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

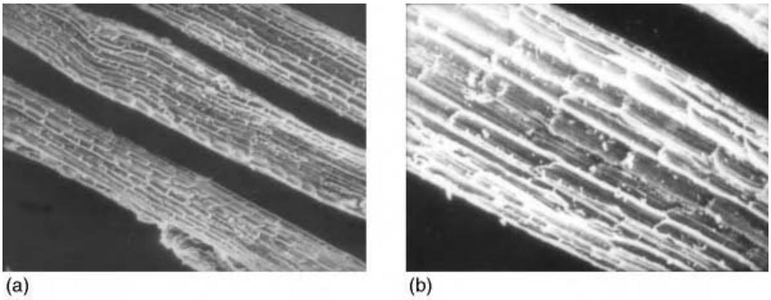


Figure 6.2 (a) and (b) longitudinal appearances of sisal fibre bundle.

Table 6.1 The microstructure data of sisal fibre[4]

Crystallinity (%)	Orientation		Birefringens		
	f_x	α	$n_\parallel$	$n_\perp$	$\Delta n = n_\parallel - n_\perp$
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

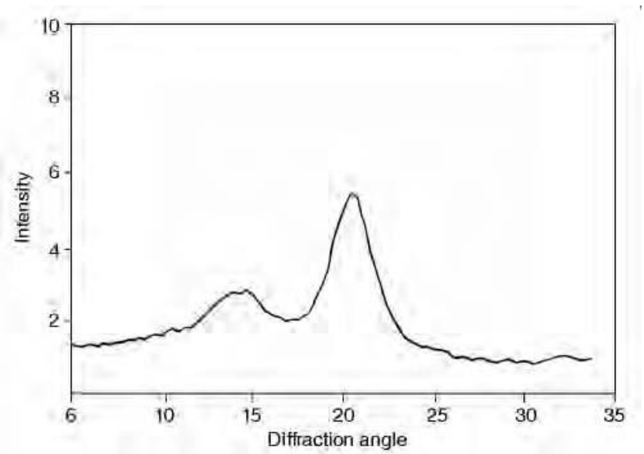


Figure 6.3 X-ray of sisal fibre.

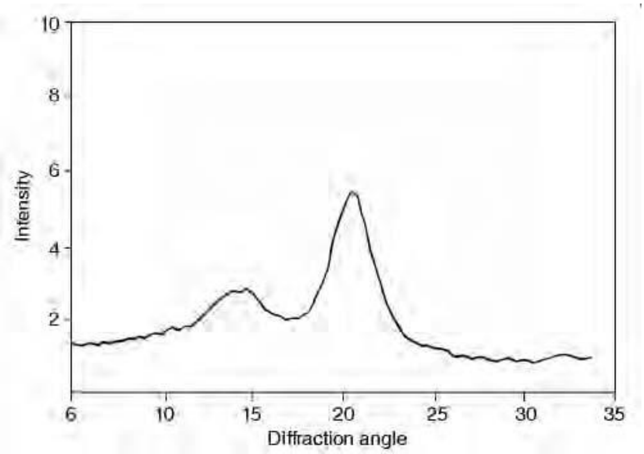


Figure 6.4 Infra-red spectrum of sisal fibre.

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.

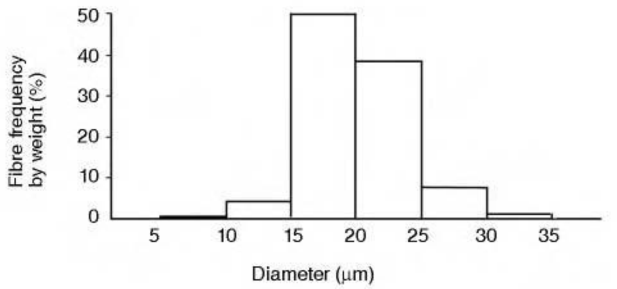


Figure 6.5 The distribution of width of single cells.

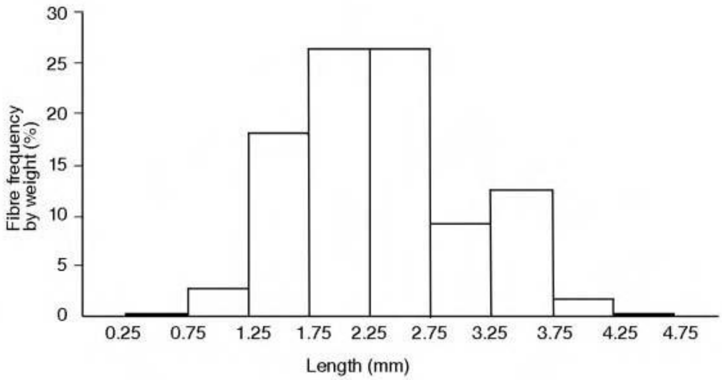


Figure 6.6 The distribution of length of single cells.

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	–	–

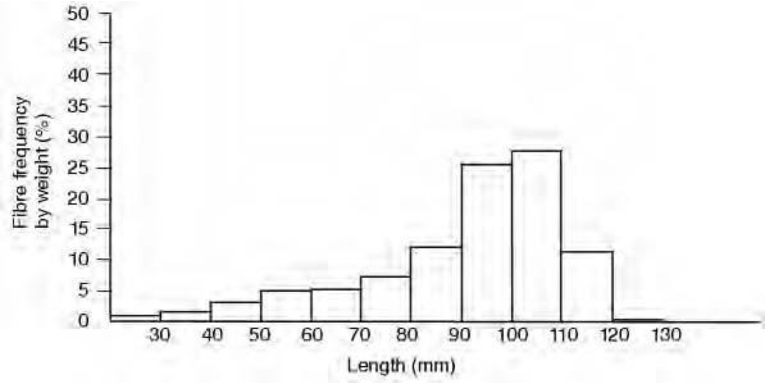


Figure 6.7 Distribution of length of fibre bundles.

