001
Telephone: 0477 2251016, 225366, 2865373
Fax: 0477 2251301, 2251201, 2863019
E-mail: konath@md2.vsnl.net.in
Website: http://www.dcmills.com
Contact person: KJ Dennis
Constitution: Limited company

M/s. Foam Mattings (India) Ltd.,
P.B. No.4619,
Alleppey, Kerala – 688 012
Telephone: 91 477 2251172, 2254081, 2264223, 2264216
Fax: 91 477 2251654, 2263948
E-mail: fomil@md3.vsnl.net.in
Website: www.fomil.com/
www.Geotextile.org.
Contact person: P.R. Luis
Year of establishment: 1979
Constitution: Public company

M/s. The Goodwill Coir Manufacturing Co.
P.B. No. 2616, Canal Ward,

Alleppey, Kerala – 688 007
Telephone: 91 477 2246338, 2246340
Fax: 91 477 2244487
E-mail: goodwillcoir@satyam.net.in
Contact person: T.V. Sreedharan
Year of establishment: 1950
Constitution: Partnership firm

M/s. Alleppey Company Ltd.,
P.B. No. 2602, Tac House,
Alleppey, Kerala – 688 007
Telephone: 91-477-2245021, 2242330, 2242835
Fax: 91-477-2243161
E-mail: coir@glasmd01.vsnl.net.in
Website: www.karan-carpet.com
Contact person: N. Venugopal
Year of establishment: 1930
Constitution: Public company

M/s. Cocopalm Products Company,
P.B. No. 3, Vazhichery,
Alleppey, Kerala – 688 001
Telephone: 91 477 2244639, 2243132, 2251382
Fax: 91 477 2243132
Contact person: George Varghese
Year of establishment: 1958
Constitution: Proprietorship firm

M/s. Jos Coir Mills,
P.B. No. 80, Chungom,
Alleppey, Kerala – 688 001
Telephone: 91 477 2259058, 2243592 (RES)
Fax: 91 477 2243021
Contact person: K.A. Joseph
Year of establishment: 1996
Constitution: Proprietory firm

M/s. Madhavan Inc.
Zilla Court Ward,
Alleppey, Kerala – 688 013
Telephone: 91 477 2235900, 2235239, 223682, 223300
Fax: 91 477 2232131
E-mail: madinc@sancharnet.in

anilmad@sify.com
Contact person: Anil Madhavan
Year of establishment: 1993
Constitution: Partnership firm

M/s. Palm Fibres & Yarns Trading Company,
P.B. No. 37, Pathirappally,
Alleppey, Kerala – 688 521
Telephone: 91 477 2258172 (5 lines)
Fax: 91 477 2258171
E-mail: palmfibr@md2.vsnl.netin
palmfibr@sancharnet.in
Website: www.palmfibre.com
Contact person: Jose Paul Mathew
Year of establishment: 1965
Constitution: Limited company

M/s. Shertallai Coir Mats & Matting Co-op. Society Ltd.,
No. 240, P.B. No. 3,
Kalavamkodam P.O.,
Cherthala, Alleppey,
Kerala
Telephone: 91 478 2812520, 2813220, 2864227
Fax: 91 478 2814029
E-mail: shercom@md5.vsnl.net.in
Website: www.cocoscooperative.com
Contact person: T.C. Ranganathan
Year of establishment: 1958
Constitution: Co-op Society

M/s. Travancore Mats & Matting Company,
P.B. No. 5, Cherthala,
Alleppey, Kerala – 688 524
Telephone: 91 478 281 2528, 2217, 2238, 2825
Fax: 91 478 281 2906, 0484 6685
E-mail: tmmc@travancore.com
Contact person: V.R. Prasad
Year of establishment: 1917
Constitution: Partnership firm

Sri Lankan coir exporters

Sancta Maria Coir Products (Pvt) Ltd
Chilaw Rd
Modukatuwa
Maravila
Telephone: (94) 32 54435, 722 83040, 773 83667
Fax: 32 54269
e-mail: salea@sanctamari.com

Rileys Limited
53/6 St Jude's Mawatha'
Mahabage
Telephone: (94) 1 958668 / 959048
Fax: (94) 1 956637
e-mail: rileys@sri.lanka.net

Osni Lanka (Pvt) Ltd
7a Havelock Place
Colombo 5
Telephone: (4) 1 586511
Fax: (4) 1 502460
e-mail: info@osnilanka.com
Contact person: Niranga Hettiarachchi

Toyo Cushion Lanka (Pvt) Ltd
193 Minuwangoda Rd
Kotugoda
Ekla
Telephone: (94) 1 232939, 236635, 232942
Fax: (94) 1 23294, 23765
e-mail: toyo@sri.lanka.net

A more detailed list of Sri-Lankan coir fibre and products exporters can be obtained from the Coconut Development Authority of Sri-Lanka:

Tel: +94 11 250 2501/8730/2503
Fax: +94 11 250 8729
e-mail cdaho@sltnet.lk

Appendix F: Quality codes and specifications of important varieties of coir mats and mattings

Code	Slack chain	Tight chain	Weft	Type of yarn Pile	Con-struction	Ends/ dm	Picks/ dm	Pile Height mm	Mass gms/ m^2
1	2	3	4	5	6	7	8	9	10
Creel mats									
BC1	–	Beach	Beach	Beach	warp cut Pile	9	24	22	4800
BC2	–	Beach	Beach	Beach	do	9	24	25	5400
VC1	–	Vycome	Vycome	Vycome	do	9	25	22	5400
Fibre mats									
FM2	Vycome	Vycome	Vycome	Fibre	Inserted fibre	12	12	28	7800
Corridor mats									
RC3	–	rope yarn	Aratory	–	brushless	5	–	–	3350
WC3	–	do	Vycome	–	do	5	–	–	3050

Coir mattings

Code	Type of warp yarn	Approximate scorage of warp yarn	Ends/ dm	Type of weft yarn	Picks/ dm	Mass kg/m^2
1	2	3	4	5	6	7
2 shaft mattings						
M2A2	Anjengo	14	31	Vycome/Beach	11	1.55
M2R2	Aratory	14	31	Vycome/Beach	11	1.47
2 shaft basket weave mattings						
M2BA1	Anjengo	15	30	Anjengo/Aratory	17	1.72
M2BR2	Aratory	14	28	Aratory	17	1.72
4 shaft mattings						
M4A2	Anjengo	14	31	Vycome	13	1.75
M4R2	Aratory	14	31	Vycome	13	1.68
Mesh mattings (geo textiles)						
See Table 7.5 on page 295.						

7.15 Glossary of terms

Baby fibre fibre cut into small lengths.

Braid mat another name for sinnet mats.

Brush mat a coir mat which has pile.

Chain mat another name for sinnet mats.

Coco logs coir filled tubular nets (used in erosion control).

Cocos nucifera Latin name for coconut palm.

Coconut pith cork like spongy material embedded to the fibre in the coconut husk.

Coir bed coir filled mesh netting bags (used in erosion control).

Coir braid three or more strings of coir yarn plaited either by hand or by mechanical device with or without inner core.

Coir briquette briquettes made from coir pith/coir pith heat pressed with other ingredients into briquettes.

Coir cordage cords, ropes, etc., made from coir fibre or coir yarn.

Coir fender fender made with coir fibre, yarn or rope for inner core material and coir rope suitably knotted for outer shell in different shapes.

Coir rope a cordage made out of a number of strings of coir yarn first twisted to make strands and then to rope with a diameter of 8 mm and above.

Core yarn the yarn or string placed inside a rope, braid, etc., to give better shape, higher weight, etc.

Corridor mats coir mats, non-brush type, with low rib effect on both sides, manufactured on frames with the aid of iron rods. Both the warp and weft are continuous in the mat throughout.

Creel mats cut pile coir mats made on looms with two or more chains. Pile is formed by cutting the brush chain bend over a grooved iron rod.

Dutch mat another name for corridor mats.

Fibre mats coir mats with brush formed by insertion of tufts of coir fibre on alternate warp strands in the process of weaving.

Hollander mat same as corridor mats.

Latex backing backing given on coir products with rubber latex containing vulcanizing ingredients, non-staining antioxidants and fillers, properly expanded by mixing air.

Lovers' knot mat coir mats made from coir rope guided through nails projected on a wooden surface in a definite order and the starting and finishing ends of rope merged with the adjacent layers. Mats are made in oval, oblong and circular shapes. This mat is also known as rope mat.

Matting a woven fabric from coir yarn generally used as rugs, runners and wall to wall furnishing.

Matting rugs mattings of different weaves cut to rug sizes with ends bound, tucked in or fringed, as required.

Mattress fibre short and resilient fibre mechanically extracted from dry husks of ripe coconuts.

Mesh mats coir mats made on frames with nails projected on it, by laying yarn in criss-cross manner and knotting the intersecting points with coir yarn, producing a mesh effect.

Mesh matting the matting woven by positioning warp and weft relatively at higher distance to form mesh effect.

Non-brush mats coir mats without brush/pile.

Non-reversible mattings coir mattings with differential weave effects on face and reverse sides.

Ratt a manually operated set of wheels for twisting and spinning coir yarn.

Retting the process of keeping the husks immersed in water for a period ranging from six to ten months during the course of which the pith and other matters become loosened, allowing easy extraction of fibre.

Rod mats coir brush mats in which brush is formed by cutting coir yarns folded two, three or more together and wound by hand on a grooved iron rod along with alternate warp strands.

Rope mats mats made with coir rope.

Scorage of yarn a number indicating the fineness or coarseness of coir yarn, which is one twentieth of the number of yarns that could be laid close to each other without overlapping in a length of 0.914 m.

Sulphur smoking treatment before shipping to disinfect coir products and obtain brighter colour.

Sinnet mats coir mat made of coir braid guided between the nails projected on a flat surface as per design with stitches to hold the layers of braid together.

Sorting selection of coir yarn based on colour, twist, runnage, etc.

Spindles an iron or wooden rod shaped into a hook at one end having a stud at the centre to receive a string around from a large wheel for its rotation, used for imparting twist for spinning.

Stationary ratt the spinning wheel fixed on the ground used for making single strands of coir yarn and also for doubling.

Three-ply yarn wheel spun coir yarn in three-ply made from medium and short stapled fibre from retted husk, hard twisted and hard spun, Brown to grey in colour, hairy, hard and tough in texture, containing varying amounts of pith, in the runnage range 40–55 m/kg (scorage: 4–8).

Traditional loom a wooden handloom traditionally in use for weaving coir mats, mattings, carpets, etc.

Two-treadle basket weave a two-treadle weave in which two or more warp threads work together with two or more weft inserted in the same shed for successive picks.

Two-treadle plain weave plain weave in which warp and weft work one up and one down and one under and one over respectively.

Webbing the material in the form of tapes used for fastening the cut ends of coir matting by stitching/pasting or the process of fixing the webbing material at the cut edges of matting.

Yarn guide a wooden block in triangular shape or any other shape with grooves running along the length to receive primary strands, used for doubling process in spinning and rope making.

8
Abaca

R R FRANCK

Abaca (*Musa textilis*)[1] is also known as Manila hemp. It is a member of the Musacea (banana) family of plants.

8.1 The plant and its cultivation

The stem of the plant is made up of a central soft core, the stem proper, around which are tightly wrapped up to 25 sheaves; these, together with the core, form a 'proto-stem'. When these sheaf-leaves have reached an appropriate stage of maturity they unwrap from the proto-stem and take the recognisable shape of banana type leaves. The plant can reach a height of 7.5 metres and therefore, since the sheaf-leaves grow from the base of the plant some of the leaves, the inner ones, will be almost as long. The outer leaves, which develop later, are consequently shorter. The leaves grow to a width of about 30 cm.

Depending on the variety, of which there are many, the plant will live for between 5 and 25 years, but the longer-living varieties are not usually cultivated for more than 15 years as their productivity decreases from then on. The plants have a shallow rooting system from which sprout vertical pseudo-stems. As it develops, a single plant may successively produce as many as 25 of these stems, maturing at different times. When the plants are between 18 and 24 months old the first pseudo-stems are sufficiently developed to be harvested and three to four stems are then cut at intervals of from 6 to 12 months, depending on their rate of growth. This, in turn, will depend on the plant variety, the meteorological conditions and the type of soil. Abaca is a tropical plant which requires good soil and regular rain.

The pseudo-stems are ready for harvesting on flowering. The stalk is cut off, or 'topped' below the inflorescence with a sickle attached to a long pole and the pseudo-stalks are then cut at their base ('tumbled') and, depending on the method of fibre extraction, either stripped of their fibres *in situ*, or removed to the proximity of the decorticating equipment or machine (see below). The leaves vary in length, the outer sheaf-leaves being shorter than the inner ones.

8.2 The fibres

The leaves which surround the stem can be classified into four groups: the outer three leaves; a group of three to four leaves between the outer and the middle group; the middle group, four to five leaves; the innermost group of seven to eight leaves. Fibre strength and fineness depend on the position of the leaf in relation to the centre of the stem. The nearest to the centre, the finer, whiter and softer the fibres. The fibres are situated in bundles of various thickness that run the length of the leaves and there are also a few smaller transverse bundles at right-angles to these.[2] The physical and chemical characteristics of abaca fibres can be found in Tables 1.1, 1.6, 1.8, 1.9, 1.10 and 1.12 of the Appendix to Chapter 1.

8.3 Early processing

Fibre extraction is done by the growers and takes place as soon as is practical after the stems are cut, whilst they are still moist and the gums which bind the fibres to each other and to the rest of the plant have not yet solidified. The first stage, called 'tuxying' is to separate the fibre bundles from the remainder. Tuxying is done manually. The leaf-sheaves are separated from the cut pseudo-stems and laid on the ground. A curved knife is inserted at the butt end, between the outer and middle layers of the leaf-sheaf, the outer layer is then grasped firmly and pulled away from the rest of the leaf. The ribbons of fibre that result from this operation, the 'tuxies' are about 5–8 cm in width and are the length of the leaf. The second stage removes the gums and any residual leaf matter adhering to the fibres after tuxying. This is done manually, semi-manually or mechanically.

Manual stripping

The tuxies are drawn between the edges of a knife and a smooth wood surface. The wooden block and the knife, which is usually serrated, are fixed in a light wooden or bamboo structure which enables the standing operative to feed one end of the tuxie through the slit between the knife and the wooden block and then wrap it round a small wood cylinder. This cylinder allows the operative to keep a sufficiently firm grip on the tuxie as he pulls it through the slit between the wood block and the knife, an operation which requires the use of considerable force (Fig. 8.1). The width of the gap between the knife and the surface of the block can be slightly adjusted, according to the thickness of the tuxies, by applying foot pressure on a pedal linked to either the block or the knife. The operative then pulls the tuxie through the slit, applying the necessary pressure on the pedal to ensure adequate removal of the non-fibrous matter from the tuxie. After the first part of the tuxie is stripped the operative repeats the

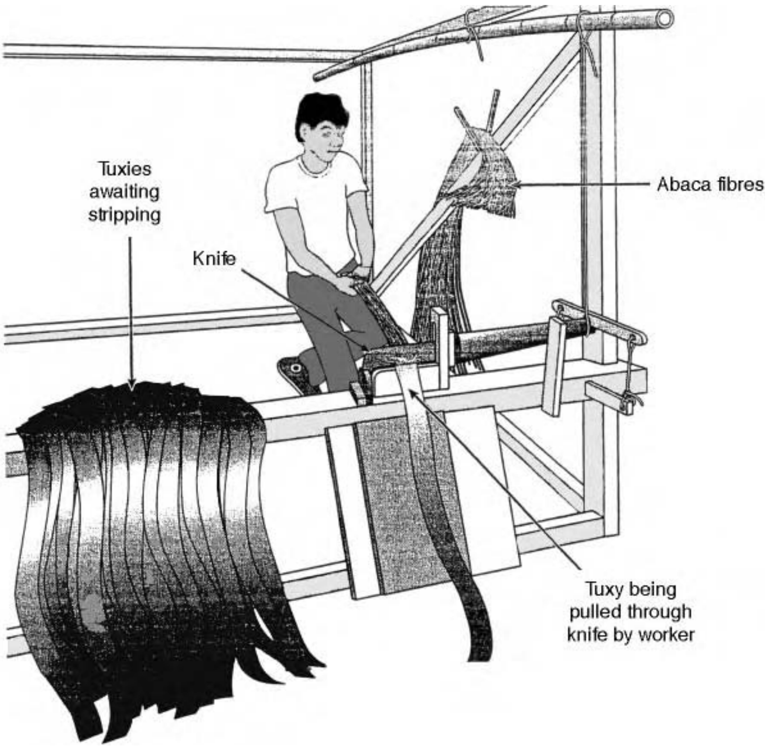

Figure 8.1 Hand stripping tuxies from abaca. Source: C. Jarman, *Plant fibre and processing: A handbook*. Courtesy: ITDG Publishing, UK.

process for that part of the tuxie which is not yet stripped because he was holding it in his hand. In this way the whole tuxie is stripped. Too little presure on the pedal will not adequately strip the tuxie but if the pressure is too great the fibres will be damaged and broken. The number of serrations of the knives used in stripping will vary according to the thickness of the tuxie and the thickness and strength of the fibres. Stripping is relatively skilled work and requires experience.

Spindle stripping

This is a mechanised version of the same principle used for manual tuxying. The machine, called a hagotan, consists of slightly tapered wooden cylinders set co-axially on a 'spindle' that is motor powered. This axle is set a convenient height so that, as in manual stripping, the operatives can feed the tuxies through the slit between the knives and the wooden blocks, attach them to the tapered cylinders by overlapping one or two turns of the unstripped tuxie and hold the tuxie as the power rotates the tapered cylinder so that the tuxie is stripped. As the wooden cylinders are tapered the operative can control the degree of stripping by guiding the tuxie across the cylinder, thus increasing or decreasing the speed at which the tuxie is pulled through the slit. A hagotan will have six or eight positions so that this number of tuxies can be processed at the same time. Hagotans increase labour productivity by two to three times compared to manual stripping.

