3
Flax

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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

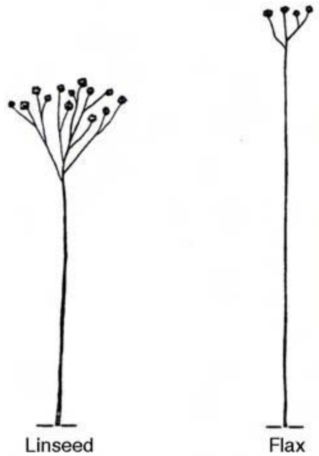


Figure 3.1 Line drawings of linseed and textile flax. Source: J. Turner, *Linseed Law: a handbook for growers and advisors*, BASF, Suffolk, UK. Courtesy: John Turner.

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

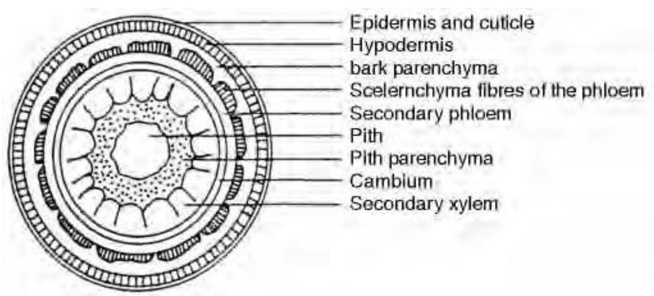


Figure 3.3 Line drawing section of flax stem. Source: Van Cotthem and Fryns-Claessens, 1972 in *The Biology and Processing of Flax*, M. Publications, Belfast, UK. Courtesy: Professor S. Sharma, ed.

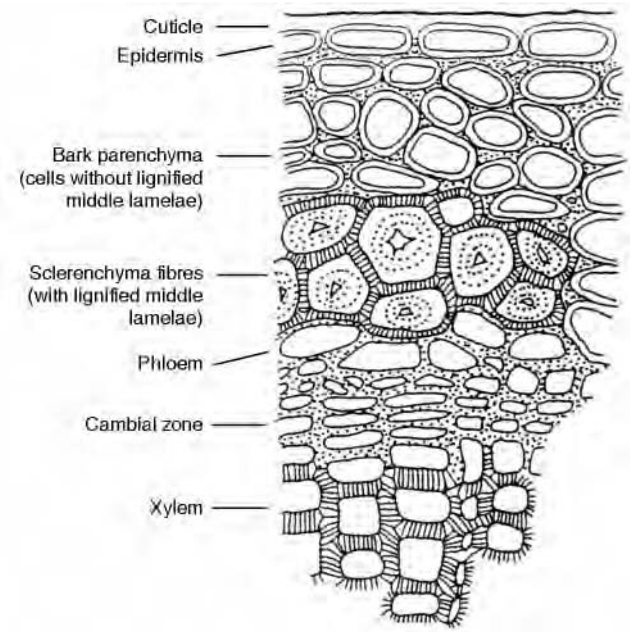


Figure 3.4 Line drawing of transverse section through a flax stem. Source: Dujardin, 1942, in *The Biology and processing of flax*, M. Publications, Belfast, UK. Courtesy: Professor S. Sharma, ed.

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

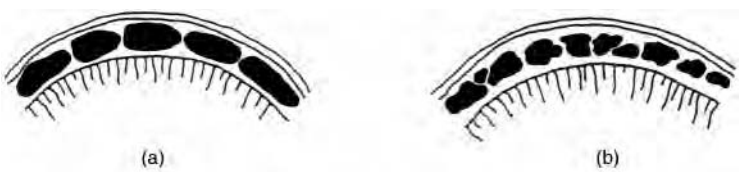


Figure 3.5 Cross-sectional diagrams of flax stalks showing (a) fibre bundles of a high quality flax and (b) fibre bundles of a low quality flax. Source: C.F. Van Sumere and Melliand Textilberichte, GmbH in *The Biology and processing of flax*, M. Publications, Belfast, UK. Courtesy: Professor S. Sharma,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