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 hemicellulose, 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

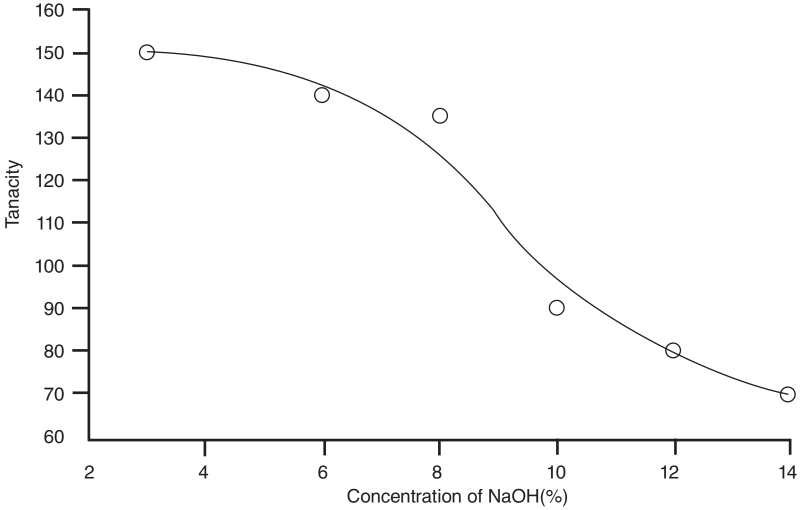


Figure 6.8 The influence of concentration of NaOH on tenacity.

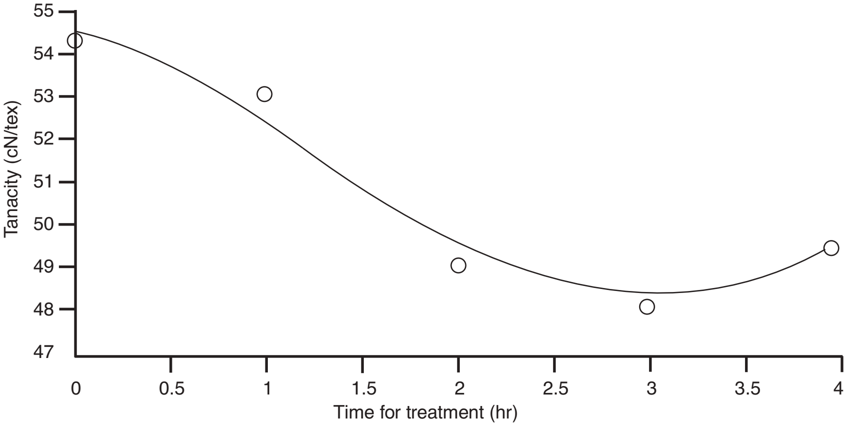


Figure 6.9 The influence of treatment time of NaOH on tenacity.

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

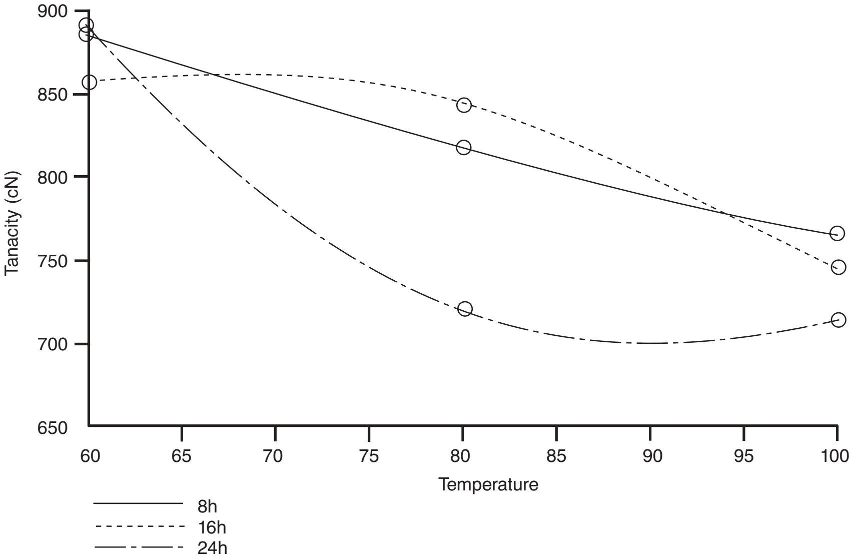


Figure 6.10 Resistance to temperatures (°C).

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.