Decorticating

This is a fully mechanised process, using a machine similar to a sisal decorticator. These machines process whole abaca stems. As one such machine can deal with the production of 2,000 to 2,700 ha they are used only on large plantations. Generally speaking the quality of fibre produced decreases with the productivity of the stripping process, but the price, naturally, increases with fibre quality. After stripping or decorticating the ribbons of fibre, which can be up to 3 m long, are hung up to dry, they are then graded, packed into bundles and baled for shipping.

There are two systems of grading used. For Philippine fibre, according to the manner of extraction, i.e. hand or spindle stripped, the fibres are graded:

Excellent; AD, EF, S2, S3
Good; I, G, H
Fair; JK, MI
Coarse; L, and
Residual; Y1, Y2, O, T, WS.[3]

Details of the grades used for different end products are set out in the Appendix. Grades for Ecuadorian fibre are 2, 3, 4, 5 and tow.

8.4 Textile manufacture and end uses

Abaca fibres are processed is a similar manner to sisal and other hard fibres, although the fibres do show a little more elasticity. The major outlet for abaca fibre is for high quality and specialised papers such as banknotes, meat casings, etc. Over half of the Philippines' production is consumed by this growing end-use. Abaca fibre textile outlets (30% of Philippine production) are similar to jute and include rope, cordage and twine, especially marine rope (where the good resistance to sea water and buoyancy are advantages), filter cloths, tea and coffee bags, disposable fabrics, reinforcement fibres for plaster, lighter weight woven fabrics mostly of an artisanal type, and other handicrafts. The cordage market is decreasing owing to competition from synthetic fibres.[3]

8.5 Production

Table 8.1 shows world production by country. The dominant producing country is the Philippines with some 70% of total production, followed by Ecuador with about 25%. The production of the other countries is very small. In the Philippines abaca production is concentrated in the three regions of Eastern Visayas, Bicol, and Mindanao.

As can be seen from Table 8.2 global production over the last few years has hovered around 100,000 tonnes per year and production in the early 1960s was also at about this level However, from 1977 to 1980 production was up to 60% higher, after which it decreased to its previous level. Over 65% of Philippine produced abaca fibre is consumed by the country's processing sectors. Exports of fibre, semi-manufactured and manufactured products for the ten-year period ending in 1999 totalled US$78 million, with about three-quarters of this export value being for semi-manufactured and manufactured products.[3]

Table 8.1 World abaca (Manila hemp) fibre production (tonnes) by country (2002)

	2002
World	99,320
Costa Rica	1,100
Ecuador	26,000
Equatorial Guinea	500
Indonesia	600
Kenya	30
Philippines	71,090

Source: FAOstat.
Courtesy: Food and Agriculture Organization of the United Nations.

Table 8.2 World abaca production 1961–2002 (tonnes)

2002	99,320	1989	81,935	1978	142,122
2001	98,232	1984	109,262	1977	168,309
2000	104,430	1982	128,697	1976	139,653
1999	99,840	1980	169,968	1969	113,801
1998	97,400	1979	160,746	1961	97,000

Source: FAOstat.
Courtesy: Food and Agriculture Organization of the United Nations.

8.5.1 The organisation of the industry

In the Philippines abaca production is in the hands of smallholding farmers, whilst in Ecuador the fibre is produced on large plantations, although there is also a co-operative of smallholders. In the Philippines the farmers, who produce and strip the fibre, sell it to local 'banranguay' dealers. These grade the fibre and sell it on to town/city dealers who then sell to exporters who deal with fibre merchants based in major economic centres such as London, Hamburg, Zurich, Tokyo and New York. There are cases where fibre producers sell directly to exporters who have their in-house grading operation and others where local co-operatives supply domestic processors.[3]

8.6 Appendix: Uses of Philippine grades of abaca fibre for various end-uses[3]

Grade	Cleaning	Layer of leaf sheath
S2	Excellent	Next to outside
I	Good	Innermost and middle
G	Good	Next to outside
JK	Fair	All except outside
Y2	Damaged during cleaning	All

Source: C. Jarman, *Plant Fibre Processing*, Intermediate Technology Publications, 1998.

8.7 References

1. Jarman, C. (1998), 'Jute-like fibres', *Plant Fibre Processing*, Intermediate Technology Publications, Rugby, UK
   Kirby, R. H. (1963), *Vegetable Fibres*, Leonard Hill Ltd, London.
2. Catlin, C. and Grayson, J. (1998), *Identification of Textile Fibres*, Archive Publications, London.
3. www.da.gov.ph/agribiz/abaca_new.html

8.8 Glossary of terms

Baranguay Local abaca fibre dealer.
Hagotan Machine for spindle-stripping.
Manila hemp Common name for abaca fibre.
Musacea textilis Botanical name of abaca plant.
Proto-stem Name of the central structure of the abaca plant.
Sheaf-leaf Leaf-like structure making up the proto-stem.
Spindle stripping Semi-manual removal of gums and extraneous matter from tuxies.
Topping Cutting-off the top part of the abaca plant during harvesting.

Tumbling Cutting down the proto-stem during harvesting of the abaca plant.

Tuxie Ribbon of abaca fibres after separation from the harvested leaf-stem.

Tuxying Stripping the tuxies off the harvested leaf-stem.

9
Pineapple, curauá, craua (caroá), macambira, nettle, sunn hemp, Mauritius hemp and fique

9.1 Pineapple

C YU and R R FRANCK

The pineapple (*Ananas comosus*) is a member of the Bromeliaceae family, which has some 1,300 species, most of which are native to South America. It is now widely cultivated for fruit in tropical and sub-tropical regions of the world. As with sisal fibre, pineapple fibre is extracted from the fresh leaf of the plant, and the appearance of the pineapple plant is also similar to the sisal plant except in so far as the fruit is concerned. Compared to sisal, the fresh leaves of the pineapple, with saw-toothed edges, are narrower, shorter, and therefore lighter. The length of pineapple fresh leaves varies within the range of 55–75 mm; the width of the leaves is usually in the range of 3–6 mm; the average weight of each leaf is 15–50 g.

The fibre yield of pineapple (extracted from fresh leaves of one to one-and-a-half-year-old plants[1]) is in the range of 1.55–2.5%. In the case of pineapple plants specially cultivated for fibre (not for fruit) the fibre yield is a little higher and the fibres are of better quality. In most cases the fresh pineapple leaves are a by-product of fruit production, and as such provide an added revenue source to the producers. As pineapple fibres are a natural and environmentally friendly product their use is expected to develop in many fields. Fifty years ago, in such countries as the Philippines, fibres extracted from fresh leaves were used to make clothing, but larger quantities were used to make ropes and twines.

9.1.1 Fibre structure and properties

The surface of a pineapple fibre shows numerous longitudinal cracks. The bundle is made up of smaller fibre bundles containing many fibres cemented together by gums. The cross-section of single fibres is irregularly round and the fibres have lumens. The microstructure of pineapple fibre is shown in Table 9.1. The chemical constituents of pineapple fibre is shown in Table 9.2. The chemical compositions of decorticated, retted and degummed fibre are also given in ref. 1 on page 327.

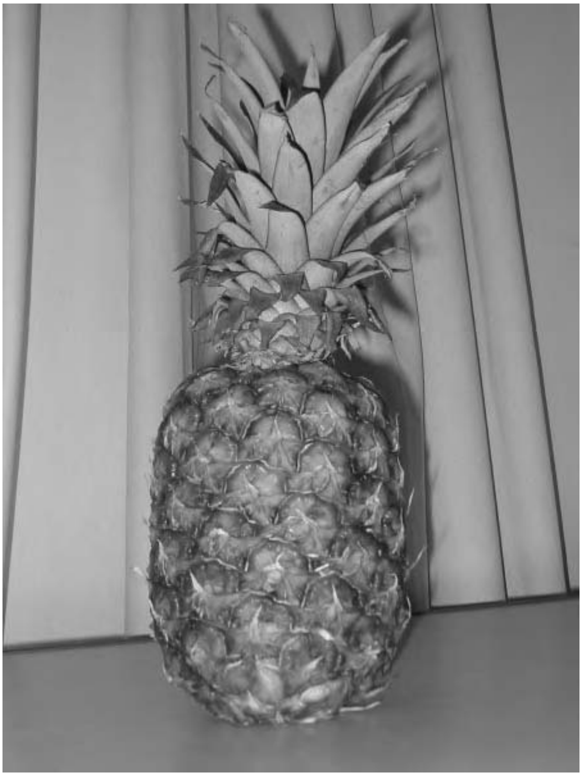

Figure 9.1 A pineapple. Courtesy: Ben Morriss, 2004.

The fibre bundle is comprised of many single fibres which are bonded together by gums such as pectins and other substances. The data in Table 9.2 shows that the chemical content of a pineapple fibre bundle is similar to that of other bast and leaf fibres. The lignin content is a little higher than that in ramie and flax, and is lower than in jute, kenaf and sisal. The physical properties of pineapple fibre are shown in Table 9.3.

Test results indicate that the properties of pineapple fibre are much closer to those of jute than to those of sisal, in other words the raw or fibre bundles extracted from fresh leaves are finer, weaker and softer than sisal fibre bundles. However, pineapple fibres are stronger and softer than jute fibre.

Table 9.1 Microstructure of pineapple fibre

Orientation		Crystallinity (%)	Birefringence	Density (g/cm^3)
Factor (f_x)	Angle (°)			
0.85–0.97	5	0.55–0.75	0.058	1.543

Table 9.2 The chemical constituents of pineapple fibre

(a) chemical content of a pineapple fibre bundle (%)

Cellulose	Hemi-cellulose	Pectin	Lignin	Water soluble materials	Fat and wax	Ash
55–68	15–20	2–4	8–12	1–3	4–7	2–3

(b) chemical composition of processed pineapple fibres (%)

	Alpha cellulose	Hemi-cellulose	Lignin	Ash	Alcohol/benzene
Decorticated fibre	79.36	13.07	4.25	2.29	5.73
Retted fibre	87.36	4.58	3.62	0.57	2.27
Degummed fibre	94.21	2.26	2.75	0.37	0.77

Source: I. Doraiswamy and P. Chellamani, 'Pineapple Leaf Fibres', *Textile Progress*, 24 (1) The Textile Institute, UK, 1993.

9.1.2 Processing and products of pineapple fibre

After cultivation, the fresh leaves are harvested and the fibres extracted. There are two methods used to extract the fibre from fresh leaves: (i) extracting fibre using decorticating machines, similar to the methods used for sisal fibre extraction; (ii) retting the leaves in water for 24–48 hours at temperatures of 15–30 °C after which the fibres can be easily separated from the leaves. This involves steeping the fresh pineapple leaves in water for five to ten days. Retting causes less damage to the fibres and maintains the high cellulose content of the extracted fibres than does decortication, at the cost of longer retting time.

The shape of the pineapple leaf is similar to that of sisal except that it has no 'saw-teeth' on the edges. Its size is smaller, which means the length of a pineapple fibre bundle is shorter and the fibre finer. The yield of fibre from pineapple leaves is usually in the range of 2–2.5% less than that of sisal which is about 5%. Decorticating machines used for sisal can also be used for pineapple fibre, except for small changes in the processing parameters because the pine-apple fibres are shorter, and finer, and therefore weaker than sisal fibres. After this early processing the extracted pineapple fibres, whose appearance is usually white and lustrous, can then be further processed according to the requirements of the end uses envisaged. [*Editor's note*: Decorticating machines specific to pineapple leaves have also been developed; these are described in ref. 1.]

For the purpose of rope and twine manufacture the pineapple fibre is usually processed on the jute processing system. In blended yarns the quality of the

Table 9.3 The physical properties of pineapple fibre

(a) physical characteristics of pineapple fibre

Single cell	
Length (mm)	3–8
Diameter (μm)	7–18
Fineness (tex)	2.5–4
Fibre bundle	
Length (mm)	10–90
Fineness (tex)	2.5–5.5
Tenacity (cN/tex)	30–40
Elongation (%)	2.4–3.4
Initial modulus (cN/tex)	570–700
Density (g/cm^3)	1.543

(b) leaf size of different varieties of pineapple

Variety	Length (cm)	Width (cm)	Thickness (cm)
Assam local	75	44.7	0.21
Cayenalisa	55	4.0	0.21
Kallara local	56	3.3	0.22
Kew	73	5.2	0.25
Mauritius	55	5.3	0.18
Pulimath local	68	3.4	0.27
Selangor green	55	3.1	0.18
Simhachalam	59	3.7	0.22
Smooth cayenne	58	4.7	0.21
Thaliparamba local	67	3.5	0.23
Valera moranda	65	3.9	0.23

Source: I. Doraiswamy and P. Chellamani, 'Pineapple Leaf Fibres', *Textile Progress*, 24 (1) The Textile Institute, UK, 1993.

yarns and their spinnability during processing will improve with the increase of the pineapple fibre content. For high-quality products of pineapple fibre, such as apparel, the raw pineapple fibres need to be further refined usually by degumming with chemicals or enzymes. The chemical degumming of pineapple can be processed according to the following procedures: preparation (immersion in acid, H_2SO_4) – washing – boiling in NaOH solution – washing – bleaching – water extraction – oiling – drying. It should be noted that the degumming process must avoid the complete removal of the gums because the single fibres, if separated from each other without the gum, cannot be spun due to their short length (as shown in Table 9.3). The effects of chemical degumming on pineapple fibres are shown in Table 9.4, which shows that the treated fibre has been improved in some properties, such as the softness,

Table 9.4 Properties of treated pineapple fibres

	Fineness (tex)	Length (mm)	Tenacity (cN/tex)	CV% of tenacity	Elongation (%)	Initial modulus (cN/tex)
Degummed fibre	1.86	–	37.52	30.52	3.85	8.78
Increment (%)	−38	–	−11.92	−9.43	−12.57	−12.11

elongation and the fineness of the fibre, at the cost of a decrease in strength and length of the fibres.

In general, the effects of sodium hydroxide concentration, treatment temperature, and time on the properties of pineapple fibre are similar to that of other fibres such as sisal, jute and ramie. The higher the concentration of sodium hydroxide, the higher the temperature and the longer the time of treatment, the greater the loss of weight and strength and the increase in the softness of the fibres. After degumming and or chemical treatment the pineapple fibre can be processed on both the cotton or worsted spinning systems. For pineapple fibres to be spun on the cotton system it is necessary to cut the pineapple fibre to a certain length, say about 30–50 mm, so that it can be blended with cotton or other fibres of appropriate length, both natural and manmade.

Fibres to be processed on the worsted system are, after being degummed or treated, already of appropriate length (between 50 mm and 70 mm) for this type of machinery. In China and India considerable research work on the processing of pineapple fibres both in cotton and worsted spinning systems is taking place. Some test results on the yarn are shown in Table 9.5.

Fabrics made from 100% pineapple yarns are usually stiff and have good air and water permeability because of the hard, coarse fibres and rapid absorption and release of water by the fibres. The appearance of the fabric is almost same as

Table 9.5 Properties of 100% and blended pineapple yarns

	100% P.*yarn	Cotton 65/P35	Polyester 70/P30	Wool 50/P50
Fineness (tex)	100	32	20	125
Tenacity (cN/tex)	10.91	10.1	7.89	7.71
CV% of tenacity (%)	14.6	13.8	15.0	23.11
Elongation (%)	3.2	3.14	3.7	3.58
Evenness of yarn (CV%)	–	33.15	28.5	16.67
Thicks (1/400m)	–	972	1434	–
Thins (1/400m)	–	1164	352	–
Neps (1/400m)	–	1664	2530	–

* Pineapple.

that of ramie and flax fabrics. The handle of pineapple fabrics is harsher than that of these fabrics, but softer than those of jute and kenaf. Therefore the pineapple fabrics, especially in blended fabrics, are considered to have potential applications in apparel, besides applications in upholstery. The dyeing performance of pineapple fibres and products is similar to that of other vegetable fibres such as flax and ramie.

Readers are referred to Doraisswamy and Chellamani's monograph on pineapple fibres, referred to in the text and published by the Textile Institute, Manchester UK (*Textile Progress*, vol. 24 no. 1) for more detailed information and discussion on this fibre, its processing and the possibilities of blends with other fibres.

9.1.3 Reference

1. Doraisswamy, I. and Chellamani, P. *Textile Progress*, Vol. 24, No. 1, Textile Institute, Manchester, UK.

9.2 Curauá

R LADCHUMANANANDASIVAM and R R FRANCK

[*Editor's note*: I am indebted to Prof. Dr R. Ladchumananandasivam of the Univesidade Federale Do Rio Grande, Brazil for much of the information in this section on curauá and similar fibres. Others who have been most helpful are Mr M. Nesbitt, of the Royal Botanical Gardens, Kew, UK and Mr Gordon Mackie. Literature sources have included *Vegetable Fibres* by R. H. Kirby and Leão. J. C., *et al.*, *Natural Polymers and Agrofibers Composites* and Leão. J. C., *et al. Natural Polymers and Agrofibers Composites*.[1]

9.2.1 Introduction and plant description

Curauá (*Ananas erectifolius*) belongs to the family Bromeliaceae (as does the pineapple) order Bromeliales. It is an economically important plant found in the Amazon region of Brazil. The fibre extracted from it is used for various purposes such as paper production, twines, ropes, hammocks, nets and today mainly for the automotive industry. The number of leaves varies from 70 to 100 per plant, according to the growing conditions during its lifetime of five years and each plant can produce up to seven scions (seedlings) per year. The length of each leaf varies from 70–150 cm, with an average width of around 5 cm, average thickness of 3–5 mm and the leaves are almost flat. The fruit is similar to pineapple with a similar taste but smaller in size. The fibre yield is around 6–7% of the weight of the leaf. One hectare with twenty thousand plants, will produce from 2.4–3 tonnes per year.