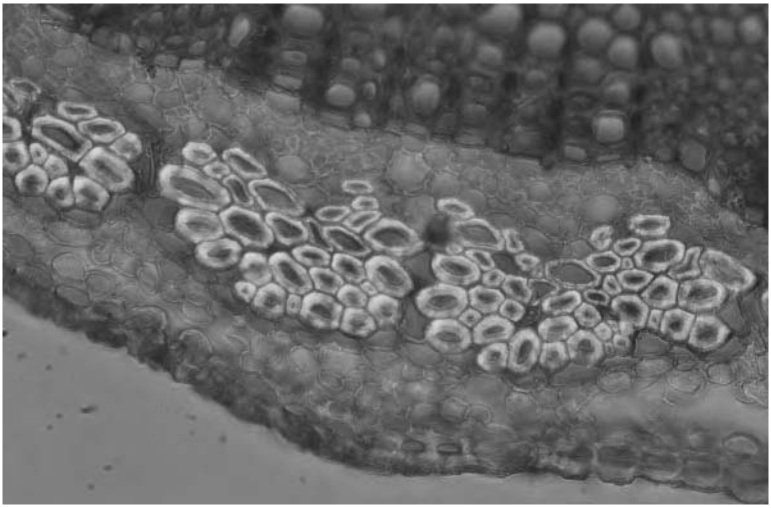


Figure 3.7 Cross-section of flax stem × 40 showing distinct fibre bundles. Source: Institut Technique du Lin, Paris.

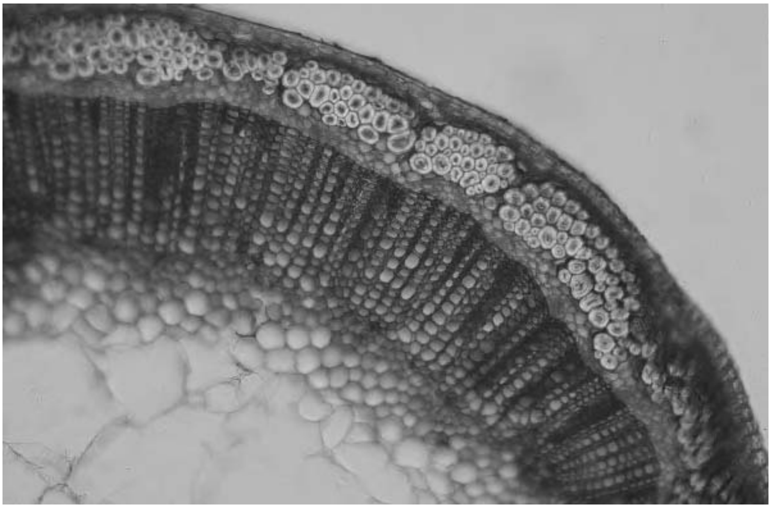


Figure 3.8 Cross-section of flax stem × 10 showing relative position of fibre bundles in the stem. Source: Institut Technique du Lin, Paris.

- 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

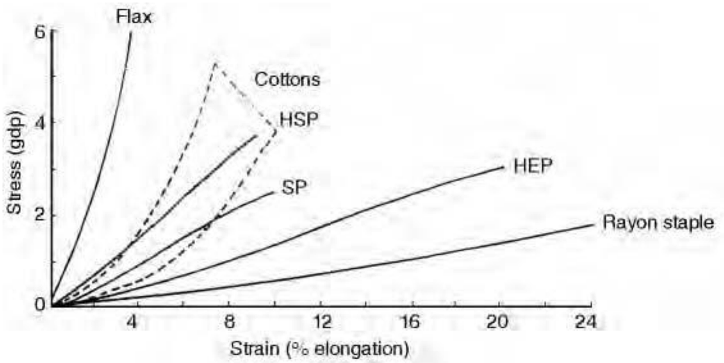


Figure 3.9 Stress-strain relationships for certain cellulosic fibres. Source: Griffiths, 1965, in *The Biology and processing of flax*, M. Publications, Belfast, UK. Courtesy: Professor S. Sharma, ed.