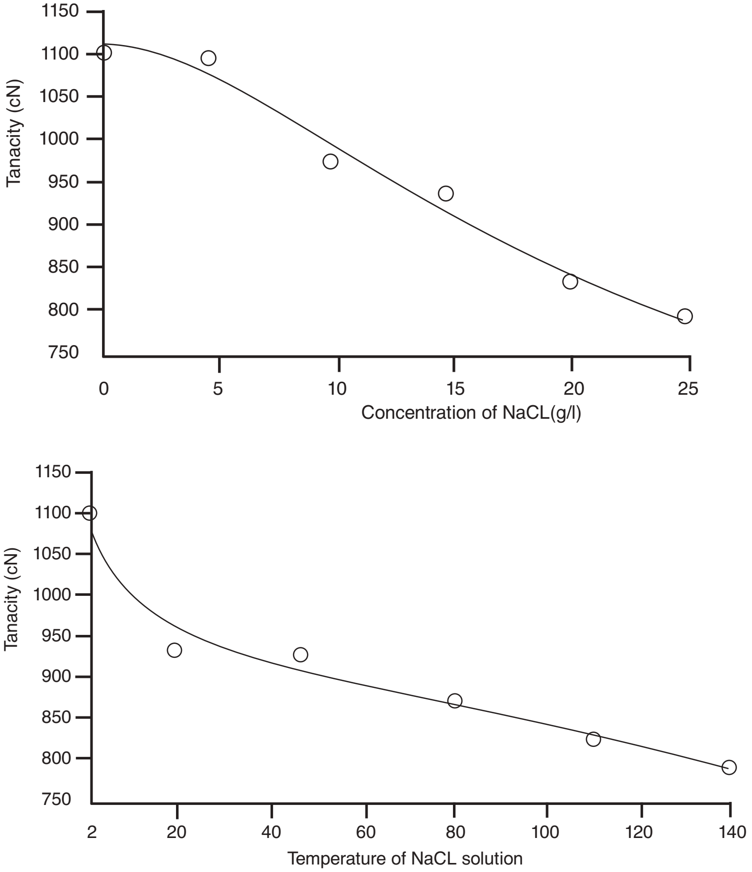


Figure 6.11 Resistance to salt (a) concentration (b) temperature.

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.

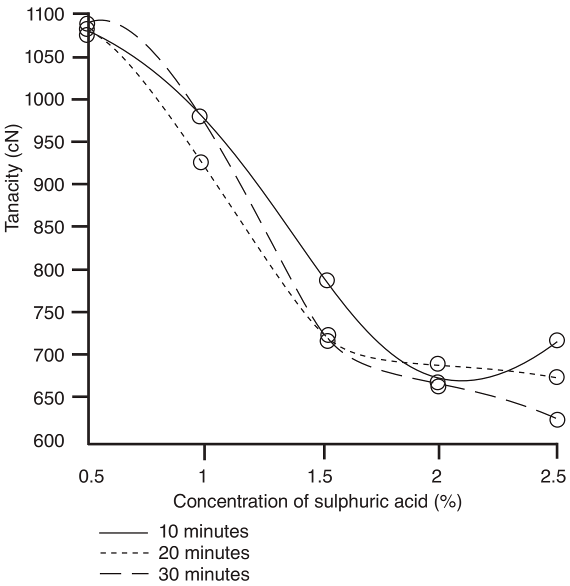


Figure 6.12 Resistance to sulphuric acid.

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

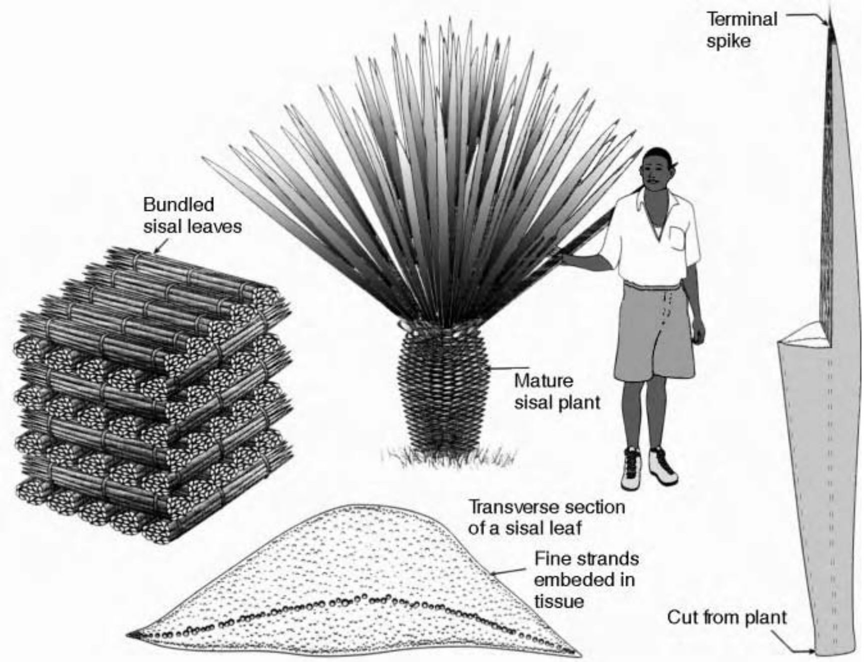


Figure 6.13 Harvesting sisal leaves. Source: C. Jarman, *Plant fibre and processing: A handbook*. Courtesy: ITDG Publishing, UK.

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.

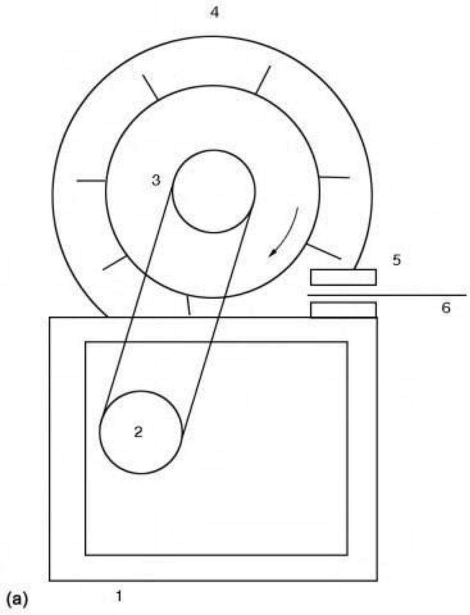


Figure 6.14 Decorticating machines for sisal fibre (a) sisal fibre decorticator (b) sisal raspador (c) crane decorticator. Source: C. Jarman, *Plant fibre and processing: A handbook*. Courtesy: ITDG Publishing, UK.