Many projects are being developed at the present time in order to cultivate this plant in local communities as a cash crop with the objective of helping to eradicate poverty as well as to discourage the devastation of the rain forest.

9.2.2 End uses

Curauá fibres are used for the manufacture of hammocks, twines, and fishing nets by the local people in remote areas of the State of Amazônia. The yarns are also used for making baskets, handicrafts, etc. These hand-made products are sold or exchanged for other products. Nowadays, there are government schemes through FUNAI (a government organism responsible for indigenous people) that helps to sell these products in the locally set up co-operative centres for tourists as well as for the local people. The fibres are now also used as a source of cellulose for the manufacture of paper and the automotive industry uses the fibre as a packing material in car production. It is also used as a substitute for coir and, blended with other lignocellulose fibres, for the manufacture of composites.

9.2.3 Cultivation and yield

The young plants are set in manured soil. The density of planting is in the range of 1.5 m × 50 cm spacing in two rows. There are 20,000 plants per hectare. Up to 1 kg of fibre is extracted from 12 leaves and the production can be in the order of 1.5 tonnes per hectare. Around 6% of dry fibre is extracted from each leaf. The present local demand in Brazil is around 370 tonnes of fibre per month. The Federal University of Pará State, in the north of Brazil, is producing about 200,000 seedlings per month, with the aim of increasing this to 3 million per month as part of a poverty eradication programme called ‘POEMA’ (‘Poverty and Environment in Amazonia’). These plants will be cultivated by the local communities of the region.

9.2.4 Fibre processing

Curauá is well known in the western region of the State of Pará but now it is also being cultivated on a large scale in the northern part of the state, in the districts of Santo Antonio do Taúá and Lagoa Grande, with the help of local and indigenous inhabitants. The leaves are cut manually and transported to a centre for the extraction of the fibres by mechanical decortication. The machine is called, in Portugese, a ‘desfibradeira’. The extracted fibres are washed in tanks with running water and put out for drying in the sun. In certain places drying chambers are set up to accelerate the drying process. Fibre yield is between 1,000 kg and 1,500 kg per ha per year. Some characteristics of curauá fibre[4] are:

Ultimate fibre length	0.40 cm
*Ash	0.79%
*Solubility in hot water	1.03%
*Solubility in NaOH 1%	19.3%
*Cellulose	70.7%
Lignin	12.7%
Crystallinity index	75.6

*Water free

The wet fibre has an average elongation of 4.5%, MOE of 10.5 GPa and MOR 439 MPa. Oven dried fibre values are 3.7%, 9.7 GPa and 117 MPa respectively.

9.2.5 Bibliography

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9.3 Crauá (caroá)

R R FRANCK

9.3.1 Description and botanical classification

This is the plant referred to by Kirby and others and found mainly in the northeast of Brazil (in the States of Pernambuco, Ceará, Paraíba, Rio Grande do Norte, Piauí). It is called crauá or caroá and its botanical name is *Neoglazovia variegata* (Arr. Camara) Mez. The leaves are thorny on their borders unlike curauá leaves. The rhizome and the fruits are used for animal and human consumption. The fibres are used for the manufacture of sacks for cereals, bags, mats, hats, hammocks, twines and yarns.

9.3.2 Fibre characteristics[1]

This fibre has the following characteristics:

Average length of fibre	1.35 m
Average width	1.2827 mm
Length to width ratio	10.524
Average weight per metre	1.194 mg
Moisture regain	10.86%

Average dry resistance	254.94 g
Average wet resistance	194.72 g
Average dry elongation	1.342 mm
Average wet elongation	8.720 mm
Torsional resistance (dry)	154.89 turns
Torsional resistance (wet)	211.69 turns
Composition	
Hydrocelulose (a)	17.02%
(b)	24.55%
Number of plants/m^2	5
Number of plants per hectare	50,000
Number of leaves per plant	5
Number of leaves per hectare	200,000
Weight of each leaf	83.1 g
Weight of dry fibre/leaf	5.5%
Production of fibre/ha	980 kg (this value varies according to the number of plants/ha from 30,000 to 80,000 plants)

9.3.3 Reference

1. O Coroá, Lauro P. Xavier, EMPARN/Fundação Guimarães Duque, Natl-RN, Brazil, 1982.

9.4 Macambira

R R FRANCK

There is another type of plant belonging to the family Bromeliaceous and known as Macambira (mainly found in the north-east of Brazil). The botanical classification is *Bromelia laciniosa*. The rhizome and the fruits are used for feeding animals. The leaves are used for the extraction of fibres and the nuts as food for human consumption. Some characteristics are:

Thickness of leaves	2–3 mm
Width of leaves	2.5–4.5 cm
Weight of leaves	30 to 100 g
Length of leaves	180 cm
Number of leaves per plant	70–80.

The fibres have similar characteristics to caroá fibre and the leaves are thorny. The method of extraction of the fibres from the leaves of all these plants is very similar; using a 'desfibradeira' or decorticator. The extracted fibres are first washed, dried and spun and woven by processes similar to sisal and jute.

9.5 Nettle

J DREYER and G EDOM

9.5.1 Introduction and history

It seems incredible that the painful and annoying stinging nettle (*Urtica dioica* L.) should ever be considered of value as a cultivated crop that can provide sufficient and high quality fibre for textiles. History teaches that when raw materials were less diverse and abundant, the nettle had a role to play and was a particular focus during times of political or economic crisis. There are approximately 500 members of the Urticaceae family distributed worldwide. Plants in this family belonging to the *Girardinia*, *Boehmeria*, *Laportea* and *Urtica* genera are well known for their fibre-yielding properties. In Europe we are most familiar with the *Urtica* species, particularly *Urtica dioica*, although in Russia and Siberia *Urtica cannabina* has long been used as a source of fibre and is sometimes referred to as Swedish Hemp.

The stinging nettle or common nettle (*Urtica dioica*) is a frequent and unpopular perennial weed of Northern Europe (Fig. 9.2). Its unendearing

Figure 9.2 Nettle.

qualities are its unpleasant sting and the difficulty of eradicating the plant once it is established. It thrives on phosphates and nitrates and can be found growing where the soil has been disturbed and human beings have left their waste. The nettle prefers rich, damp soil and a shady habitat and propagates itself by seed or by extending rhizomes from the parent plant.

The fibre from several plant species of the Urticaceae family has been used throughout the course of history. The abundant *Urtica dioica* has always been a source of fibre for cordage or textiles and assumptions have been made about the extent of its use based on limited archaeological finds, historical records, folklore, literature and etymology. Nettles have certainly been used for fibre in Europe, but mostly as a handcraft and sometimes alongside other fibrous plants. However, whenever there was a bigger revival of interest in the plant, beautiful textiles were often produced as a result, for example in Denmark, during the 18th and 19th centuries.

The first attempt to commercialise the production of nettle fibre was in Germany during the 1720s. Since then there have been frequent efforts in several European countries to cultivate nettles and develop a method of extracting the fibre that could be applied on a large scale. Most of this research was carried out in Germany, particularly during the 19th century. Unfortunately, there does not seem to have been a successful, cost-effective method of nettle fibre extraction resulting from all this activity. It was Dr Gustav Bredemann who turned the tide with his research from 1927 to 1950. He interbred selected plants of *Urtica dioica* and produced several high fibre clones that could be cultivated. The criteria for selecting the plants were that they should be frost-resistant, have long, straight stems with minimal branching and of course a high percentage of fibre in the stem.[1] These varieties were given the name Fibre Nettle. Bredemann's work was quietly forgotten for many years after his book *Die Große Brennessel* was published in 1950.

During the 1990s Dr Jens Dreyer from the Institute of Applied Botany in Hamburg re-identified the individual fibre nettle clones that still survived in the Institute and revived and tested Bredemann's research. The fibre nettle is now being used as a basis for several commercial nettle fibre projects in Europe and advances in technology are making it possible to process the nettle more successfully and cost effectively. The use of the wild nettle for fibre is still also possible. The Kalajokilaakso Nettle Fibre Project in Finland has demonstrated this by producing a nettle fibre yarn from wild nettles that have been carefully selected and cultivated.

The use of nettles for fibre is just one possible application for the plant. For centuries the nettle has been employed in a myriad of ways. It has value as a food, tonic, herbal medicine, homeopathic remedy and animal feed. It has been used to make tea, beer, wine, cordials, cosmetics and in cheese-making. Research has confirmed the effectiveness of all parts of the nettle plant for a number of medical conditions and supplies are increasingly required for commercial preparations. Most raw materials for herbal teas, veterinary products and animal feed are imported from eastern Europe. Smaller companies requiring nettles of a particular standard either cultivate them or select carefully from the wild. It is feasible that cultivated nettles could supply a variety of markets.

9.5.2 Chemical and physical properties

Research into the chemical and physical properties of nettle fibre has been taking place for the last five years. All the available information has been gathered together from projects in Finland, England and Germany and where possible a comparison has been made between the wild nettle (*Urtica dioica*) and the cloned fibre nettle (*Urtica dioica convar. Fibra*). Fibre nettles can be

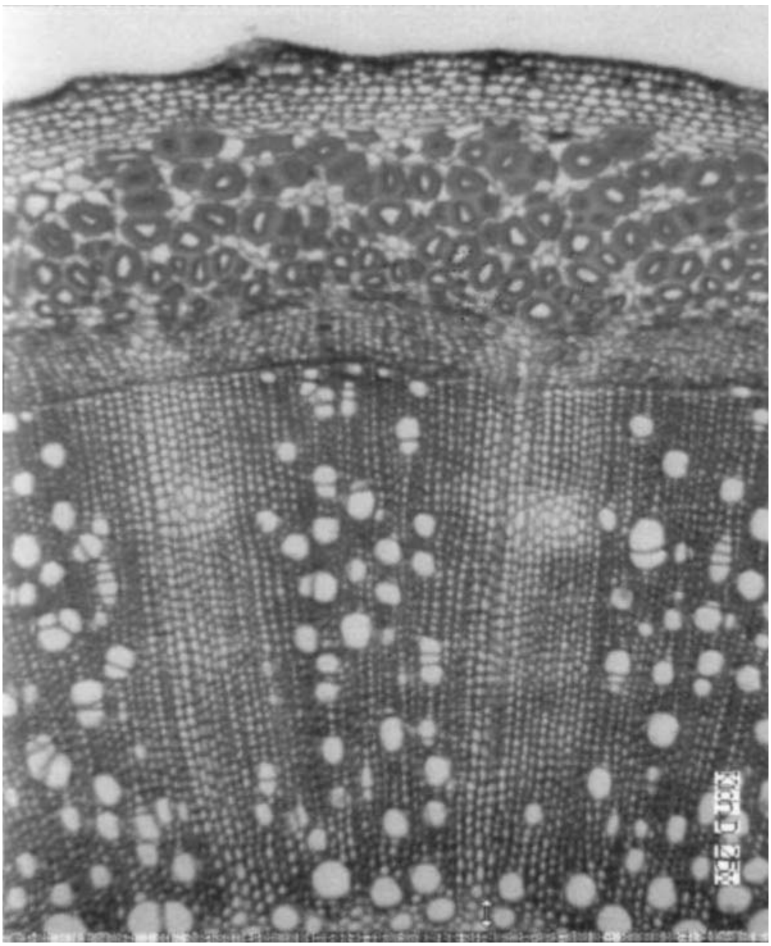

Figure 9.3 Photomicrograph of cross section of nettle stem.

distinguished from wild nettles by their larger quantity of individual fibre cells with bigger cell walls. The plants are selected because of their lack of branching from the stem, they have only a few stinging hairs and will lose most of their leaves in August which gives fewer problems of biomass in the straw. Most work on the characteristics of fibre has been done by the Faserinstitut Bremen e.V, although much of the data is still unpublished.

Hemp, flax and nettle all have fibres that lie along the length of the stem beneath the surface of the outer bast layer. These lengths of fibre are known as fibre bundles in flax and hemp, but a more accurate description for nettle fibre should be 'fibre groups'.[2,3] They are less compacted together and as a result are easier to separate from the bast material.[1] The individual fibre cells are composed of cellulose and held together in their groups by pectins and hemicellulose. The shape of the cells is oval to round polygonal.[3] The oldest and thickest fibres are in the outer part of the bark. The length and diameter of the long fibre is influenced by the species of nettle, its level of maturity and nutrition, where it is found on the plant and the method of extraction.[2] After mechanical separation the average measurement of length is 4–7 cm and 40–50 μm in diameter. There is no information on the combing of the long fibres to separate the long from the short. Treatment by alkali or enzymes leads to 40% of the fibres measuring 4–5 cm long and 25% measuring 5–6 cm long, when the fibre length distribution by mass is calculated. Their fineness is approximately 15–25 m in diameter.[4] The average measurement of fibre length by the Bremen Faserinstitut was between 5 and 7 cm with a high degree of variation.

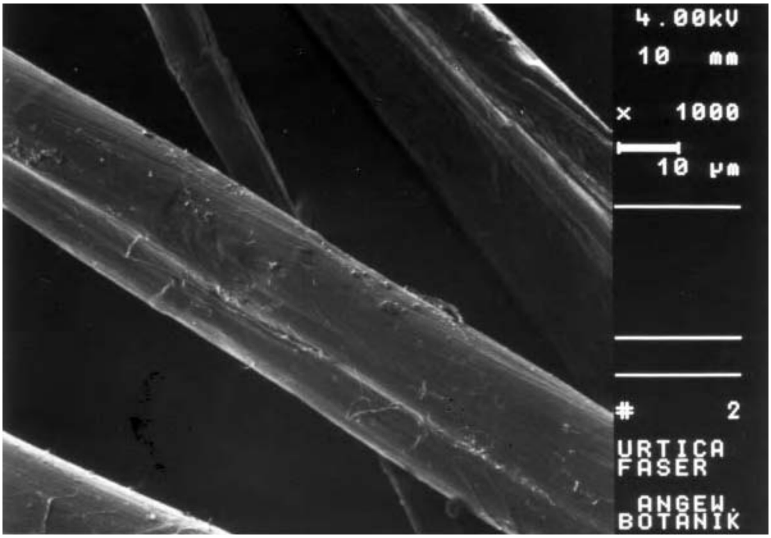

Figure 9.4 Photomicrograph of nettle fibres.

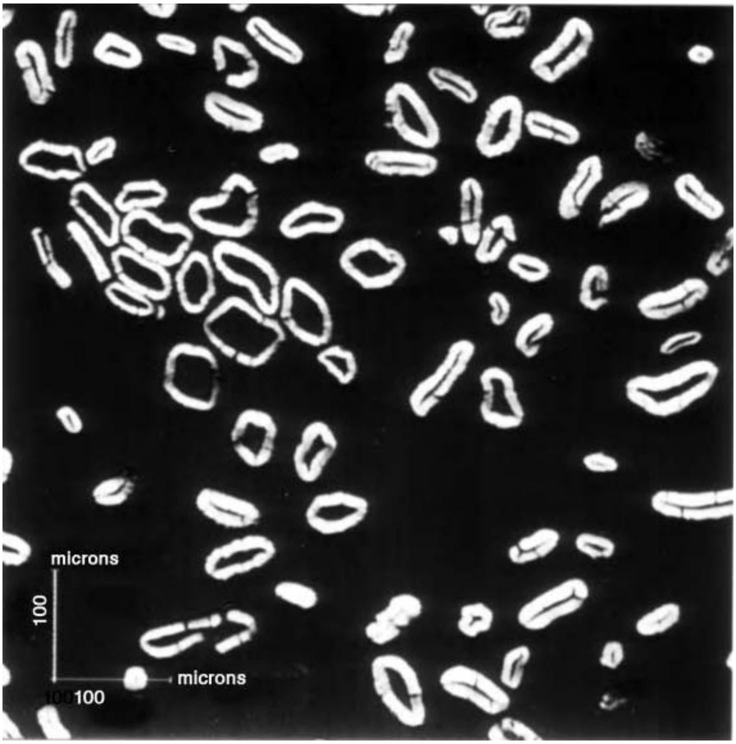

Figure 9.5 Photograph of cross section of nettle fibre.

The pure fibre content of the best-cultivated nettle plants from Hamburg is about 15% of dry mass, therefore six tonnes of harvested dry stems would give an average yield of approximately 900 kg of fine fibre.[2] This high quantity of fibre can be harvested as a result of the long period of breeding of selected nettles undertaken by Professor Bredemann during the 1920s and 1930s.[1] Wild nettle is approximately 3–8% of dry mass.[4] Fibre from nettle is known as nettle wool due to its softness[1] and the natural colour is cream/white, so it is easy to apply a coloured dye to the fibre or fabric.[1]

The Degree of polymerisation (DP) of the cellulose in the cell wall is about 2280.[5] Nettle is a strong fibre with 50 cN/tex, as measured by the Stelometer method at the Bremen Faserinstitut, but the method of spinning is important.[1] A

Table 9.6 Length measurement with *almeter al 101*: (a) fibre length distribution by mass (M)

Middle length	ML(M)	69.7 mm
Coefficient of variation	CV(M)	50.8%
Fibre content < 25 mm	L(M) < 25 mm	8.6%
Length at 25% of measured M	L(M) 25%	92.7 mm

Table 9.7 Physical and chemical composition of nettle fibre before and after retting[7]

Parameter	Before retting	After retting
Fibre strength (N/mm^2)	740 (WV)	
Fibre strength (cN/tex)	50 (FB)	25–35 (FB)
Fineness (dtex)	5 (WV)	
E-Modulus (GPa)	64.8 (WV)	
Strain (%)	1.2 (WV)	
Cell wall density (g/cm)	1.51 (WV)	
Length of fibre (mm)	40–50, but lengths up to 215 can be found (FB)	
Cellulose (%)	54	88
Hemicellulose (%)	10	4
Pectin (%)	4.1	0.6
Lignin (%)	9.4	5.4
Wax and fats (%)	4.2	3.1
Water-soluble products (%)	18	2.1

Compiled from: Wurl and Vetter (1994), Faserinstitut Bremen, Dreyer (1994) and Diploma Thesis.

lot of the strength can be destroyed if the machinery used is too aggressive, which is possible, for example with mechanical fibre extraction. The fibre can be separated mechanically and then with enzymes to get strengths of 23–35 cN/tex in comparison with cotton that has a strength of about 20 cN/tex.[6] Nettle fibre is very fine with only 5 dtex (the equivalent of about 50–80 μm in diameter). This is similar to ramie, which is the best natural fibre for spinning. The strain is important for spinning, but as with most plant fibres it has a low value of only 1.2%, so there is not much flexibility. The Emodul (elasticity module) is about 65 GPa and can be compared with E glass or good separated flax fibres. It is much higher than jute or banana. Moisture absorption is about 11%. No data exists on the electrical properties or specific heat of nettle fibre.