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.

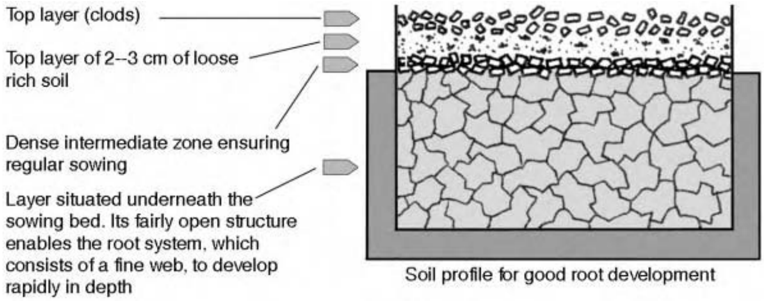


Figure 3.11 Soil profile for good root development. Source: *Linen: Technical aspects of production*, Confederation Internationale du Lin et du Chanvre. Courtesy: Institut Technique du Lin, Paris.

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 ºC day (the sum of the daily average temperatures after

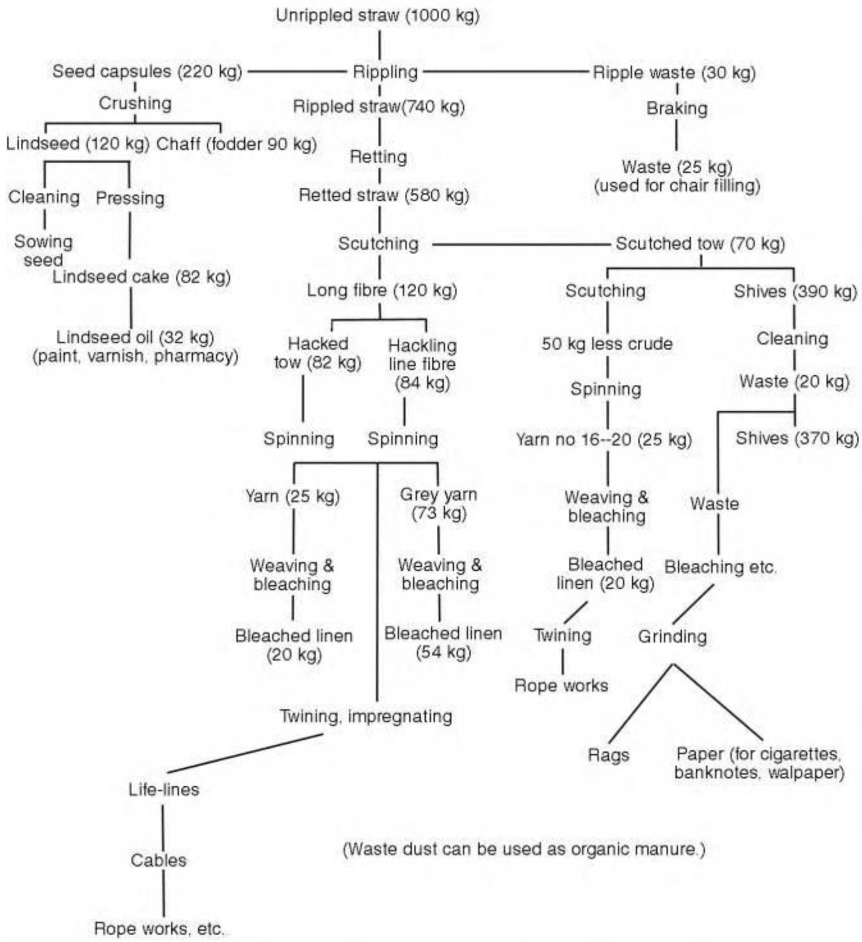


Figure 3.12 West European flax production flowchart. Adapted from G. Demeestere, Dewilde (1987) and Marshall (1989) in *Biology and processing of flax*, M. Publications, Belfast, UK. Courtesy: Professor S. Sharma, ed.