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

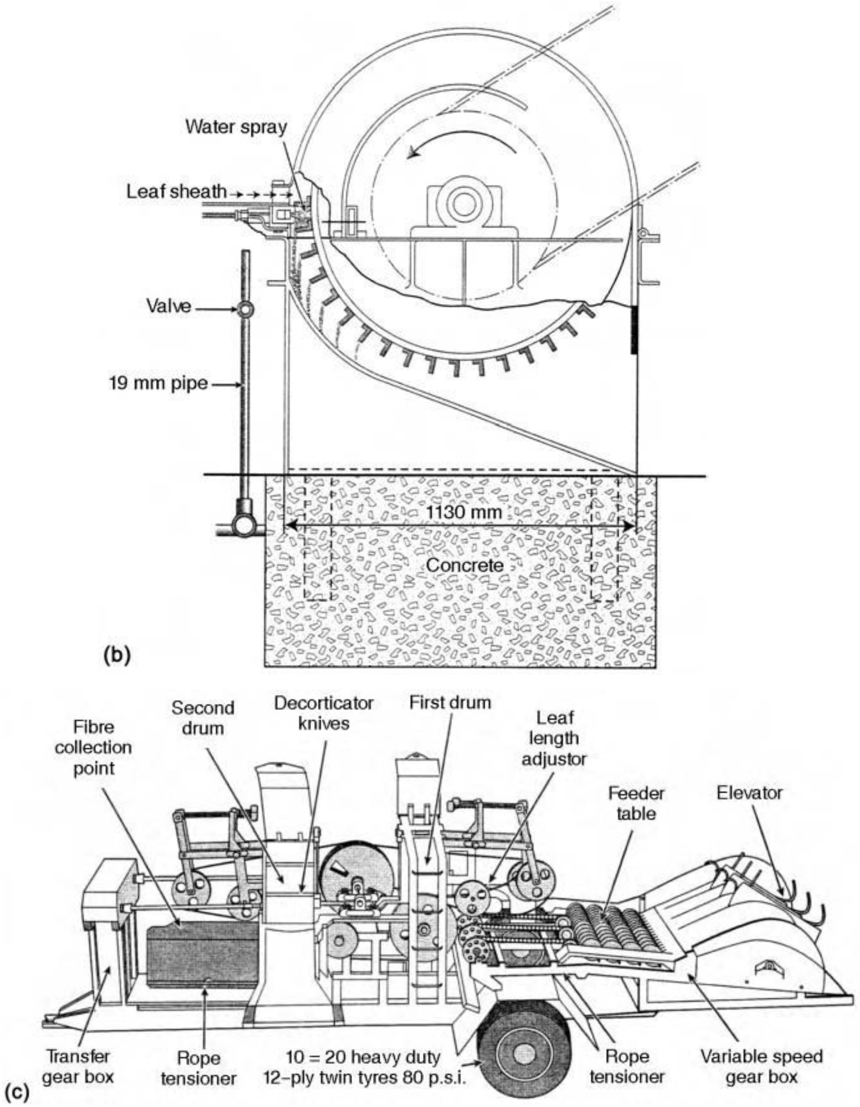


Figure 6.14 contd.

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.

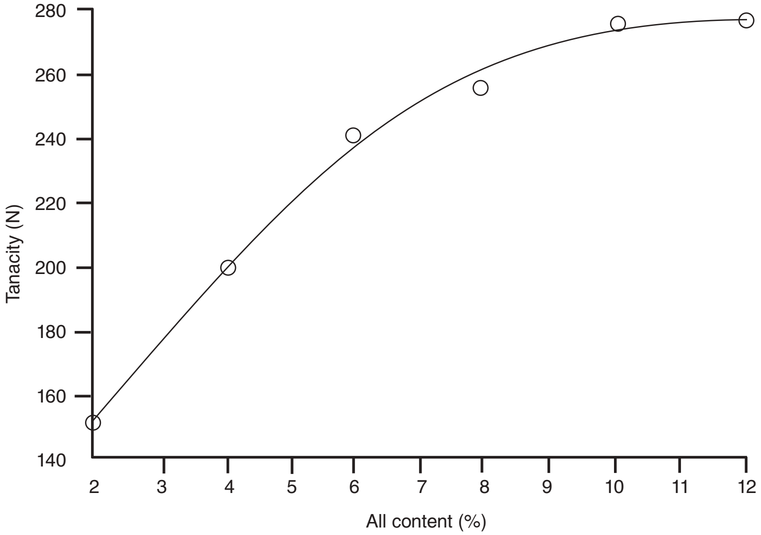


Figure 6.15 Yarn tenacity (N) vs oil content (%).

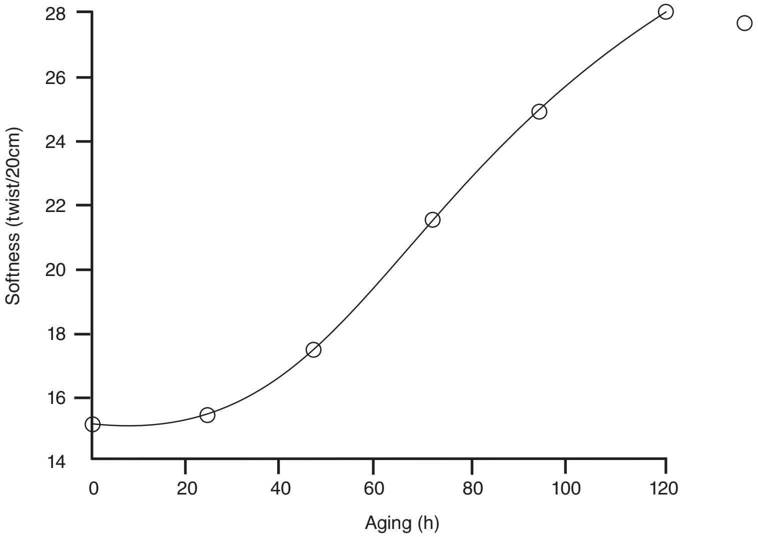


Figure 6.16 Softness (torsion-ability) of fibre vs ageing time (days).