The fibres contain about 54% pure cellulose and about 10% of arabinane, xylane, galacturonane and other hemicelluloses. Nettle fibre contains about 4% pectin. This is an important factor because it has to be removed from the fibre to get a good and fine yarn. This can be done with sodium hydroxide or by more environmentally sound methods of enzymatic retting. By using pectinases (polygalacturonase, esterases, etc.) the pectin can be broken down thus freeing the individual fibres.

9.5.3 Fibre production and early processing

The nettle (*Urtica dioica*) is adapted to survive in a wide range of climatic conditions in Europe and moderate climates in other parts of the world except the tropics and polar region. The plant depends on a good water supply. It prefers loamy, clayey soils[8] and a moist, partly shaded position rather than open, dry and sunny.[9] If there is enough water (750 mm/m^2 per year) the nettle can be highly productive in a sunny habitat. Nettles need good soil conditions with a sufficient supply of nitrogen and a pH of 6.5. It is the host plant to a variety of indigenous invertebrates,[10] and only grasses are able to compete with its growth when the best conditions for growing nettles exist.[9]

There are considered to be a number of benefits associated with the cultivation of nettles. The nettle is a perennial and can be harvested year after year without replanting. A life span of 10–15 years for a cultivated crop has been suggested where optimum soil conditions are maintained, the application of some fertiliser and the control of grass weeds.[11] Nettles require low levels of fertiliser and little or no herbicide to control grasses.[11] They have the potential to process farmyard and liquid manure and the potassium nitrate of the soil increases as the result of nettle growth.[8]

Research has shown that nettles may be propagated by various methods; seed, seedlings, cuttings and the planting of rhizome pieces, although there is very little information regarding the last method. The advantage of growing by seed is that it is economical, but germination is unequal and the seed needs constant moisture after planting. Seedlings can be planted in May with vegetable planters when they have reached five to six weeks' growth.[9] The fibre nettle (*Urtica dioica convar. Fibra*) is propagated by stem cuttings. The cuttings require four to eight weeks pre-culture and can then be planted out by machine.[12] Weed control is particularly important at this time. The recommended number of plants per hectare is between 30,000–40,000 and the planting distances recommended range from between 25 cm apart with 50 cm between rows[12] to 30 cm apart with 60 cm between rows.[11] Weed control should start before planting and a pre-crop such as potatoes or maize put in to prepare the ground. Another method of cultivation is to plant the seedlings in potato ridges. The machine used to do this can then weed between the ridges. The nettle rhizomes are then protected within the ridges from damage by the machine.[9]

There are varied assessments as to the right levels of NPK fertiliser that should be applied to cultivated nettles. Nettles require easy access to nitrogen in the early stage of growth to maximise the height and weight of the stem. Clovergrass (*Trifolium repens*) planted between the rows also leads to a very high stem weight per plant.[11] Harvesting of the plants may be done from mid-August until early September.[8,9,12] One method of assessing whether the crop is ready to be harvested is to look for a large amount of leaf fall, but before the formation of new sprouts takes place.[12]

The possible yield of fibre from a cultivated crop of nettles must take into consideration the type of nettle planted (either wild or a fibre nettle clone, each of which has a different potential). One must also consider the method and year of harvesting. It is generally agreed that harvesting in the second year of cultivation yields a greater mass of fibre than in the first. For example, the fibre yield for one year was 335–411 kg/ha and in the second, 743–1,016 kg/ha.[13] This means a stem yield of about six tons per ha. Harvesting during the first year of growth will exhaust the nettles. The final value of the fibre should compensate for the extended waiting time before the first harvest. The nettle is an indigenous plant and therefore more robust in inclement conditions than other crops. A high fibre content (about 13%) in the stem is important for the effective and efficient mechanical decortication of fibres from the woody core.[14] On the other hand, a large quantity of leaves is not desirable because it slows the drying process.[14]

After harvesting the stems should be dried thoroughly and carefully before further processing, but retaining approximately 15% moisture. Literature shows that the stems were sometimes processed in their green state,[15] but generally they were dried first. This can be done by stacking in the field[1] or artificially with a warm dryer.[9] Until recently the fibre extraction methods used have been by dew or water retting, decorticating machine or the use of chemicals. Effective mechanical decortication is by using a pair of rollers and the separation of the woody parts from the fibre with machinery used in flax processing. The resulting fibre is then treated by enzymatic retting and research is ongoing to identify appropriate enzymes. The future success of nettle fibre extraction would appear to be through enzymatic retting and research is ongoing to identify appropriate enzymes. Further trials are also needed to produce finer yarns and textiles by this extraction method.

9.5.4 From fibre to fabric

Little information exists about the process of turning nettle fibre into cloth. Comparisons may be made with ramie, flax and hemp, although nettle stems are irregular in their size and the fibres are prone to break at the point where the stem branches. There are very few positively identified textiles remaining from the past and the most up-to-date research on nettle fibre is still at an incomplete stage. The traditional view of nettle fibre cloth was that it was soft, hardwearing and warm to the skin. This opinion has been reinforced by more recent research.[16,8] As with flax, nettle fibre has finer fibres than coir, sisal and hemp and forms a softer, better integrated material.[17] The Kalajokilaakso Nettle Fibre Project in Finland has produced yarn and textiles from nettle fibre extracted from cultivated indigenous species of *Urtica dioica*. The nettle fibre is mixed with other fibres that include cotton, silk, viscose and flax and up to 80% nettle fibre has been used in some of the blends. The fibres have been processed by retting with industrial enzymes and selected microbes.[18] Other European nettle fibre projects have produced nettle fibre textiles that have the appearance of linen.

The retting process not only separates the fibres from the plant stem, but also breaks down many of the fibre groups into single fibre cells or ultimate fibres. The consistency of well-retted nettle fibre is something between fine wool and cotton, but it is possible to extract longer fibres by retaining the individual fibres in their groups. A minimum retting period would be needed for this method and the emphasis would be on decortication.

The nettle fibres extracted in the Finnish project were formed into yarn by first putting them through a scutching machine originally made for cleaning short flax fibres. They were then carded twice on a flax card to open the fibres and remove the shiv. Fibre blending took place when the fibres were put through a wool card and the mixed fibres split into slivers before spinning on a woollen spinning frame.[18,19] Enzymes could be used to wash yarn and fabric to soften it.[14] Where enzymes were not used, scouring and bleaching of the fibres appeared to be successful in reducing the shiv and dust of basic decorticated fibres.[20] Another purpose of bleaching is to remove the lignin,[5] but as the lignin content in nettle fibre is little or non-existent, in this case the process would be unnecessary.

The dyeing process is similar to flax and other bast fibres. It has been found that if nettle fibre is dyed with reactive colours it requires the same dye recipe as flax, but less dye in the solution than cotton to get the same colour tone.[19] It is generally recommended that as with other bast fibres, nettle fibre yarn is woven rather than knitted into fabric. The machine knitting of nettle fibre yarn can be successful, although the irregularity of the fibre can cause ‘catching’ on the machine.[19] Hydroentanglement of nettle fibre is another successful alternative method of producing non-woven fabrics in order to produce finer preformed webs and a better fabric finish.[20] Very little research has been completed on the properties of nettle fibre and fabric, although it has been observed that the fine fibres formed a good ’bat’ of fibre suitable for needling which held together well during handling.[17]

9.5.5 End products

It has been assessed that technical and textile grade fibres can be extracted from the stem.[14,20] The long fibres can be technically upgraded to be competitive with wool and cotton, if shiv monitoring and control could be improved.[21] Nettle fibre has the potential for replacing glass fibre as reinforcement fibre in some application areas for polymer matrix composites and is 30–40% lighter and more flexible than glass.[14] It is suitable for composite mats for the interiors of cars[22] and UF-bonded particleboard.[20] The Kalajokilaakso project aimed to produce nettle fibre yarn and cloth for use in the luxury textiles and handcraft market.[19] The woody matter obtained during fibre production can be used to make cellulose and produce special grades of paper.[8]

9.5.6 Problems

One problem for nettle fibre that limits its acceptability (as in the processing of hemp or flax) is the presence of dust and shiv during decortication,[16,20] although some mechanical treatment and enzymatic retting improves the level of cleanliness of the fibre. Water retting is inappropriate because it is highly polluting and the bacteria work too fast on nettles. The ease of turning fibre into fabric may improve if the machinery used is designed for the purpose instead of depending on machinery designed for the processing of other fibres.

9.5.7 Economic and cost considerations

An evaluation of the cost of the cultivation and processing of nettle fibre and its end products is not possible at the moment until an ongoing infrastructure to produce and sell nettle fibre textiles is securely in place.

9.5.8 Environmental issues

The nettle species *Urtica dioica* is an indigenous plant of Britain and Europe. As such it is an important food plant for native invertebrates and promotes the population diversity of local flora and fauna. The nettle is a perennial plant and its long-term cultivation will decrease soil erosion.[23] It requires a low input of resources, including minimal fertiliser and pesticide[14] and may improve soils containing high levels of nitrates and phosphates.[23] Nettle fibre is an environmentally friendly alternative to cotton and synthetics. It can be cultivated locally and different parts of the plant used for a variety of products. All waste is therefore minimal and biodegradable. Enzyme retting of nettle fibre requires a low water temperature and the liquor may be recycled.[11]

9.5.9 Health and safety issues

In the textile industry in the past there was a link between working with plant fibres and the lung disease Byssinosis. This was thought to be because the retting of the fibres caused a high degree of microbial activity. If the method of fibre extraction gives rise to the possibility of dust inhalation, then facemasks should be used.

There is anecdotal evidence that handling fresh nettle plants might cause an allergic reaction similar to hay fever in some people.[24]

9.5.10 Nepalese nettle

There are several nettle species in the Urticaceae that produce fibre. A particularly well known one is the Nepalese Nettle, *Girardinia diversifolia.* Products made from this nettle are available in this country. The long tradition of removing the fibre from this plant and using it for textiles has continued up to the present. However, the fibre from this species should be distinguished from that of *Urtica dioica*. Each of these plants has its own distinctive geography and culture. *Girardinia diversifolia* is a perennial that grows at an altitude of between 1,200 and 3,000 metres in Nepal. It reaches from one to three metres high and is covered with very large stinging hairs. It prefers a natural habitat of partial shade in damp soil.[25] The local name for *Girardinia diversifolia* is Allo and the fibre has traditionally been woven on a backstrap loom to make cloth for bags, sacks, jackets, porters' headbands and mats. It has also been made into cordage for ropes and fishing nets by indigenous groups such as the Rais, Sherpas, Magars and Gurungs.[26]

The nettles are harvested between September and December. The bark is stripped from the stem and boiled for approximately three hours in wood ash and simmered overnight. The fibre is then beaten and washed to remove extraneous plant material. Finally it is rubbed with a micaceous soil and dried in the sun.[27] Because this plant grows predominantly in forested areas, its continued use for fibre should be encouraged to ensure that the high forests are not depleted. The products made from the fibre are also an important commodity to the communities living in mountainous regions, who do not possess land suitable for crop cultivation. In 1984 a group of women weavers in the Sankhuwasabha district sought help from KHARDEP (Koshi Hill Area Rural Development Programme) to improve methods of extracting and processing nettle fibre and to expand the quantity and variety of items that were produced. This initiative spread and efforts are continuing to improve the processing method and to establish a secure market for the finished products.[28]

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9.6 Sunn hemp

R R FRANCK

Sunn hemp (*Crotalaria juncia*) fibre is also known as Indian, Bombay and Jubblepore. It is a plant of the Leguminosae family, Papilionatae subfamily. It grows in both temperate and tropical climates and when cultivated reaches a height of three metres in most kinds of soil, as long as they are well drained. Apart from its use in textiles sunn fibres are also used to make paper. The plant is also grown as animal fodder. As it is a Leguminosae it roots fix nitrogen and it is thus a useful rotation crop. Its main source is India although some is grown in Pakistan and Bangladesh.

Some of the principal characteristics and a morphological description of the fibres can be found in Tables 1.6, 1.8a. 1.8b, 1.10 and 1.12 in the appendix to Chapter 1. The fibre, after retting, is extracted manually from the plant, dried and hand combed.[1] Sunn hemp is used for the same kind of end-uses as jute and it is difficult to understand why it is not included in the group of 'jute-like' fibres. Perhaps the reason is that it would seem that most of the fibre intended for textiles is manually processed and used locally. Its annual production is estimated at several thousand tonnes.

9.7 Mauritius hemp and fique[1]

R R FRANCK

The Amaryllidacaea (Narcissus) family of plants, to which these two species belong, is closely related to the Agaves and their appearances are similar. Their fibres are also processed in the same way as sisal and sisal-like fibres. Mauritius hemp (*Furcraea gigantea*), as its name would indicate, is produced in Mauritius and also in Reunion and Central and South America. The Mauritius hemp fibre is whiter, finer, softer. and longer than sisal, but weaker. The ultimate fibre lengths range from 1.3–6 mm with a mean of 2.9. Their diameters range from 18–32 microns, with a mean of 23 microns. Fique (*Furcraea macrophilia*) is grown in Colombia. The fibres are similar to sisal but, as with Mauritius hemp, it is said to be finer, softer and longer.

Table 9.8 World production of agave fibres apart from sisal, henequen and maguey for selected years from 1968–2002

Year	Tonnes
1968	39,648
1978	62,365
1988	58,258
1998	52,110
1999	54,983
2000	54,825
2001	54,163
2002	54,275

Source: FAOstat.

It is difficult to assess the scale of the annual production of these fibres because they are grouped with other fibres in the FAO statistics but it seems unlikely that their production exceeds several thousand tonnes per year. Many other species of fibre producing *Furcraea* grow wild in Central and South America and the Carribean Islands. These include *F. cabaya*, *F. andina*, *F cubensis* and *F. humboltiana*.

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10
Bast and leaf fibre composite materials

J MÜSSIG, M KARUS and R R FRANCK

10.1 Introduction and background

The use of textile fibres for reinforcing composite products is not new but the last decade has seen the development of an entirely new market for bast and leaf fibres in this area; their use as plastic panel reinforcement (composites) for the interior trim of cars. According to Eisele (1994) the automotive industry was using vegetable fibres in car interiors before the 1970s. Examples of the uses of these fibres in older models are:

- jute needle-felts for sound insulation, placed under the carpet
- wadding, based on wool and cotton for seats and door trim panels
- rubberised coir upholstery for seats
- wood fibres for door trim panels.

During the 1970s and 1980s these fibres were partially replaced by petrochemical polymers (e.g. non-reinforced acronynitrile butadiene styrene (ABS) plastic) because of their optimised properties and their faster manufacturing processes. However, in 1999 50,000–70,000 t of wood fibre and 50,000–60,000 t of reclaimed cotton were still used in the manufacture of these products by the German automotive manufacturers alone because they are technically effective and economical.

In the mid-1980s it was thought that the use of natural fibre reinforced composites could offer an interesting alternative to these plastics because of their technical, economic and ecological advantages and social benefits (Harig and Müssig 1999). Several international and national bodies, and in particular the European Union and several of its member countries, provided R & D grants aimed at investigating the technical possibilities of reinforcing these panels with natural fibres and thus improving their performance. These projects were part of wider R & D programmes whose purpose was to develop potential industrial uses for locally produced vegetable fibres and other non-food crops and so help to persuade farmers to decrease those of their products that are subsidised under the European Union's Common Agricultural Policy and whose supply exceeds demand. At about the same time and owing to the completely international nature of the automobile industry similar work on using vegetable fibres to reinforce vehicle trim panels was being carried out in the United States and Japan.

Despite encouraging results from R & D work during this period it produced little concrete follow-up from the automobile industry until the mid-1990s when the first bast fibre reinforced plastic panels were incorporated into a German standard production model. Bast and leaf fibres are now penetrating the market due to the development of new manufacturing techniques. The advantages of these new composites in automobiles compared to those made with wood fibre or reclaimed cotton are:

- lower density of fibres, leading to a reduction in weight of 10% to 30%
- improved mechanical and acoustic insulation properties
- improved processing properties – lower wear of tools
- potential for one-step manufacturing, even when making complex parts
- improved accident performance – high stability, no splintering
- improved eco-balance, both during manufacture and during vehicle use (due to lighter weight)
- improved health benefit in manufacturing in comparison to glass fibres
- no release of noxious/toxic gases
- less condensation of emissions (fogging) compared to phenol-bonded composites
- price and ecological advantages compared to previously used technologies using synthetic or glass fibre
- positive effects on agriculture
- positive effects on the balance of payments in countries with temperate climates under which flax and hemp can be grown
- positive effects on the European Union's Common Agricultural Policy – decrease in excess agricultural production of subsidised crops.

According to a 1996 report by the IFEU (German Institute for Energy and Environmental Research) and nova-Institut, each kilogram of hemp fibre that replaces glass in this end-use saves 1.4 kg of carbon dioxide.

Since then the use of bast, and to some extent leaf fibres for this purpose has developed. Consumption in the European Union reached 18,000 tonnes in 2003 (Table 10.1).