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

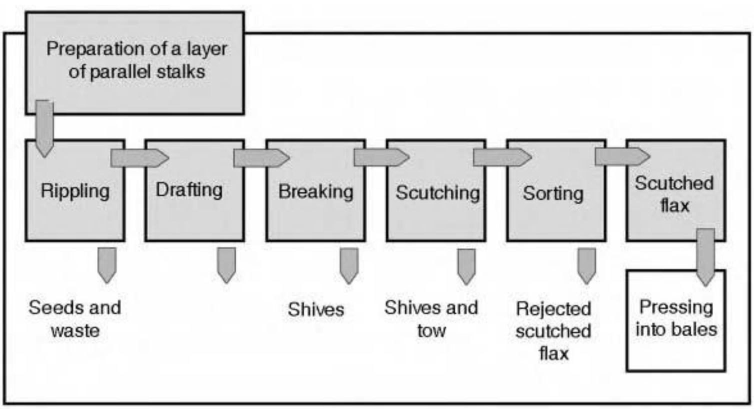


Figure 3.14 Scutching line. Source: *Linen: Technical aspects of production*, Confederation Internationale du Lin et du Chanvre. Courtesy: Institut Technique du Lin, Paris.

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

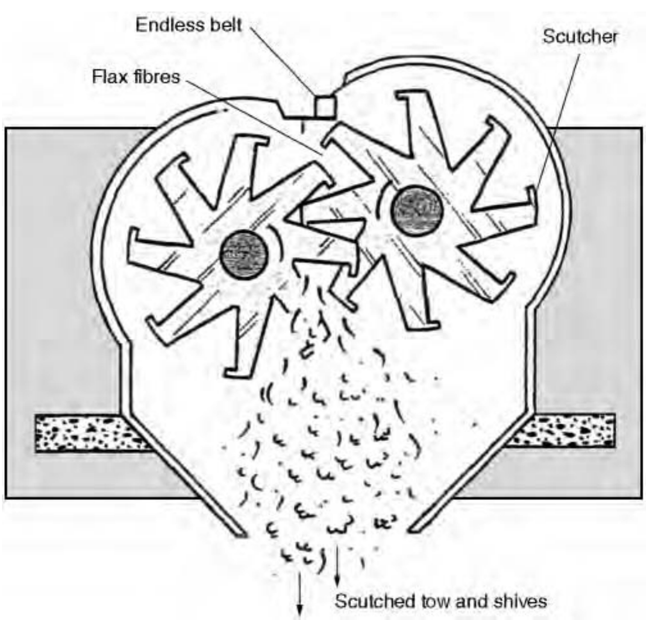


Figure 3.15 Cross-section of scutching turbines. Source: *Linen: Technical aspects of production*, Confederation Internationale du Lin et du Chanvre. Courtesy: Institut Technique du Lin, Paris.

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).

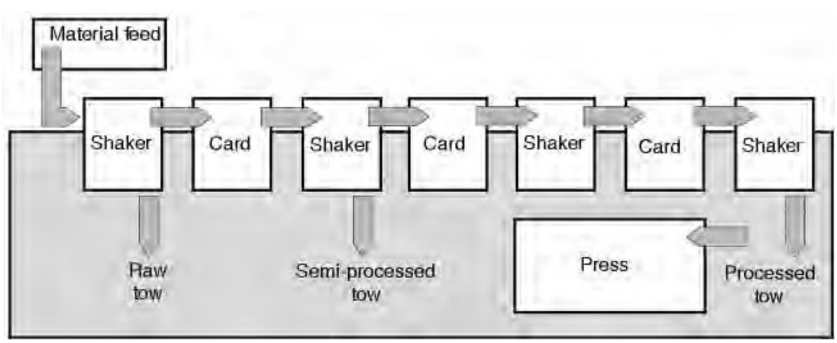


Figure 3.16 Tow processing flowchart. Source: *Linen: Technical aspects of production*, Confederation Internationale du Lin et du Chanvre. Courtesy: Institut Technique du Lin, Paris.