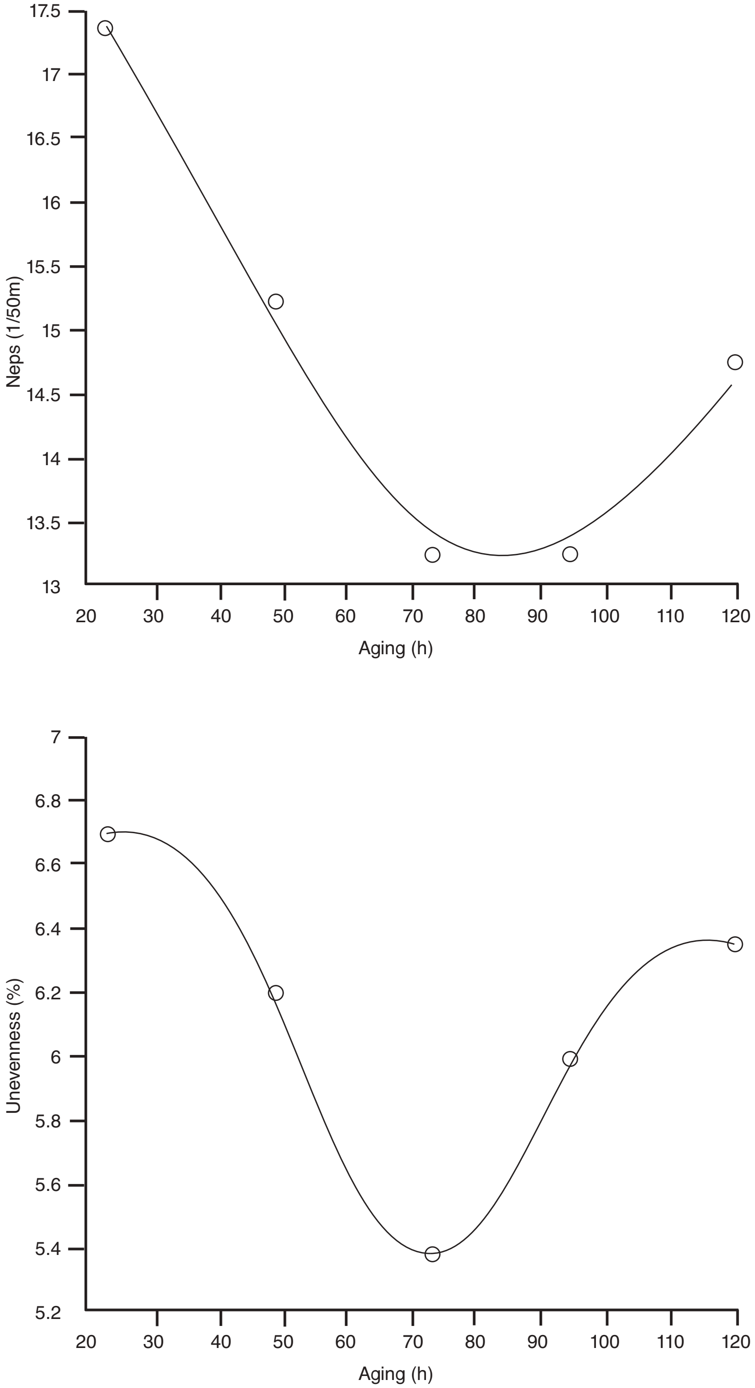


Figure 6.17 Yarn quality of sisal vs ageing time (a) and (b).