10.2 The market, demand and supply

10.2.1 Demand

It can be seen from Table 10.1 that there is an almost linear increase in total fibre consumption averaging 10–20% per year from 1996 to 2002. In 2003

Table 10.1 The use of natural fibres by the German automotive industry 1996–2003 (composites, excluding seat upholstery)

	1996	1999	2000	2001	2002	2003
Flax	2,000	7,000	9,000	8,500	9,000	9,400
Hemp	0	300	1,200	1,600	2,200	2,300
Exotic fibres (jute, kenaf, sisal, coir, abaca)	2,000	2,300	2,000	5,000	6,000	6,300
Total	4,000	9,600	12,200	15,100	17,200	18,000

Source: Karus *et al.* 2004.

consumption of these fibres continued to increase, but at a lower rate of about 5%. However, within these totals, different fibres were responsible for the overall growth of the market. Until 2000 this was due to an increase in the use of flax, but the price of flax tow increased considerably in 2001, due to the increased demand for linen. Since its 'rediscovery' in 1996 hemp has shown a continuous increase to about 2,200 tonnes in 2002 but this production started from a very low base and supply was unable to meet demand.

This shortage of hemp, despite a considerable increase in production, and the high price of flax allowed the 'exotic' fibres (jute, kenaf and sisal) to enter the market and partially replace them in 2001 and 2002. Although the use of all these fibres continued to increase in 2003 that of the 'exotics' was somewhat more marked than that of the other fibres. This was probably due to the slightly lower prices of the exotics, which, in its turn, was probably due to the marked decrease in the US$–€ exchange rate.

As stated above, in 2003 some 18,000 tonnes of these natural fibres were used to manufacture composite materials for the automotive industry in Germany and Austria, with a market value of approximately €10 million. This gives an average price of €0.55 to 0.60 per kg.[1] As it is known from previous market research[2] that the consumption of these two countries comes to two-thirds of the total European Union consumption, this is estimated at about 26,000 tonnes for that year.

At present these vegetable fibre composites are used in the manufacture of press-moulded thermoset or thermoplastic panels and 5–10 kg of fibre is used per car. Typical applications include door inserts, baggage racks, pillar covers, and boot linings. From a survey carried out on the ten European manufacturers of composite panels for the automotive industry in 2002, the use of vegetable fibres in the manufacture of these product is expected to increase at an average yearly rate of 14–15%. Table 10.2 lists the models of European cars which, between 1997 and 2001, were trimmed with bast or leaf fibre reinforced press-moulded panels.

1. 'Use of natural fibres in the German and Austrian automotive industry', nova-Institut, 2002.
2. 'Markets and prices for natural fibres in Germany and EU', nova-Institut, 2002.

Table 10.2 The use of natural fibre composite for series production in the automotive industry (1997–2001)

Manufacturers/ Customers	Model/application (dependent on model)
Audi	TT, A2, A3, A4, A4 Avant (1997), A4 Variant (1997), A6, A8 (1997), Roadster, Coupe Seat back, side and back door panels, parcel tray, boot lining, rear flap lining, rear storage panel, spare tyre lining
BMW	3, 5 and 7 Series and others Door inserts/door panels, headliner panel, boot lining, seat back
Citroen	C4 (2001) Door inserts
Daimler/Chrysler	A-Klasse, C-Klasse, E-Klasse, S-Klasse Door inserts, windshield/dashboard, business table, column cover
Fiat	Punto, Brava, Marea, Alfa Romeo 146, 156, Sportwagon
Ford	Mondeo CD 162 (1997), Cougar (1998), Mondeo (2000), Focus Door inserts, B-column cover, parcel tray, in the future also motor protection (cover undershield)
MAN	Bus (1997) Headliner panel
Mitsubishi	Miscellaneous models (since 1997)
Nissan	Miscellaneous models
Opel/Vauxhall	Astra, Vectra, Zafira Headliner panel, door inserts, column cover, instrument panel, rear shelf panel
Peugeot	New model 406
Renault	Clio, Twingo
Rover	Rover 2000 and others insulation, rear storage panel
Saab	Coupe (1998) Door inserts
SEAT	Door inserts, seat backs
Toyota	Miscellaneous models
Volkswagen	Golf A4, Golf 4 Variant (1998), Passat Variant, Bora Door inserts, seat backs , rear flap lining, parcel tray
Volvo	C70, V70, Coupe (1998) Door inserts, parcel tray

Source: nova-Institut 2001.

10.2.2 The potential market

Approximately 18 million automobiles and lorries are presently manufactured in Europe per year. At 5 kg–10 kg of fibre per unit this would indicate a potential market of between 90,000 amd 100,000 tonnes per year. When the 37 million car and light vans manufactured in the rest of the world are taken into account the global potential market rises to between 250,000 tonnes and 500,000 tonnes.

At present all the bast fibre composite panels are produced using press moulded technology. Should the development of vegetable fibre injection-moulded composites take off, the size of the potential market would increase still further, possibly by as much as one million tonnes per year. However, one must bear in mind that potential markets are one thing, and the rate of penetration of a market by new techniques and products is another. This question is discussed in section 10.5 below.

10.2.3 Supply

Table 10.1 above gives details of the consumption of the various fibres used up to now to reinforce plastic car panels in the German automobile industry. At present (early 2004) the preferred fibres are flax, hemp, jute, sisal and kenaf, and Table 10.1 shows that, at the moment, short fibre flax, usually called flax tow (see Chapter 3 sections 3.5 and 3.12) is the principal fibre used. To a certain extent, these fibres are interchangeable and a composite manufacturer will bear in mind certain considerations. The market price for fibres used in the manufacture of these composite panels has settled in the range of €0.50 to €0.60 per kg in Europe.

Flax

At the price mentioned above the only grade of flax available is scutched tow. The other important market for this grade is the paper industry where it competes with wood pulp and reclaimed vegetable fibres, mainly cotton. These, in normal circumstances, limit the price obtainable by flax tow for this market to between $300 to $350 per tonne. Composites are therefore obviously preferred to paper as a market for these qualities of flax, even if this entails further processing the flax tow to reduce impurities to below the 2% level by weight required by the composite panels manufacturers (see section 10.4).

Hemp

All hemp fibre in the EU is produced on ‘total fibre’ lines, which produces fibres for speciality paper pulp (at between €0.40 and €0.45 per kg) or for industrial (as opposed to textile) uses for automobile composites or building insulation (at between €0.50 and €0.60 per kg). The price of hemp is more stable compared to that of flax (see Fig. 10.1).

Non-European fibres

The prices quoted for these are generally FOB and it is therefore necessary to add between US$100 and $50 to the quoted price for delivery to Europe or North America. When considering different fibres (apart from their delivered prices),

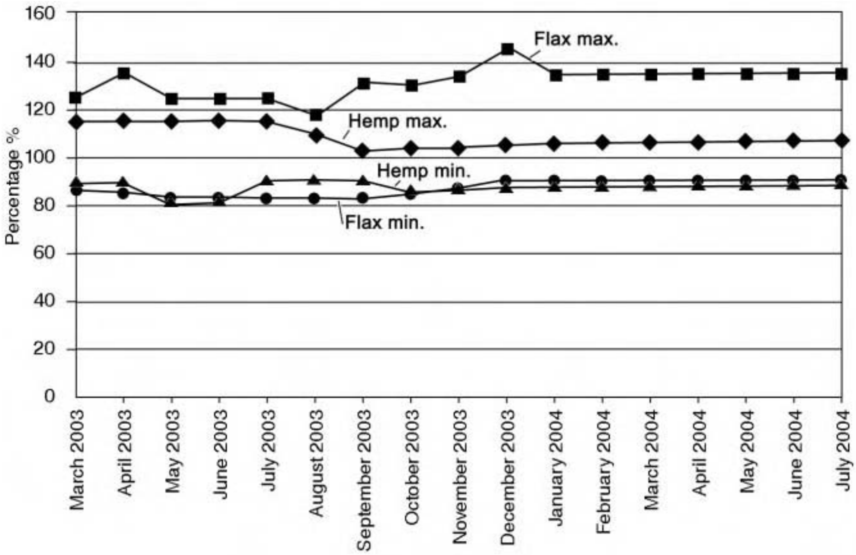

Figure 10.1 The relative price stability in percentage terms of hemp and flax fibres for use in composite products. Adapted from: European Industrial Hemp Association, Source: Karus *et al.*, 2004 (www.industrial-crops.ed)

composite manufacturers and other suppliers to the automobile industry take the following into consideration:

- Price stability. As Fig. 10.1 shows they can obtain this to a reasonable extent from hemp and, to a less extent, from flax. However, it is true that flax, in this respect, does present a particular problem. This is that the tow fibre used for composites is a by-product of the production of line (long fibre) flax and, when the demand for line is high and its price rises, then the price of tow may also increase by 200% or 300%.. Prices of the other fibres are generally stable but do vary according to supply and demand and also due to exchange rate fluctuations, and especially that of the US dollar.
- The cleanliness of the fibre is important to the satisfactory bonding of the fibres that make up the composite product.
- The fineness of the fibre. Technically it is desirable to use a mixture of finer and coarser fibres (see section 10.4.3).
- There is a strategic requirement to diversify a composite manufacturer's sources of raw materials, thus reducing the risk of any interruption of supply. This diversification applies to the kind of fibre, its countries of origin and security of delivery. Coir (coconut) fibre is not interchangeable with the other fibres because its physical and chemical characteristics are very different (see Chapter 7 and Tables 1.1, 1.6, 1.9 and 1.12 of the Appendix to Chapter 1).

10.2.4 Availability

Taking the fibres in the order in which they are listed in Table 10.1.

Flax

Flax tow is a by-product of the production of line (long fibre) flax (see Chapter 3; section 3.5 and Table 3.11). Total world textile flax production is around 350,000 tonnes, of which it is reasonable to estimate that more than half is tow and the rest line, giving a world annual production of tow of more than 135,000 tonnes. Of this quantity perhaps not more than half, or 85,000 tonnes, is available for use in composites. This is due to several reasons: because of already existing markets for these qualities of flax from other, mostly textile end uses, because of lack of proximity – it is uneconomic to transport a fairly cheap product over long distances; and because not all of these tow fibres are of adequate quality for use in composites. At present levels of demand, therefore, there are sufficient supplies of flax to supply the market, but whether this will be the case in the medium to long term is not so certain and is discussed in section 10.5 below.

Hemp

Whilst the supplies of hemp are not, at present, large its production within Europe can easily be increased from year to year to meet the rising demand. The main countries producing hemp fibre in the European Union are France, Germany, the UK, and the Netherlands. Spain also produces substantial quantities, but all for the paper industry. The total world hemp fibre production is 50,000–60,000 tonnes. (See Chapter 4, part 2 for a fuller discussion of world, and particularly European hemp production.)

Other fibres

The global supply of jute, sisal, kenaf and coir is discussed in the chapters covering these fibres and is adequate to cover the present and future quantities required for the manufacture of composites for the automobile industry. If necessary their production can readily be increased. In Europe, jute fibres have been important in the automotive sector for many years. However, due to oily softening finishes, which are often used to improve the processing characteristics of jute fibres, problems are caused in terms of odour and fogging. This led to reduced acceptance in the automotive industry (Harig and Müssig, 1999). It is now clear that the decision to use natural fibres is not only the purchaser's, but that product requirements must be discussed by the entire production chain, if the highest possible and most reliable quality is to be achieved. Demand for kenaf fibres has risen continuously in the automotive industry in the last few years.[3]

3. M. Karus, private communication, 2000.

10.3 The influence of fibre properties and the possibilities of measuring essential fibre characteristics

10.3.1 Introduction

In the last few years discussions on topics such as saving fossil resources, recycling, lightweight construction, the ecologically sustainable selection of materials and product-integrated environmental protection have led to a new attitude in the sector of material sciences. As a consequence of this new attitude each step in the flow of materials development, including research, production, processing, distribution, use, and recycling needs not only to meet functional and economic criteria but must also fulfil the ecological and social requirements of sustainability (Müssig, 2003).

In this context, the use in composite materials of natural fibres obtained from plants offers an interesting alternative to industrially created products and in the automotive industry in the last few years research has increased aimed at re-introducing natural fibres into the automobile construction industry. At the present time, all European automotive manufacturers have integrated components with natural fibres in the interior trim of their series production (Table 10.2). Present products range from the cladding of tailgates, columns and boots to covers for baggage compartments and door panels and the first structural elements for external application are being tested.

At the present time (2004), the full potential for natural fibre composites is far from having been achieved, and this is clear if we consider the great variety of possible applications for the interiors of many different types of car and other vehicles (Müssig, 2001). The market survey carried out by nova-Institut for 2003 (Fig. 10.2) shows that compression mouldings using the duroplastic (e.g. polyurethane matrix) method of manufacturing accounted for 35% of total natural fibre composites used by German automotive manufacturers and the

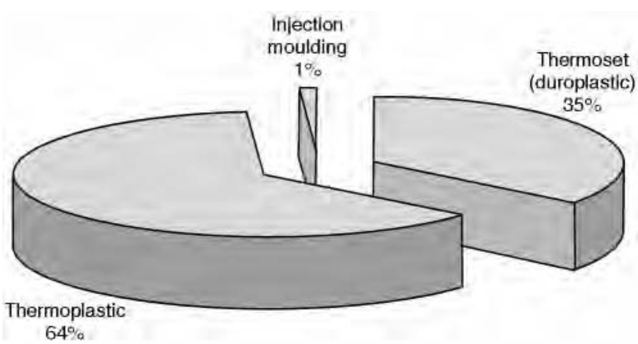

Figure 10.2 Processing technologies for natural fibre composites in the German automotive industry. Source: Karus *et al.*, 2004

thermoplastic (mostly polypropylene) method for 64%. Injection moulded composites appeared for the first time in these market surveys and although they came to only 1% of total vegetable fibre composite production this is probably a very significant development.

As far as future trends to 2005 are concerned, an analysis of market surveys carried out by the nova-Institut show that 32% of the corporations or institutes questioned expect an increase in the importance of natural-fibre injection moulding (Kaup *et al.*, 2003). Thus this sector may become an important factor of growth in the future application of natural fibres in composites (Müssig *et al.*, 2003). This forecast is also confirmed by the present activities of the research institutes and research departments of industry.

Whilst, in the past, most work has been concerned with the extrusion compounding of short wood fibres, in the last few years the question of polypropylene/natural fibre injection moulding based on annual fibres such as flax or hemp has been the subject of intensive research. (Compare, for instance the work of Michaeli *et al.* (1995), Mieck *et al.* (1999), Snijder (2000), Jakwerth (2002), Reußmann *et al.* (2002), Specht *et al.* (2002) and also Ruch and Fritz (2002)). Nabi Saheb and Jog (1999) point out the importance of the use of adhesion agents in natural fibre/thermoplastic processing and also mention essential work on this subject.)

A particular problem in injection moulding concerns the introduction of the natural fibres into the processing units. Several different manufacturing processes were tested in this respect and also partially applied. In consecutive order these were:

- the trial of the metered addition of cut or pelletised natural fibres in the extruder
- the use of mixing batch techniques as described by Bornemann (2002), Karmaker and Youngquist (1996) for jute/polypropylene and Sanadi *et al.* (1995) for kenaf fibre reinforced compounds)
- the use of card sliver (Ruch and Fritz, 2002)
- the development of long fibre granulate production (Nechwatal *et al.*, 2002).

All of these are quite different concepts.

Beside these aspects of technical implementation, the ecological framework must also be taken into account and in this context the use of whole plants should be mentioned. As stated by von Buttlar *et al.* (2003), the use of natural fibres from whole plants, after they have been thermo-mechanically separated, represents a technically and economically interesting concept for injection-moulding applications with polypropylene. Hornsby *et al.* (1997) describe the possibilities of using a pulping extruder to pulp the stems of linseed flax before the pulp is mixed with polypropylene.

As well as publications and presentations there are many national and international patents, e.g., for the continuous manufacturing by extrusion of composites based on polymers and cellulosic fibres (Snijder *et al.*, 2003). Beckmann (2002) mentions a method for the production of natural fibre material, bonded with a thermoplastic, in a pourable and dispensable form.

There are also important developments in Japan. Kadowaki *et al.* (2003) give a circumstantial overview of the processing techniques published as patents in that country.

- A method in which natural fibre is kneaded to mix it homogeneously in molten thermoplastic resin using a roll kneader. The mixture is then cooled so as to solidify, and the product is crushed to form resin pellets (J-P-A No. 108161/1982).
- A technique in which discontinuous fibre is spun to form spun yarn. This is then processed to form fabrics; woven, nonwovens or mats. The processed product is impregnated with molten polymer in a bath and then cooled to solidify. The cooled product is then cut into a suitable configuration and size to form resin pellets. (J-P-A Nos. 28307/1983, 7307/1991, 30916/1991, and 41280/1997).
- A device in which molten polymer and discontinuous fibre are kneaded using a kneader or a kneading extruder and the molten mixture is then extruded, cooled, and solidified to form a rod, after which the rod is cut into pellets of the required length (J-P-A Nos. 146945/1987, 146947/1987, and 290453/1991).
- A processing technique by which a yarn spun from the reinforcing fibre is twisted with a yarn spun from the thermoplastic fibre. This composite two-ply yarn is then heated, cooled, solidified and cut into pellets of suitable size (J-P-A No. 163002/1992).
- A method in which a reinforcing fibre yarn is impregnated with molten thermoplastic resin, cooled and solidified, and then cut into pellets of a suitable length (for example, J-P-B Nos. 37694/1988, 57407/1994 and J-P-A Nos. 178411/1989, 119807/1992).

As shown above, the activities in the area of natural fibre-injection moulding have become more intense. However, a comparison of fibre and/or matrix properties is sometimes difficult due to differences in the procedural parameters and the different possible combinations of the fibre, matrix and adhesion agent. In view of these difficulties a first series of comparative tests of the different natural fibre-injection moulding procedures of eight leading corporations and institutes were carried out in 2002 (Karus *et al.*, 2002). The evaluation of the results offered a first approach towards improving the comparability of the current combinations of manufacturing, fibre and matrix developments on the basis of reproducible results. For these tests hemp fibres were prepared for processing with PP. It was not possible to use the available fibres as raw material for each of the different processes, which emphasises the difficulties of adding natural fibres to the compounding process.