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.

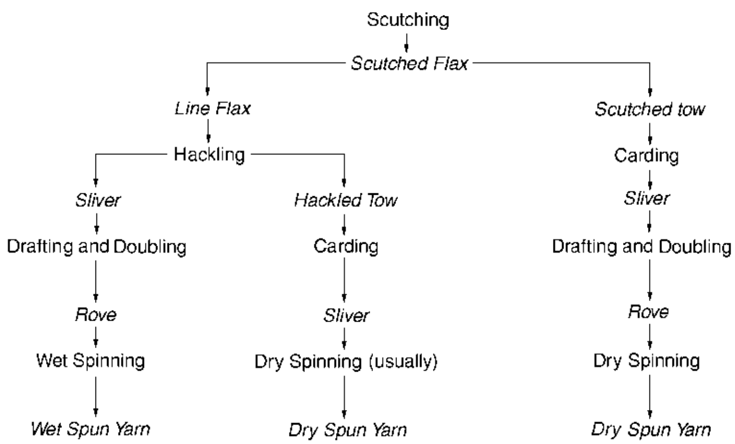
3.6 Yarn preparation and spinning

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

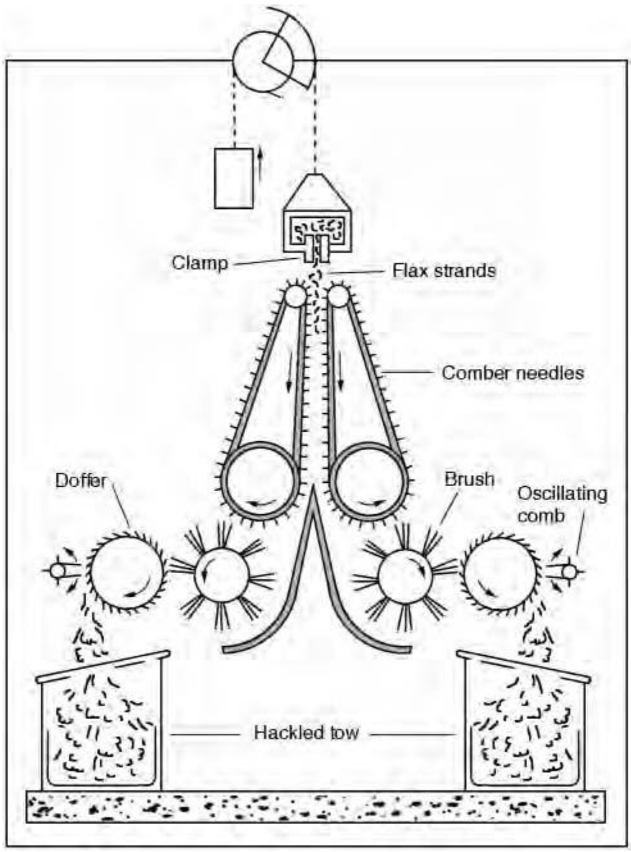


Figure 3.18 Continuous flax hackling. Source: *Linen: Technical aspects of production*, Confederation Internationale du Lin et du Chanvre. Courtesy: Institut Technique du Lin, Paris.

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.