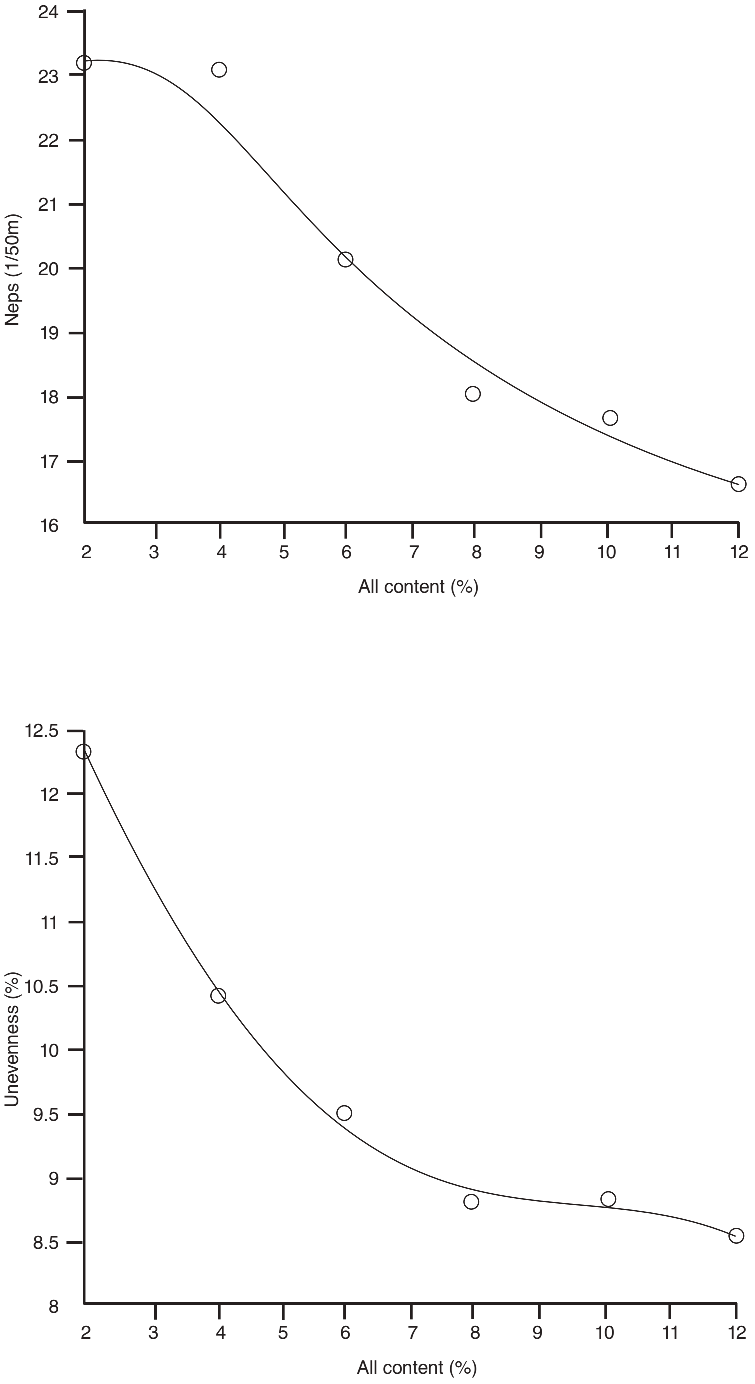


Figure 6.18 Yarn quality of sisal vs oil content (a) and (b).

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.

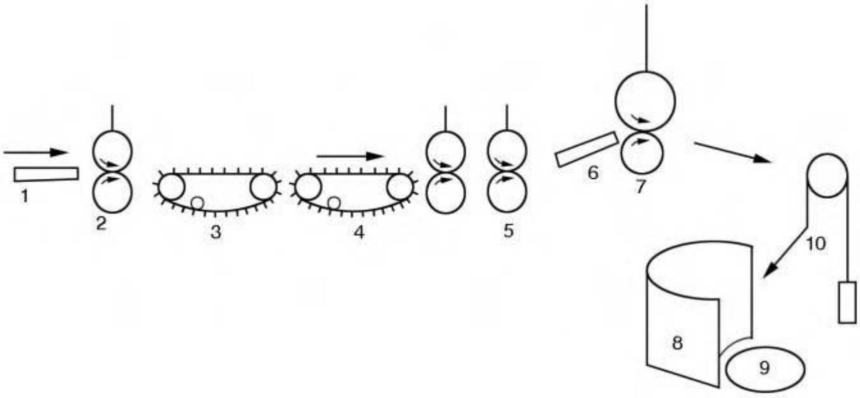


Figure 6.20 Schematic drawing of drafting line.

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

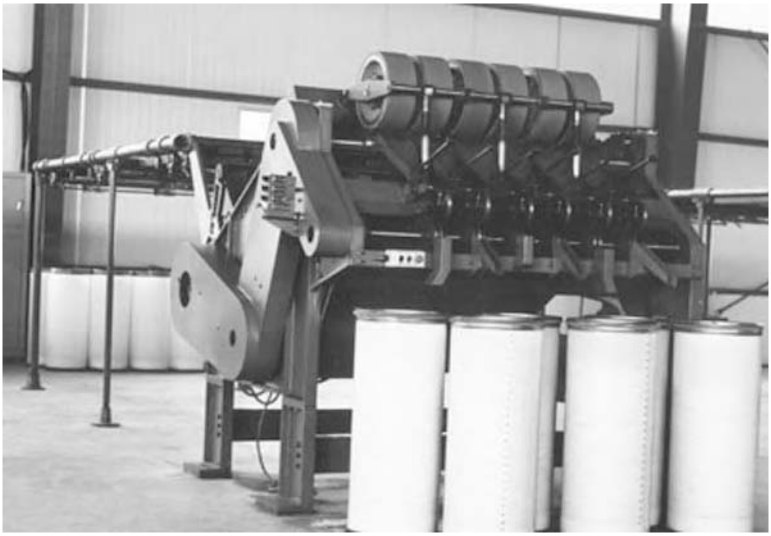


Figure 6.21 Doubling machine.

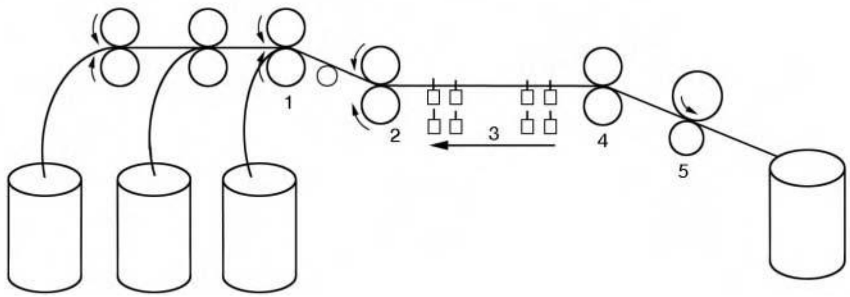


Figure 6.22 Schematic drawing of doubling line.

- 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.

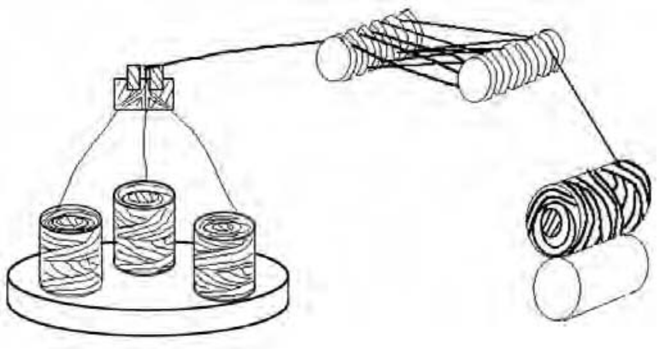
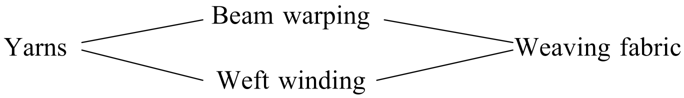


Figure 6.24 Vertical rope making machine.