The samples of composites obtained were tested for their mechanical properties (flexural, tensile and impact strength). Obvious differences between the tested samples were obtained:

- The addition of adhesion agents clearly improved the flexing and tensile properties.
- An increase in impact resistance is achieved by adding fibres with special force-elongation characteristics (Karus *et al.*, 2002).
- Of particular importance is the influence of the fibre properties on the behaviour of the manufactured composites.

In the following section the relationships between fibre and composite material characteristics are addressed and the possibilities of testing fibre properties are presented.

10.3.2 Fibre and composite material characteristics

The influence of fibre length

In automotive manufacturing, polypropylene is increasingly replacing plastics and metals in components such as dashboards, front-ends or cladding for the underbody. As summarised by Bürkle *et al.* (2003), PP can fulfil the required mechanical characteristics only if the stiffness and impact resistance of the material are increased by reinforcing the final product with fibres. The component production takes place as shown in Fig. 10.3 with the aid of compression or injection moulding techniques. With the aid of GMT very good mechanical characteristics may be achieved due to the possible length and isotropic properties of the fibres. However, due to economic aspects (amongst others) the LFT-procedures and also the IMC-technology represent interesting alternatives. For the processing of natural fibres both the LFT-procedures (compare for instance the work of van den Heuvel (2002)) and the IMC-technology (compare for instance the work of Zimmet (2002) and Ruch *et al.* (2002)) have been studied.

In order to ensure that a fibre that is introduced into a composite shows the highest applicable reinforcement effect the length of the fibre must be greater than the so-called critical fibre length (lc). (The critical fibre length is defined as the minimum length at which a fibre will improve the mechanical characteristics (strength and impact) of the composite concerned.) The polymer may be effectively reinforced by using fibres whose length exceed the critical length in an ideal fibre-matrix-adhesion combination. A connection between fibre length and composite properties is shown by Bürkle *et al.* (2003) as a rough orientation for glass-fibre-reinforced polypropylene (see Fig. 10.4). In natural-fibre reinforced polymers the connection between the length of the fibres and the properties of the composite material is not always as easy to

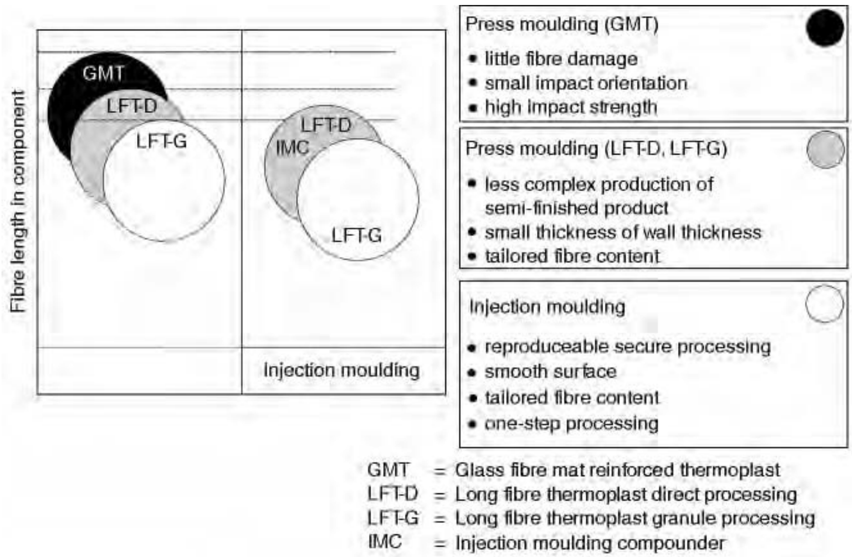

Figure 10.3 Processing techniques for long fibre reinforced thermoplasts. Source: adapted from Bürkle *et al.*, 2003.

forecast as might be expected from the descriptions of glass-fibre/PP composites.

Ruch and Fritz (2002) report that unlike the reinforcement with extremely resistant glass and carbon fibres, the absolute length of flax fibre-bundles plays a less dominant role with regard to the mechanical properties of a composite. Due to processing with extrusion techniques and the application of combing elements arranged in a screw-type concept, ideally the fibre bundles are afined down to the individual fibres. As shown in Fig. 10.5, the length to diameter ration (l/d)

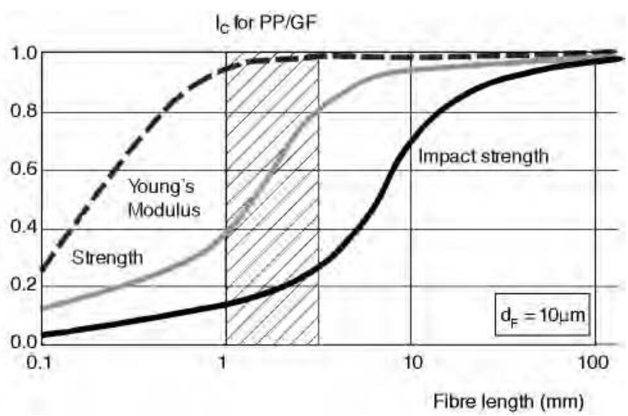

Figure 10.4 The influence of fibre length on composite material characteristics. Source: adapted from Bürkle *et al.*, 2003.

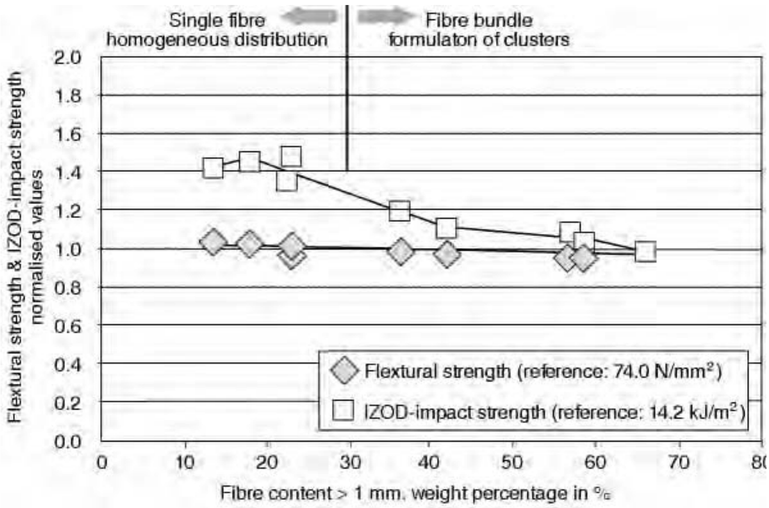

Figure 10.5 The flexural strength and IZOD impact strength as a function of fibre content. Source: adapted from Ruch and Fritz, 2002.

ratio of the fibre strongly influences the mechanical properties of a composite. Thus excellent mechanical properties may also be achieved by a broader distribution of fibre lengths.

Recycling

The comparison of recycling characteristics between glass and flax fibre-reinforced thermoplastics is clearly in favour of the natural fibres. As shown in the work of Aurich *et al.* (1998), the repeated re-processing of the brittle glass fibres leads to a considerable reduction of fibre length. For glass-fibre-reinforced thermoplastics this leads to a reduction of 50% of the tensile properties after five reprocessing cycles, whilst the characteristic values of the flax-fibre-reinforced variant remain on the same level.

Apart from fineness and length the orientation of the fibres also plays an important role. Since orientation plays a key role in the improvement of mechanical properties, finer fibres also allow more fibres to be orientated in the 0º direction. This effect has been demonstrated by experiments published in de Albuquerque *et al.* (2000). They determined properties of jute-polyester composite depending on fibre volume fraction and fibre orientation. Their results show that the mechanical properties of samples improve with the number of fibres orientated in the longitudinal direction.

In the use of sisal fibres (*Agave sisalana* P.) for the reinforcement of polyethylene (LDPE), Joseph *et al.* (1993) observe maximum stiffness values for fibre lengths of 6 mm. At lengths of 2 mm and 10 mm, lower mechanical characteristics are determined. At 2 mm, the length of the fibres is insufficient for ideal force transmission, a reorientation of the 10 mm long fibres takes place in processing, so that in this case force transmission is also not ideal. This description stresses the importance of the influence of fibre orientation and that it must also be taken into account for short fibre lengths. In section 10.3.3 the possibilities are mentioned for combining the measurement of fibre orientation with the determination of fibre fineness.

In order to explain the dependence of mechanical properties on the degree of separation of the fibre bundles, the construction of a flax or hemp fibre bundle must be explained and the influence of fibre fineness on the composite behaviour must be pointed out.

The influence of fibre fineness

As shown in Fig. 10.6 in stalk plants such as hemp (*Cannabis sativa* L.) or flax (*Linum usitatissimum* L.), the fibre bundles are embedded in the outermost layer of the plant bark. The fibre cells are glued together to form fibre bundles with adhesive substances of the plant and may be decorticated and separated by physical, physical/chemical, chemical or microbial processes into finer fibre-bundles or into individual fibres.

As mentioned in the work of Ruch and Fritz (2002), in natural fibre flax the mechanical properties of the composites show a strong dependence on the degree of separation of the fibre bundles. As shown in Fig. 10.5, the values for flexural strength are slightly higher when homogeneously distributed individual fibres are present in the polymer. The influence of fibre bundle afinement becomes much clearer when the values for impact strength are considered. Afinement of the flax-fibre bundles into individual fibres and their homogeneous distribution considerably increases the dynamic properties of the composite. Ichazo *et al.* (2000) also report that, in sisal-fibre-reinforced polyolefins the fibre bundles are separated due to their processing in a twin-

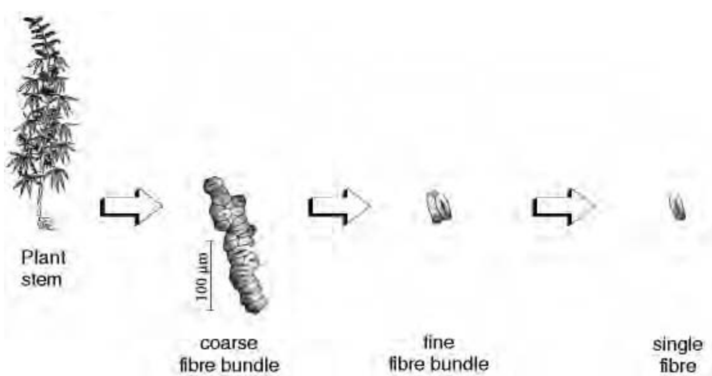

Figure 10.6 From plant stalk to individual fibre.

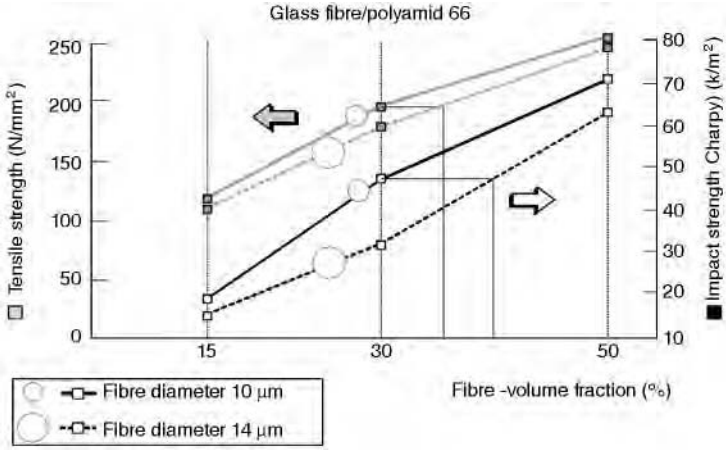

Figure 10.7 The influence of fibre fineness on composite material characteristics. Source: adapted from Anon., 1995.

screw extruder. Due to this afinement of the fibre bundles, their effective surface area is increased which, on the whole, leads to an increase of the possible contact surface of the polymer and to an improvement in its mechanical properties.

For glass-fibre-reinforced polyamide, similar correlations apply and are represented in the graph of Fig. 10.7. For the combination of glass/PA66 it was shown that impact resistance changes far more than tensile strength when the fibre diameter is reduced. With an increase of the glass fibre diameter from 10 to 14 μm the impact resistance is reduced by 35% at a fibre content of 30% in the composite material glass/PA66. The values of tensile strength, however, change only by 10% (Anon., 1995).

Our own studies of the influence of fibre bundle refinement on the behaviour of the composite materials show similar tendencies (Müssig, 2001). The application of very fine steam pressure-separated hemp fibre bundles results in improved values for tensile strength compared to coarser separated fibre bundles, but also and above all, in an improvement of the impact strength values. The use of finer fibres provides advantages due to a more favourable length/ diameter ratio, a larger contact surface between fibre and polymer, a larger amount of fibres with the effect of reduced tension concentration at the fibre ends and higher energy loss due to stronger fibre pull-out from the polymer. Kohler and Wedler (1995) arrive at the same conclusions in their work on composites of the moulded type flax-epoxide-2D-2D-combination. It thus becomes clear how important fibre fineness is for the behaviour of the composite. In the section 'Measurement of selected fibre properties' an automated image-analysis system is presented, which supplies reliable measurement values across the whole range of fibre finenesses.

The influence of the force-elongation characteristics of the fibre

Within the framework conditions of ideal adhesion and above-critical fibre length a fibre – with a corresponding force-elongation curve – may effectively improve its tensile properties for instance. Figure 10.8 shows the principle of reinforcement of a polymer by the introduction of stiff fibres that are orientated in the direction of the force applied.

If plant fibres are to be selected that correspond to the basic construction principles of composite materials according to Fig. 10.8, nature offers a great variety of possibilities. As reported by Herrmann and Hanselka (1995) the fibres of stalk plants such as hemp (*Cannabis sativa* L.), flax (*Linum usitatissimum* L.) or ramie (*Boehmeria nivea* H. et A.) offer high stiffness and are suitable according to Fig. 10.8 for application in composite materials. The influence of the fibre properties, for instance, on flexural properties of composites is, however, not uni-parametric and depends not only on fineness but also on the stiffness and the force-elongation characteristics of the fibre (Müssig, 2002).

If natural-fibre composites are to be optimised in terms of impact resistance values it is necessary to use fibres that provide a special force-elongation characteristic. By the use of strong cotton fibre with simultaneously high elongation values, impact resistance properties may be achieved that are considerably improved over the stiffer hemp fibre (Müssig, 2002). The increase of impact resistance of natural fibre and cellulose fibre composites by the use of fibres with increased energy at breakage is also described by Mieck *et al.* (1999), Reußmann *et al.* (2002) and Weigel *et al.* (2002).

In the area of injection moulding the results of a series of tests (Karus *et al.*, 2002) show that the hemp-fibre-reinforced polypropylene varieties provide

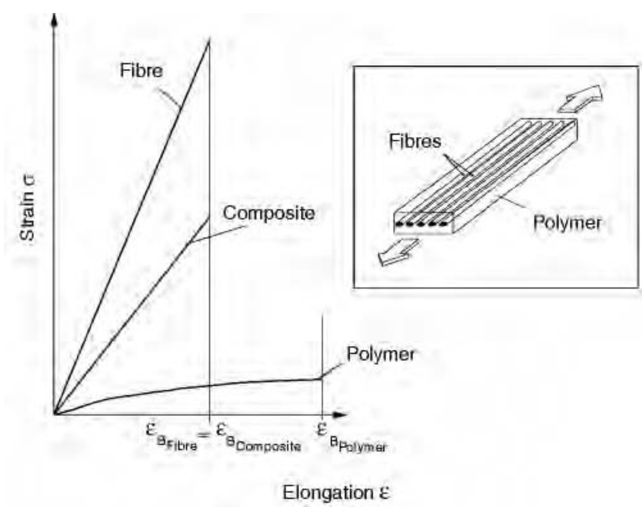

Figure 10.8 The properties of one-directional composite materials.

relatively low impact strength values. By the addition of PAN-fibres the impact resistance values may be more than doubled compared to the pure hemp/PP variant. The combination of cellulose fibre/PP leads to clearly improved impact resistance values compared to all other trial variations in the test. In summary, it may be stated that compared to all other values of mechanical properties, the impact resistance values show the largest differences within the samples tested.

As shown above, the influence of the fibre force-elongation characteristics is the decisive factor concerning achievable properties of a composite material. However, for the determination of the tensile properties of fibres, reproducible and reliable methods are required which allow the determination of fibre characteristics that may also be used for material models for structural simulations. A method which can meet these requirements is described in the section ‘Determination of the force-elongation characteristics of fibres’.

10.3.3 The measurement of selected fibre characteristics

Fibre fineness

The reproducible and quick measurement of fibre fineness is an important precondition for the determination of reliable fibre property values. Until recently, hardly any suitable systems existed for the measurement of the broad spectrum of finenesses of natural fibres that respected the framework conditions mentioned above. In order to solve this problem, a system has been elaborated in the last few years which allows the measurement of all fibre thickness distributions across all types of fibre. The new system is based on a high-performance scanner and image-analysis software that was developed for particle and diamond analysis (Schmid, 1998).

According to Schmid *et al.* (2002), in the development of the new, fully automated image analysis system FIBRESHAPE the following aspects were taken into account:

- development of a fast working method for the determination of thickness distribution of fibres or fibre-bundles
- determination of additional information such as colour, length and orientation
- quick and simple sample preparation
- reliable and reproducible results with little user influence
- no use of natural fibre standards for calibration of the tools.