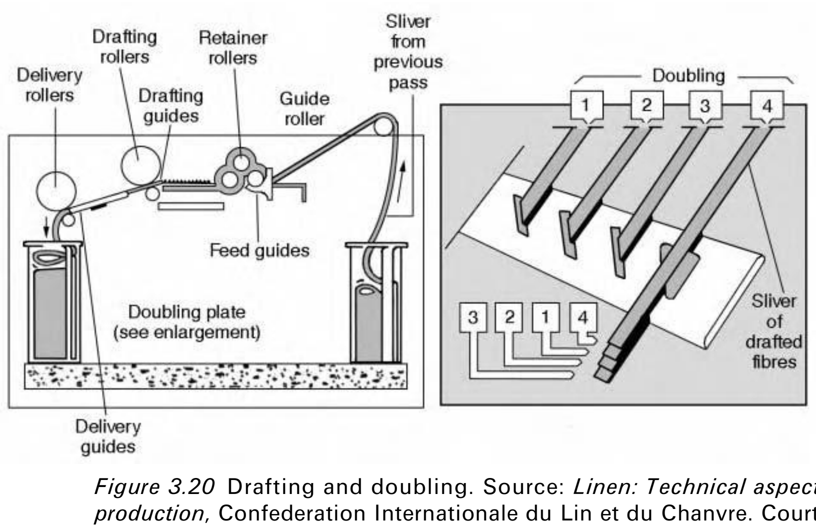


Figure 3.20 Drafting and doubling. Source: *Linen: Technical aspects of production*, Confederation Internationale du Lin et du Chanvre. Courtesy: Institut Technique du Lin, Paris.

- 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.

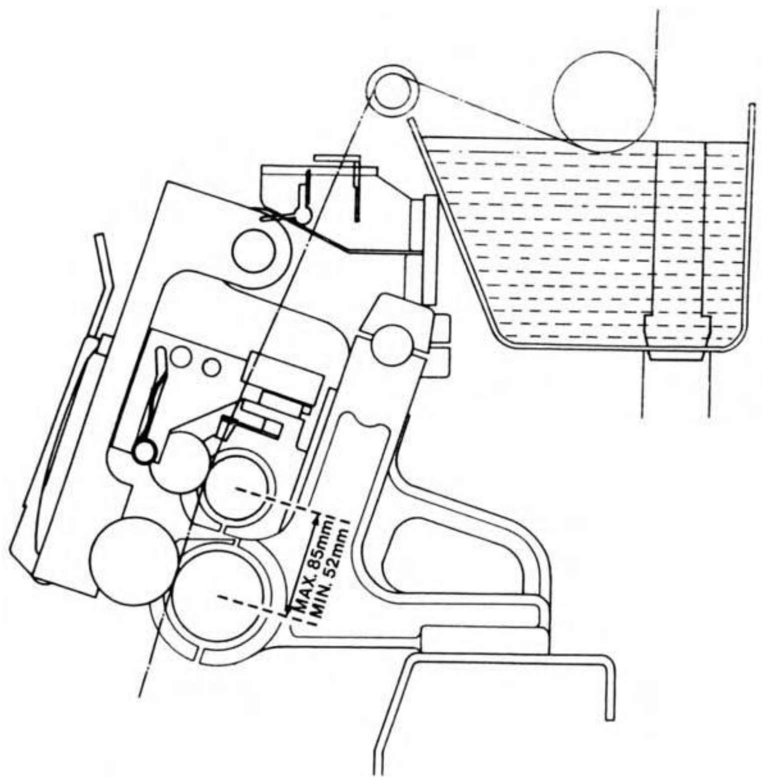


Figure 3.21 'Linmack' drafting zone. Source: *Biology and processing of flax*, M. Publications, Belfast, UK. Courtesy: Professor S. Sharma, ed.