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:



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 °C, 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

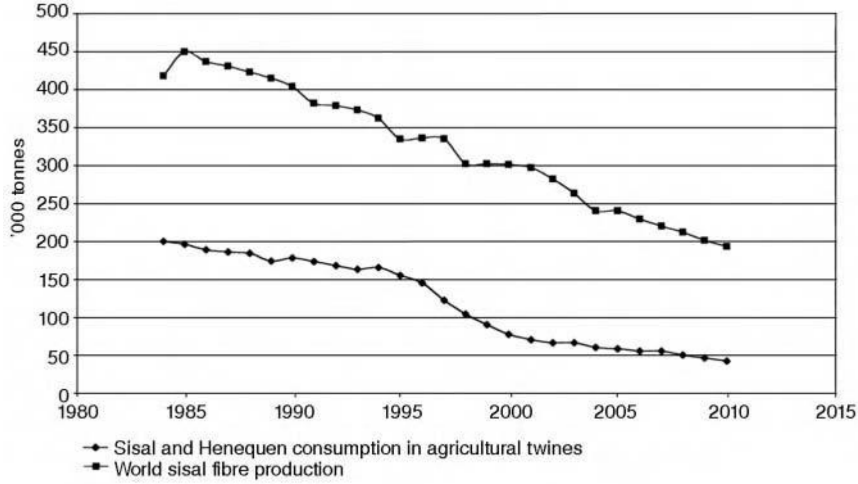


Figure 6.27 World sisal production and consumption 1985–2010. Courtesy: Gordon Mackie.

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.

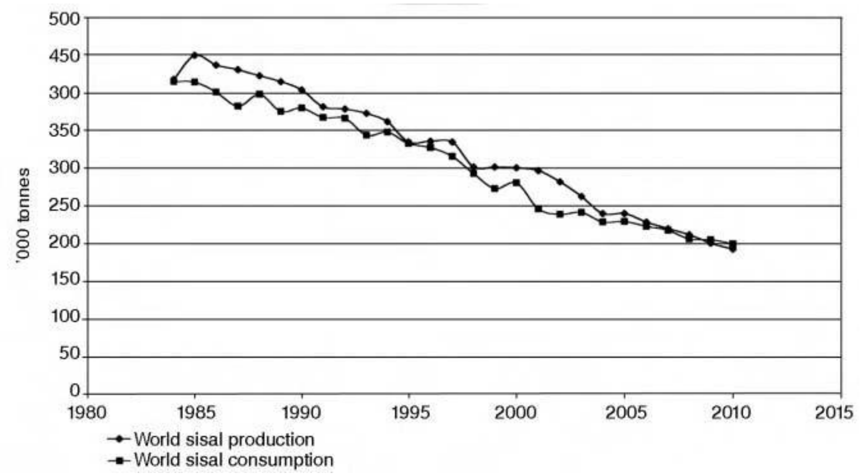


Figure 6.28 World sisal production 1900–2020. Courtesy: Gordon Mackie.

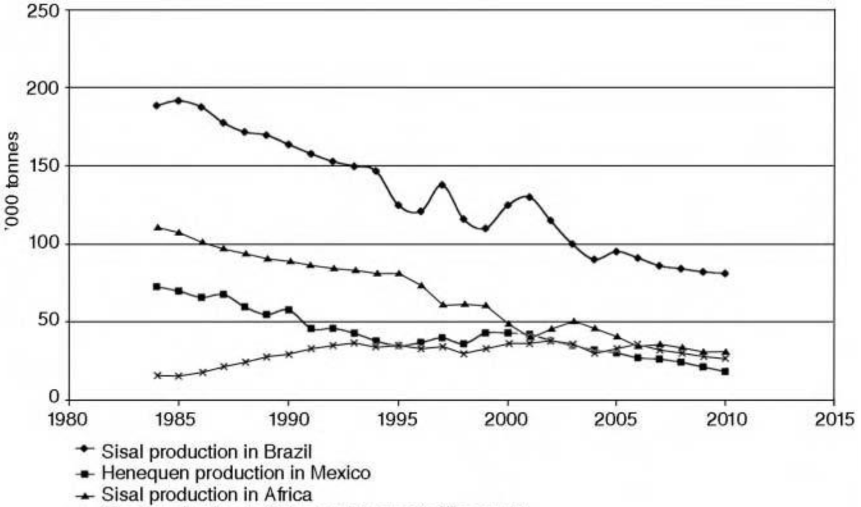


Figure 6.29 World sisal production by country. Courtesy: Gordon Mackie.

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

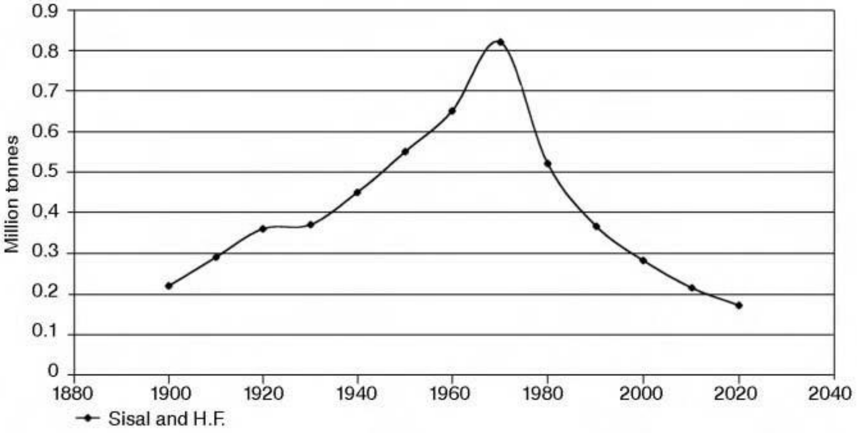


Figure 6.30 Sisal production and twine output. Courtesy: Gordon Mackie.