In the following section the results of the test with the image analysis system FIBRESHAPE are presented. The fibre samples used were stored in a standard climate (20 °C, 65% rel. humidity) for 24 hours prior to preparation. These fibres were: cotton fibres, US-Pima-variety of the type *Gossypium hirsutum* L. (Müssig, 2002); coconut fibres (coir) (*Cocos nucifera* L.) type Omat from Sri Lanka (delivery December 2001); the fibres were provided for the tests by the company Hayleys, Sri Lanka; glass fibres, fibres from an E-glass filament (Nm 15) from a woven material of the company SSB, Bochum; hemp fibres/ mechanically separated, fibre bundles from the medium separation (MS) of hemp stalks (Felina/WE 96) of the unretted variety from the crop-year of 1996 in Oldenburg (Müssig, 2001).

The fibres were laid on a microscope slide with the aid of tweezers and were covered with a second microscope slide. The microscope slides were held together with adhesive tape applied to the short sides. Three microscope slides were prepared per sample. Scanning took place with the instrument Canoscan FS 4000 US and with the scanning software FilmGet FS 1.0 for Windows, and a resolution of 4,000 dpi (half-tone picture/positive) and a monitor with a gamma-value of 1,57 was selected. The exposure and focus were set to automatic. The analysis of the images took place with the image analysis software DIASHAPE Version 4.2.2/Software module FIBRESHAPE. The menu setting AFAS 4000.D00 was used. The results of the test are represented in the graph of Fig. 10.9. As well as the relative frequencies of fibre widths or fibre bundle widths the total frequencies were also noted. While the fibre types that are present as individual fibres (cotton and glass) show an almost normal distribution, the broad deviation to the left is noticeable in the distribution of the hemp fibre bundles.

It is shown that with FIBRESHAPE, on the one hand, a broad spectrum of possible fibre types may be tested, and on the other hand, the distribution of width of different elements may be measured quickly and reliably with little preparation work. As discussed in the section 'Influence of fibre length', the orientation of the fibres has a considerable influence on the properties of the composite. With the image-analysis system presented here it is possible to combine the analysis of width with the determination of fibre orientation. In order to document the feasibility of this option, ramie fibres were cut and prepared without any fibre orientation. Chinese chemically separated ramie (*Boehmeria nivea* H. et A.) – used for card sliver manufacturing (delivery 2000) – was used for this. The fibres were made available by the company Buckmann, Bremen. The prepared fibres were scanned and measured with the aid of FIBRESHAPE (menu setting AOR2400.D00/setup-change 4,000 dpi). In this measurement setting both fibre width and fibre orientation are measured as shown graphically in Fig. 10.10. For the scanned sample the orientation result is shown with a slight prevalence of orientation around 100º.

Force-elongation characteristics of fibres

The influence of fibre stiffness and the force-elongation characteristics on composite behaviour is clear. Reproducible methods are required for the determination of the stated fibre properties that provide measurement values with the best possible usefulness for composite material development.

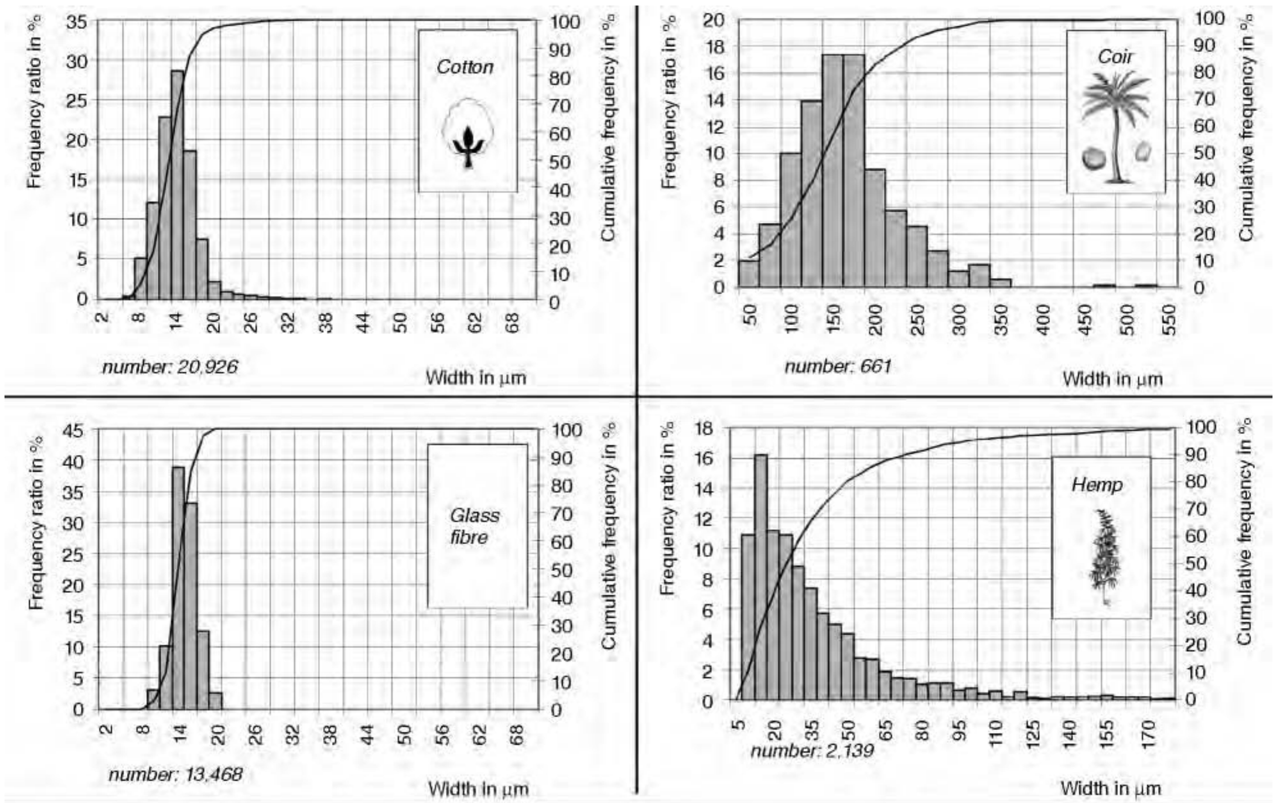

Figure 10.9 Fibre and fibre bundle width distribution of cotton, coir, glass and hemp fibres. Source: Müssig, 2003.

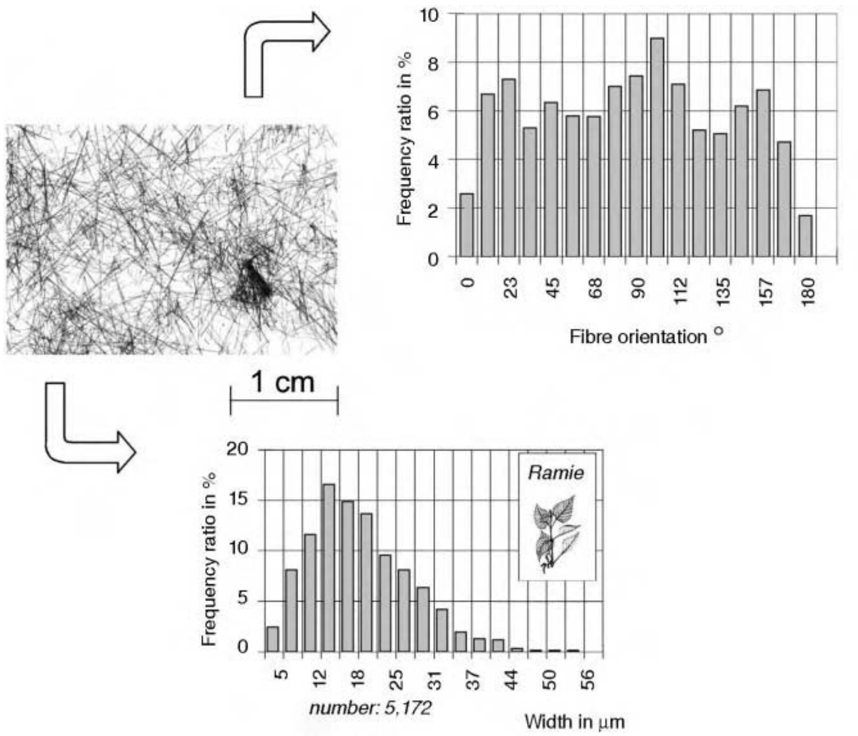

Figure 10.10 Fibre width and fibre orientation distribution of Ramie. Source: Müssig, 2003.

According to Nechwatal *et al.* (2003) the single element test is of particular importance in the determination of the tensile properties of fibres. Problems in the implementation of such tests lie particularly in:

- the influence of the clamping mechanism and of fibre-slip in the clamp
- various fibre gauge lengths and accounting for this influence
- the determination of the fibre or fibre bundle cross-sectional area
- the calculation of the fibre modulus.

In order to solve the problems mentioned above and to reduce the number of possible influences on the testing result, an appropriate testing instrument was procured after an intensive exchange with the company DIA-STRON Ltd., UK and adapted to requirements.

Using the new method, the individual elements to be tested are no longer clamped but glued in order to reduce the influence of clamping and may be tested at gauge lengths of 30, 20, 10, 5 and 3.2 mm. The compliance of the system, 99% of which is due to the load cell, is corrected directly in the analysis. The compliance of the glue is negligible. Forty-five individual elements may be prepared per auto-sampler which are automatically brought to a laser, one after

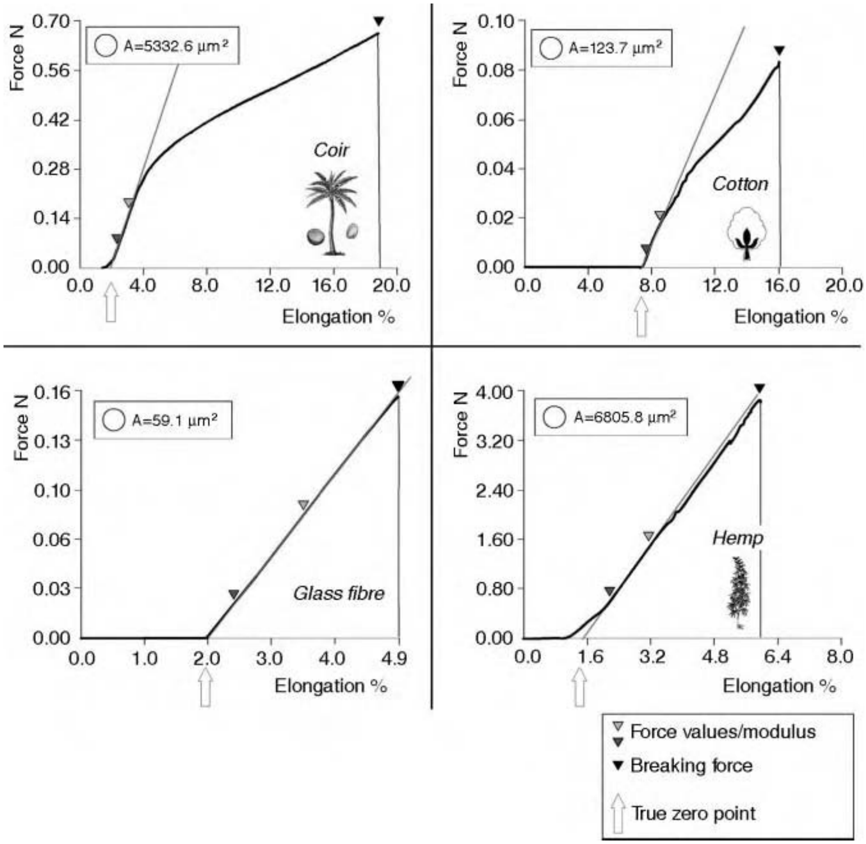

Figure 10.11 Tensile properties of selected fibres. Source: Müssig, 2003.

another, which measures the cross-sectional area in several places (i.e. with 10 mm gauge lengths in five places). The sample is then automatically brought to the tensile system. After the tensile test with deliberate setting of the desired pre-tension, the sample containers are removed and the next samples are tested automatically. The software allows both the determination of areas (N/mm^2) and of fineness related values (cN/tex).

The analysis programme allows an extensive evaluation of the data, such as the determination of the true zero point, elongation correction, extensive possibilities for module determination, determination of breaking energy, and also the energy required for the removal of fibre crimp and the cross-section determination of the elements. In Fig. 10.11 the force-elongation curves from single-element tests (10 mm gauge length/velocity 1 mm/min) are shown as an example. The fibres shown are those that were used for the FIBRESHAPE-measurement in the section on fibre fineness. The tested fibre types show clear differences concerning the force-elongation curves, the maximum force achieved, elongation and stiffness and also in the cross-sectional areas that were determined.

With the system available from the company DIA-STRON and the method adopted, fibre parameters may be determined in a way that is useful for material sciences by responding to the need for a quicker determination of tensile properties of individual fibres and fibre bundles.

Natural fibres in compound materials

Natural fibres from the stalks of plants offer particularly interesting properties for this end-use. Due to their supporting function in the plant they are naturally endowed with very good mechanical properties. Table 10.3 offers an overview of the properties of a few stalk fibres in comparison with glass fibre. These values are mean values whose purpose is to give a rough idea of the comparative characteristics of the fibres. Variation of characteristics due to influences of cultivation, harvest, retting and processing are not taken into account.

According to Herrmann and Hanselka (1994) those natural fibres with characteristics of high stiffness and low density are suitable for use as reinforcement of polymer products. According to Table 10.3, ramie, hemp and flax are particularly suitable. However, jute and kenaf also have interesting properties in composite materials for use as interior trim for automobiles. The possible uses for natural fibres in interior parts are quite comprehensive. One already widely established series component made of natural fibres is the interior door cladding. There are various composite materials with natural fibres and polymers on the market. One widely used combination is that of natural fibre needlefelt and polyurethane resins (Kleinholz *et al.*, 1996, Prömper, 1997 and Müller and Fries, 1998). The application of natural fibres need not be limited purely to interior trim. As Herrmann and Hanselka (1995) note, the potential of natural fibres, particularly hemp, reaches much farther and could allow their use in structural elements that today are typically made of glass-fibre-reinforced plastics.

Table 10.3 Physical characteristics of selected fibres

	E-Glass	Jute	Hemp	Flax	Ramie
Density (g/cm^3)	2.54	1.44–1.49	1.47	1.48	1.50–1.55
Tensile modulus (kN/mm^2)	77	5–14	–	–	5–7
Breaking force (N/tex)	1.38	0.3–0.4	0.5–0.6	0.5–0.6	0.5–0.7
Breaking elongation (%)	1–4	1.3	3–4	3–4	2.4
Tensile strength (kN/mm^2)	3500	435–580	780–910	770–890	760–1,060

Source: Hermann and Hanselka, 1995.

Conclusions

Material development must increasingly not only fulfil functional and economic criteria, but must also meet ecological and social requirements of sustainability. This has led to a change in attitude in the sector of material sciences towards the selection of more environmentally friendly materials. The use of natural plant fibres in composites offers an interesting alternative to industrially created products in this context. The influence of fibre properties on the behaviour of composites is manifold and was shown for the properties of fineness, length, orientation and force-elongation characteristics with various examples and our own results. From this, procedures may be derived which may simplify the creation of material properties. For the determination of tensile properties of individual fibres and of fibre bundles, reproducible and reliable methods are required that allow the determination of fibre properties which can also be used for material models for structural simulations.

With the system presented from the company DIA-STRON, reproducible fibre properties may be determined, which hitherto were determined in time consuming and error-prone ways. The influence of fibre-fineness must particularly be taken into account with natural fibres in a bundle structure. The fibre bundles may be divided into finer bundles or individual fibres with the aid of processing techniques and thus the properties of composites may be improved. For the determination of the width distribution of the fibres or fibre bundles a measurement system was introduced, with which a simple, reliable determination could be carried out. In addition to the large measuring capacity for very different types of fibres the measurement of fibre orientation is also possible. If natural fibre composites can be established as calculable materials with reliable measurement values, the products made from these materials will achieve a broader market introduction and will become an alternative on a lasting basis.

10.4 Manufacturing

10.4.1 Introduction

At the present time and as stated previously, practically all bast/leaf/fibre composites are manufactured using press-moulded technology, thermoplastic or thermoset. In 2000, these two types of manufacture had approximately equal shares of the market but there is a clearly identifiable trend toward thermoplastic matrix systems using, for example, polypropylene and away from thermoset, usually using polyurethane (see Fig. 10.12). By 2003 only about 34% of natural fibre composites were manufactured via the thermoset route.

The reasons for this change lie in the easier processing and recycling possibilities of thermoplastics as well as certain ‘fogging’ problems that sometimes arise when using duroplastic matrix systems. However, one should

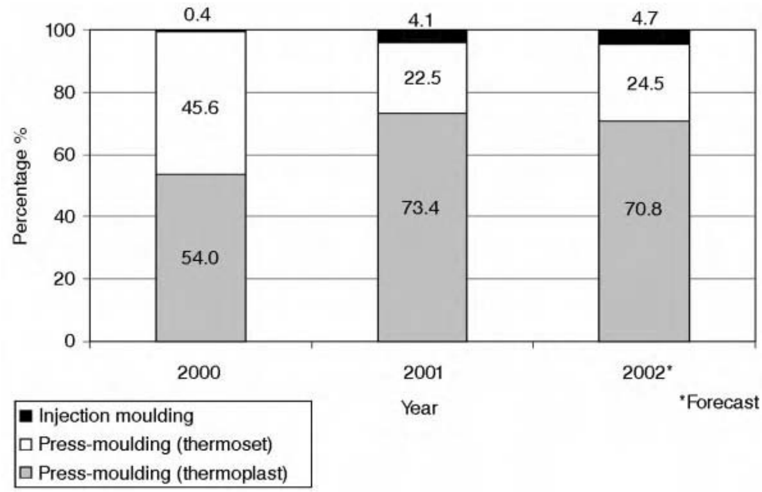

Figure 10.12 Percentage proportions of various processing techniques of natural fibre composites: 2000–2002. Source: Kaup *et al.*, 2003.

note that the thermoplastic processing of natural fibres produces more odours than thermoset (duroplastic) processing. This trend away from thermoset processing is expected to continue.