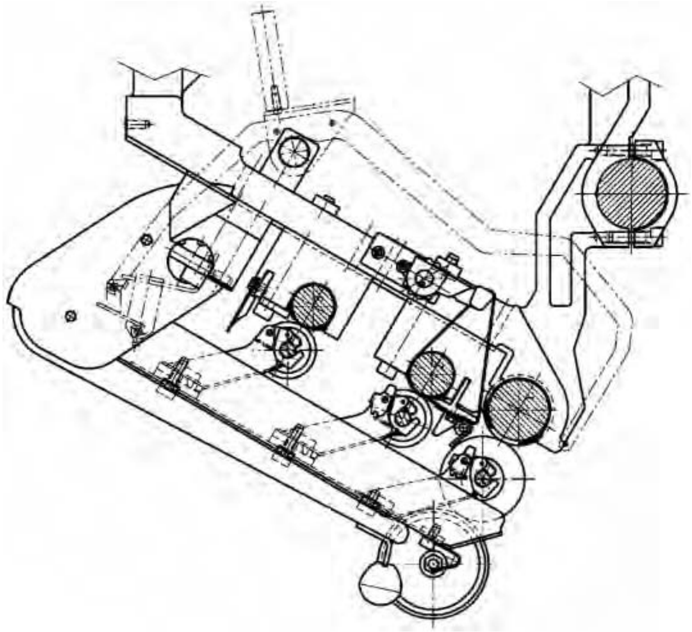


Figure 3.22 'Linimpianti' drafting zone. Source: Linimpianti Mod. 7002 Metier a filer au mouille (promotional leaflet) Courtesy: Linificio e Canapificio Nazionale Spa.

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.

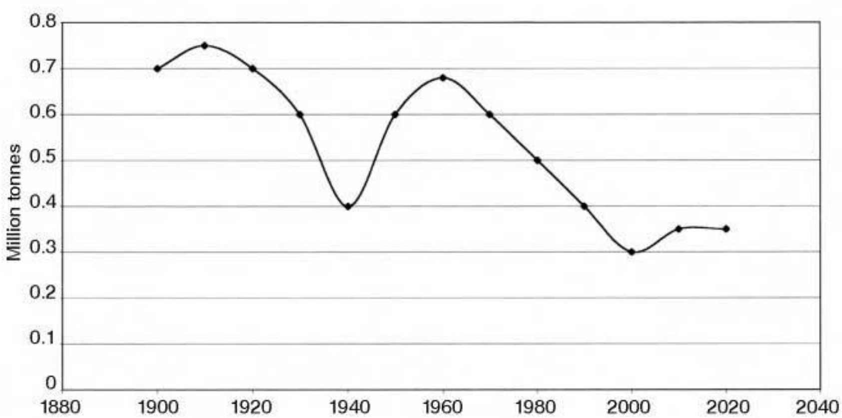


Figure 3.23 World flax fibre production. Courtesy: Gordon Mackie, International Textile Consultant, Northern Ireland.

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

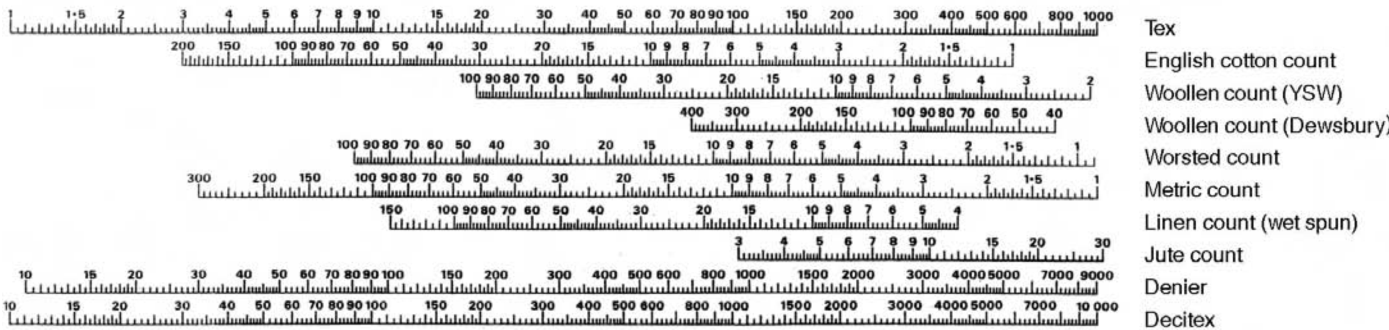


Figure 3.24 Relationship between common systems of yarn counts. Source: Slide rule. Courtesy: Bludell Harling.

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 'optical white' ≥4	– dyed linen ≥4/5 '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

Throughout this chapter the authors have made extensive use of information published in the following:

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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.