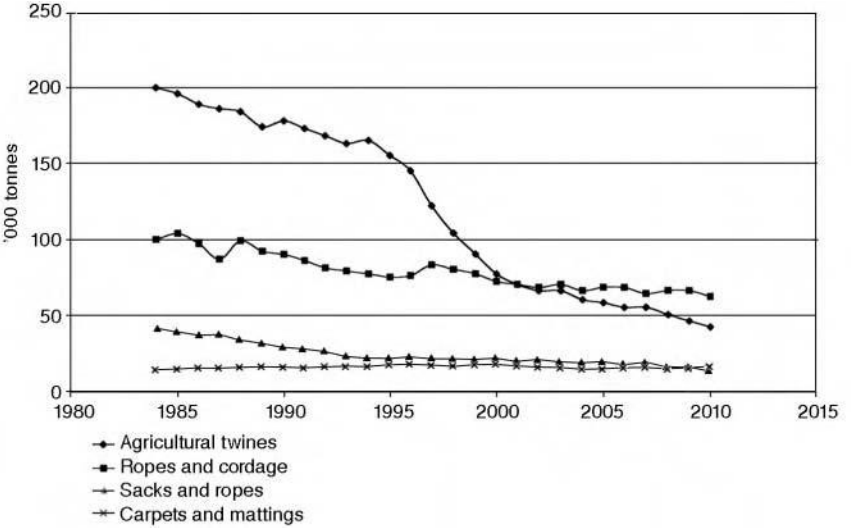


Figure 6.31 Major end uses of sisal and hard fibres. Courtesy: Gordon Mackie.

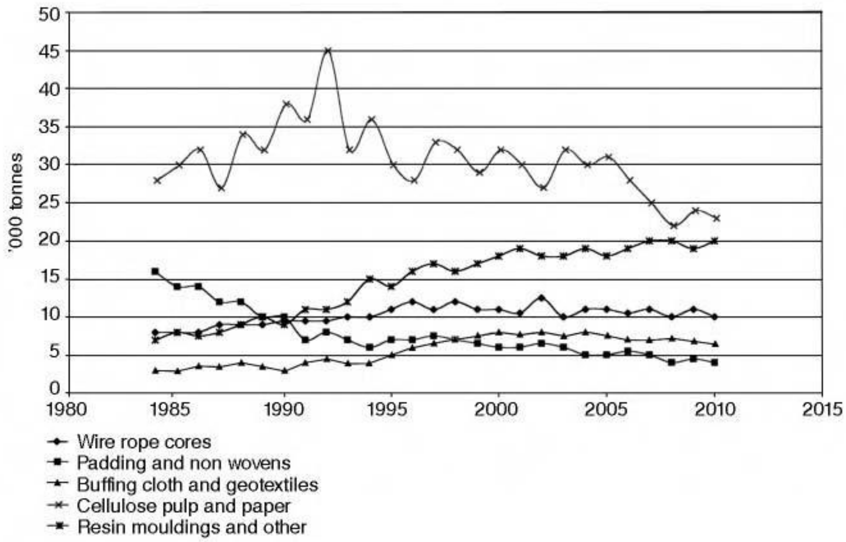


Figure 6.32 Minor end uses of sisal and hard fibres, excluding abaca. Courtesy: Gordon Mackie.

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

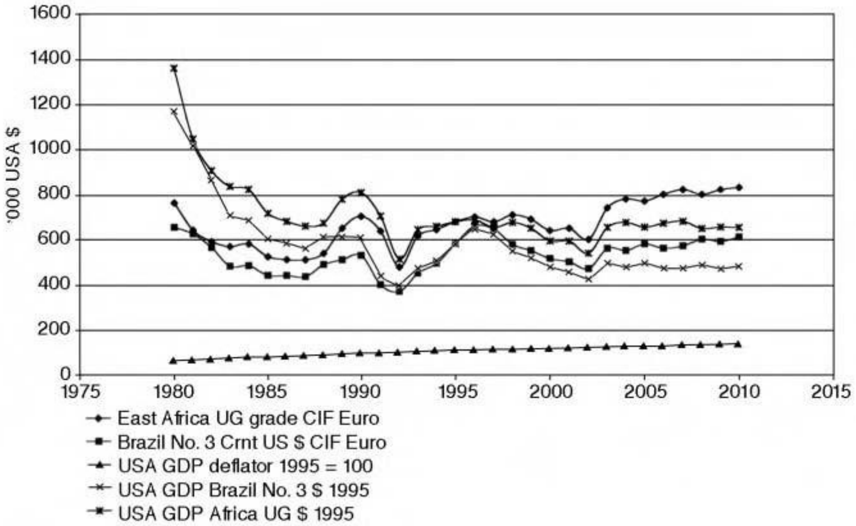


Figure 6.33 Sisal prices in current and constant 1995 US$ values. Courtesy: Gordon Mackie.

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

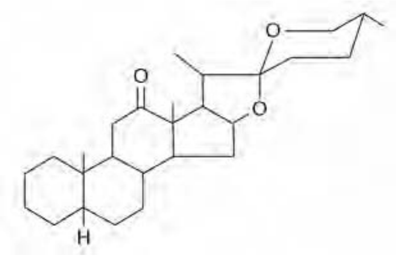


Figure 6.35 Hecogenin ($C_{21}H_{42}O_4$).

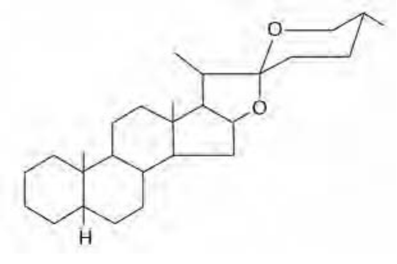


Figure 6.36 Tigoenin ($C_{27}H_{44}O_3$).

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.