It is also interesting to note that 2003 saw the beginning of the production of injection moulded vegetable fibre panels. In general, injection moulding is the preferred route to manufacturing the more complicated shaped panels that are difficult, if not impossible, to make by using the press-moulded, methods; composite panel manufacturers expect that injection moulding will become increasingly important.

10.4.2 Thermoplastic manufacturing

In this process either of two methods of blending the vegetable fibres with polypropylene (PP) fibres are used. The fibres are first cut to lengths of between 80 and 120 mm and then either the fibres are blended as uniformly as is practicable before being carded and made into a felt by needle punching, or separate vegetable fibre and PP needle felts are made. These are then built up into as many layers as necessary and are then placed in the moulding presses under heat to achieve the size and shape panel required. So as to improve the PP-natural fibre bonding a small amount of a compatibiliser is sometimes used as an interface between the fibre and the matrix. This is often MAPP, a malic anhydride modification of PP.[4]

4. Nabi Saheb and Jog (1999).

10.4.3 Thermoset manufacturing

The vegetable fibre needle felts are sprayed with or soaked in synthetic binders such as epoxy resins or polyurethane and then moulded to the desired shape. Concerning the fibres used, it has been found helpful to blend the finer vegetable fibres (flax, jute) with a proportion of the coarser fibres (hemp, sisal, kenaf) as the finer fibres impart stability to the blend but may prevent their complete permeation by the binder if used on their own.

10.4.4 General

It is important, whether thermoplastic or thermoset technology is used, that the fibres used be reasonably clean. If not, the adherence of the fibres to each other and to the plastic component of the composite may be diminished, with the consequent possibility of rupture during use. Also, after lamination, the shives appear as blemishes on the surface of the panel. For flax tow, for example, a maximum of 2% impurities is allowed by the composite manufacturers.

In both thermoplastic and thermoset manufacture approximately equal weights of reinforcing fibres and PP or binders are used to create the textile semi-products before thermo-processing. As the vegetable fibres have lower densities than glass fibre the final composites are also lighter, by between 10% and 30%, than those made with glass or wood fibre, or than ABS panels. It should, however, be noted that these vegetable fibres must not be considered, despite their price advantages, as being capable of replacing glass fibre in all composites because of the very different mechanical characteristics of the fibres (see Table 1.1 of the Appendix to Chapter 1). Nonetheless, according to Weigel *et al.* (2002), there is, at present, intensive research into the possibility of replacing some glass fibre used in composites by fibres based on renewable resources.

10.5 The future, trends and conclusion

From the information set out in section 10.2 of this chapter we can summarise the present (late 2004) situation as follows:

1. European consumption of natural fibres in composite products for the automobile industry in 2003 was approximately 26,000 tonnes and is expected to grow at around 10% per year, which by 2010 would come to about 50,000 tonnes. Mr Gordon Mackie[5] estimates world consumption at between 110,000 and 120,000 tonnes (Fig. 10.13) but this is not just for

5. Mr Gordon Mackie, Textile Consultant, 228 Ballylesson Rd, Drumbo, Lisburn BT27 5TS, UK. Private communication.

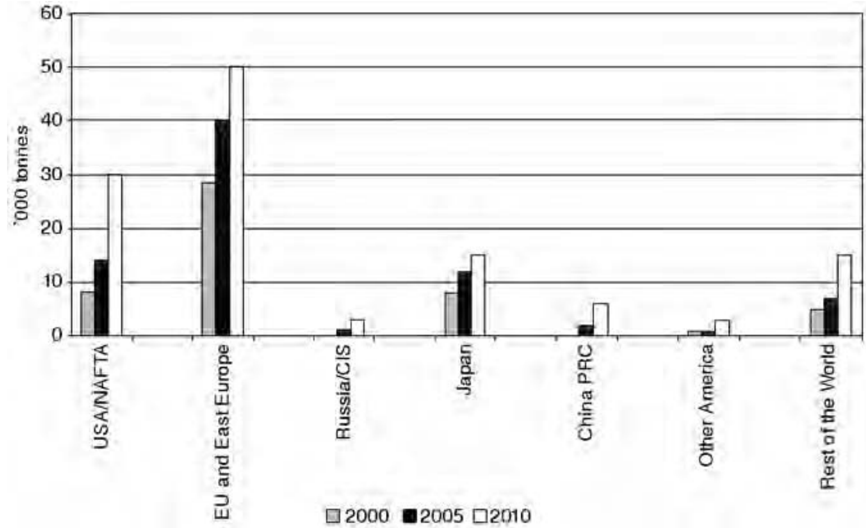

Figure 10.13 Estimated natural fibre use in reinforced plastics. Source: Gordon Mackie.

automobile panels and includes penetration of the market for composites in other industries held by glass at the moment (Fig. 10.14).

2. When used in cars and light commercial vehicles and using present technology between 5 kg and 10 kg of natural fibres are used per car in Europe.
3. 58,000,000 cars were manufactured in the world in 2002 and this figure is expected to increase to 69,000,000 in 2008, an increase of about 20%.[6]
4. If the fibres are used in simple door panels, vegetable fibre composite panels are more expensive than those made entirely from plastic or reinforced with wood or reclaimed vegetable fibres.

It would be reasonable, therefore, to suggest that the entire market of over 50,000,000 vehicles is not open to vegetable fibre composites at the present time and that they will be used only in the interior trim of top and middle range cars where the door panels are more complex and laminated. Then the 'one-shot' press moulding technique is price competitive. In lower range cars vegetable composites are too expensive because they utilise unlaminated, simple door panels.

We should also take into account, again at present, that only small quantities of vegetable fibres are used in the manufacture of injection moulded composite panels and that this market is still the preserve of glass fibre. It would seem that the factors preventing greater use of vegetable fibres are that certain technical

6. Society of Motor Car Manufacturers and Traders, London. Private communication.

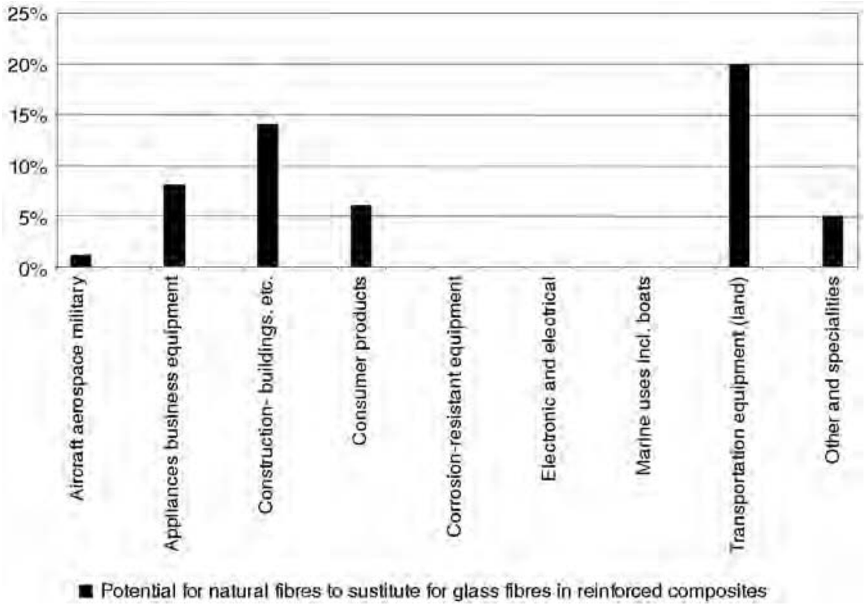

Figure 10.14 An estimation of substitution/penetration for natural fibres to replace glass fibres in reinforced composites by 2010. Source: Gordon Mackie.

problems still need to be resolved and also that investment in new or modified manufacturing plant will be necessary. It is expected that over the coming few years these technical obstacles will be overcome and that the investment will take place (see Fig. 10.15).

At this point in time the future of bast and leaf fibres in this market looks very encouraging; however, experience shows that just extrapolating into the future the growth rate that a new technical development achieved in its early years can be very misleading. It is therefore appropriate to be cautious when assessing the situation but it would seem reasonable to think that the consumption of vegetable fibres in automobile composites in 2010 would be within the following brackets: for press moulded panels, 40,000–100,000 tonnes; for injection moulded panels, 20,000–50,000 tonnes; total, 60,000–150,000 tonnes. It is, however, difficult to estimate the share taken by individual fibres, but the following market shares, based on present experience, would seem to be reasonable: flax 45%; hemp 15%; 'exotic' 40%.

Looked at from a global point of view, consumption in the Americas and Asia should be added to these quantities. In 2000, Kline & Company (www.klinegroup.com) published the study 'The outlook for natural-fibre composites 2000–2005'. The main conclusion was that the growth in use of natural-fibre plastic composites (including wood fibre applications) had almost reached the ambitious five-year annual rate of 60%.

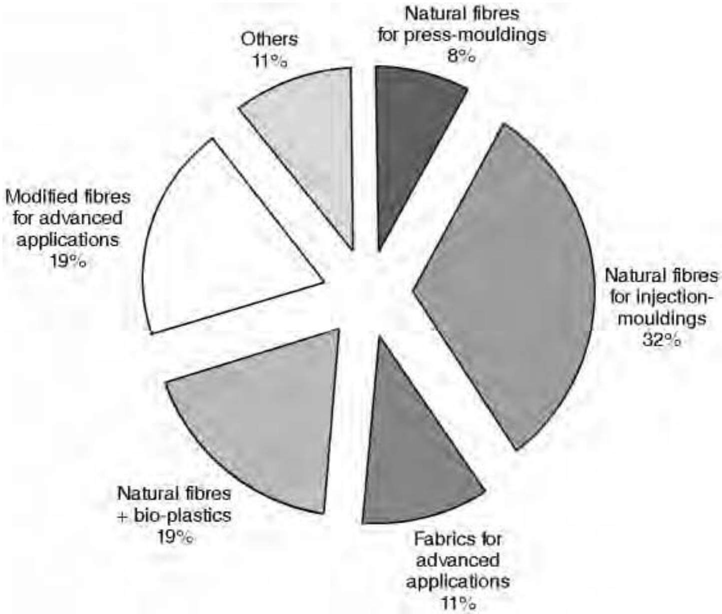

Figure 10.15 Future trends 2005: which natural fibre technologies for composites will gain in significance? Source: Kaup *et al.*, 2003.

The situation in Japan is also developing rapidly.[7] The present fibre raw materials for car trim are low quality cotton waste and rags, priced at not higher than US$400 per tonne. Various reasonably low cost fibre replacements are available locally, rice straw and Chinese flax tow, for example, but these are both too weak to be technically acceptable. However, as in the rest of the world, considerable research and development effort is taking place, mostly based on jute and kenaf which are available in quantity from several not-too-distant countries. The market has developed to the extent that 4,500 tonnes of these fibres were imported into Japan for the manufacture of composites in 2002 and it expected that the use in Asia generally of bast fibre composite materials for vehicle interior trim will continue to evolve as it is doing in Europe and North America.

A further point should be made concerning the productive potential of China concerning the supply of jute and kenaf, and possibly other fibres for this rapidly developing sector. Chinese agriculture is in a position to supply large volumes of jute and kenaf fibres (FAO, 2001). The decline in plant cultivation since 1985, due to the decrease in demand for 'gunny bags' used for the transportation of agricultural products has resulted in fibre processing capacities being unused and available. Delivery reliability, which is so important for the automotive industry is thus assured.

7. Y. Akai, Akai Shoton, Kyoto, Japan. Private communication, 2004.

There is a particular need for research in order to determine, implement and supply on an industrial level, fibres with special properties that may be used in the sector of composite materials. However, fibre processing, which at present is strongly geared to the production of yarn, would have to be expanded in the direction of the production of non-wovens. Also Chinese agriculture will become a reliable partner of the automotive industry on a sustainable basis only if quality management starts with the cultivation of the crops.

In the manufacturing of composites from 100% renewable resources, not only natural fibres but also thermosets on the basis of plant oils may be the target of the future. Linseed oil and soy-oil for instance represent interesting raw materials. By the synthesis of plant oils, thermoset systems may be produced that show properties comparable to conventional resin systems. The work of Schönfeld (2000) and Williams and Wool (2000) should be mentioned in this context. With the combination of agriculturally produced plant oils and natural fibres the automotive industry could develop exemplary lightweight constructions on the one hand and on the other, the agricultural structures of China could be strengthened on a sustainable basis.

10.6 Acknowledgements

The nova-Institut reports are listed in the references at the end of the chapter.

We are also indebted to Mr Gordon Mackie for his permission to include his graphs on the present and estimated future development of natural fibres in this market.

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Appendix I: List of fibre-producing plants

	Botanical name	Common name
Agavaceae	*Agave sisalana*	Sisal
	Agave sp.	Maguey
	Agave lechuguilla	Mexican fibre
	Agave cantala	Cantala
	Agave fourcroydes	Henequen
	Agave letonae	
	Agave striata	
	Furcraea cabuya	Cabuya
	Furcraea gigantea	
	Furcraea macrophylia	Fique
Apocynaceae	*Apocynum cannabinum*	
	Tabernaemontana pachysiphon	
Araliaceae	*Acanthopanax sciadophylloides*	
Asclepiadaceae	*Asclepias* sp.	Milkweed
	Calotropis gigantea	
	Calotropis procera	Kapok
	Barringtonia racemosa	
	Barringtonia sp.	
Bombacaceae	*Adansonia digitata*	Baobab
Bromeliaceae	*Ananas comosus*	Pineapple
	Ananas erectifolius	Curauá
	Bromelia laciniosa	Macambira
	Bromelia magdalenae	
	Neglazovia variegata	Crauá, caroá
Cannabaceae	*Cannabis sativa*	Hemp
Caprifoliaceae	*Lonicera periclymenum*	Honeysuckle
Compositae	*Chrysanthemum leucanthemum*	
	Gerbera lanuginosa	
Convolvulaceae	*Convolvulus* sp.	
Cupressaceae	*Chamaecyparis nootkatensis*	Yellow cedar, Yellow cypress
Cyclanthaceae	*Asplundia insignis*	
Cyperaceae	*Eriophorum polystachion*	
	Eriophorum vaginatum	
Fagaceae	*Quercus nigra*	Water oak, Spotted oak, Possum oak

	Botanical name	Common name
Gnetaceae	*Gnetum gnemon*	Bago, Spanish joint fir
Gramineae	*Ammophila arenaria*	
Leguminosae-caesalpinioideae	*Bauhinia retusa*	
	Brachystegia boehmii	
	Brachystegia spicaeformis	
Leguminosae-papilionoideae	*Crotalaria juncea*	Sunn hemp
	Lathyrus odoratus	Sweet pea
	Pueraria lobata	
	Spartium junceum	Spanish broom
	Sesbania bispinosa	Dhaincha
Liliaceae	*Samuela carnerosana*	Palma istle
	Sansevieria sp.	Bowstring hemp
	Yucca glauca	
	Yucca baccata	
	Yucca filamentosa	Eve's thread, Adam's needle
Linaceae	*Linum usitatissimum*	Flax
Malvaceae	*Abutilon angustatum*	
	Abutilon theophrasti	Chinese jute/hemp
	Gossypium arboreum	Cotton
	Gossypium	Cotton
	Hibiscus radiatus	Monach rosemallow
	Hibiscus cannabinus	Kenaf
	Hibiscus subdariffa	Roselle
	Hibiscus tiliacus	Sea hibiscus
	Plagianthus pulchellus	
	Sida sp.	Malva
	Urena lobata	Urena
Moraceae	*Antiaris africana*	
	Antiaris toxicaria	
	Artocarpus communis	Bread fruit
	Artocarpus elastica	
	Brosimum sp.	
	Broussonetia papyrifera	Paper mulberry
	Cannabis sativa	Hemp
	Ficus brevicuspis	
	Ficus natalensis	
	Ficus sp.	
	Ficus thonningii	
	Kadsura japonica	Kadsura
	Morus alba	White mulberry
	Morus nigra	Black mulberry
	Musa basjoo	
	Musa fehi	
	Musa sp.	
	Musa textilis	Abaca
Orchidaceae	*Dendrobium* sp.	
	Dendobrium Jamesianum	
	Diplocaulobium regale	

	Botanical name	Common name
Palmae	*Cocos nucifera*	Coir, coconut
	Copernicia alba	Caranday
	Corypha umbraculifera	
	Hyphaene thebaica	Doum palm
	Metroxylon sp.	Sago
	Phoenix dactylifera	Date palm
Pandanaceae	*Pandanus spiralis*	Screw pine
Phormiaceae	*Phormium tenax*	New Zealand flax
Schizaeaceae	*Lygodium* sp.	Climbing fern
Sterculiacease	*Abromqa augusta*	
	Sterculia sp.	
Thymelaeaceae	*Edgeworthia gardneri*	
	Lagetta lintearia	Lacebark tree
Tiliaceae	*Clappertonia ficifolia*	Napunti
	Corchorus japonicus	
	Corchorus olitorius	Brown or tossa jute
	Corchorus capsularis	White or China jute
	Tilia cordata	Lime
	Triumfetta rhomboida	Punga
Tropaeolaceae	*Tropaeolum majus*	Nasturtium
	Tropaeolum sp.	
Ulmaceae	*Celtis* sp.	
	Trema orientalis	Charcoal tree, Gunpowder tree
Urticaceae	*Boehmeria nivea*	China grass, rhea, White ramie
	Girardia sp.	
	Girardinia diversifolia	Allo, Nigiri
	Girardinia heterophylla	
	Pipturus gaudichaudianus	
	Urtica dioica	Stinging nettle

Sources: Centre for Economic Botany, Royal Botanic Gardens, Kew; Kirby, R. H., *Vegetable Fibres*, Leonard Hill, London; Jarman, C., *Plant Fibre Processing*, Intermediate Technology Publications, Rugby, UK; Prof. R. Ladchumananandasivam. Universidade Federal do Rio Grande, Brazil.

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