Handbook of hemp cultivation, processing and applications

From farm to products

PUBLIC

Martien van den Oever, Dieuwertje de Wagenaar (WFBR), Gerard Hosper, Mark Reinders (HempFlax), Sofie Vermeire, Alexandra de Raeve (HOGENT), Michiel Scheffer (Polisema), René Sauveur (Pantanova), Linda Calciolari, André Jurrius (Ekoboerderij de Lingehof), Jan Mahy (Saxion), Francesco Mirizzi, Lorenza Romanese (EIHA, Translation to English)

WAGENINGEN
UNIVERSITY & RESEARCH

Handbook of hemp cultivation, processing and applications

From farm to products

Authors: Martien van den Oever, Dieuwertje de Wagenaar (WFBR), Gerard Hosper, Mark Reinders (HempFlax), Sofie Vermeire, Alexandra de Raeve (HOGENT), Michiel Scheffer (Polisema), René Sauveur (Pantanova), Linda Calciolari, André Jurrius (Ekoboerderij de Lingehof), Jan Mahy (Saxion),Francesco Mirizzi, Lorenza Romanese (EIHA, Translation to English)

This This study was carried out by Wageningen Food & Biobased Research, HempFlax, Ekoboerderij De Linge, Giesen Crop Research, Saxion, HOGENT University of Applied Sciences & Arts, FTILab +, EIHA, subsidised and funded by Stichting TKI Agri&Food.

Wageningen Food & Biobased Research
Wageningen, December 2023

Public

Report 2509
DOI: 10.18174/642557

WAGENINGEN
UNIVERSITY & RESEARCH

WFBR Project number: BO57-001-030-WF&BR
Version: Final
Reviewer: Paulien Harmsen (WFBR), Francesco Mirizzi (EIHA)
Approved by: Jan Jetten
Carried out by: Wageningen Food & Biobased Research, HempFlax, Polisema, Pantanova, Ekoboerderij De Linge, Saxion, HOGENT University of Applied Sciences & Arts, FTILab +, EIHA
Subsidised and funded by: Stichting TKI Agri&Food
This report is: Public
Photo cover: CANN

PO box 17, 6700 AA Wageningen, The Netherlands, T + 31 (0)317 48 00 84, E info.wfbr@wur.nl, www.wur.eu/wfbr.

Content

Preface

The transition to a sustainable and circular economy requires replacing fossil raw materials in a variety of products by renewable, especially biobased, raw materials. The consequently large demand for biobased raw materials requires a substantial scale-up of production of relevant crops. Hemp is one of the promising crops as feedstock for the bioeconomy. However, public access to knowledge on fibre hemp is limited. This paper aims to serve as knowledge support for farmers who want to grow the crop, for entrepreneurs and designers who want to use this crop in manufactured goods, or for students who want to do so in the future.

This document was produced in collaboration with LTO-Noord, Ekoboerderij de Lingehof, Hempflax, Giesen Crop Research, Pantanova, JKD International, Polisema, HAS Den Bosch, Saxion, HOGENT University of Applied Sciences & Arts, FTILab + and European Industrial Hemp Association (EIHA).

This project was carried out as part of the Kennis-op-Maat programme, which aims to make existing knowledge usable in practice for SMEs. It received financial support from the Knowledge and Innovation Agenda for Agriculture, Water, Food. Within the KIA, business, knowledge institutions and government work together on innovations for safe and healthy food (and a green living environment) for 9 billion people in a resilient world.

1 Introduction – What you need to know about hemp

Hemp is a versatile crop used to produce fibre, food, feed, construction products and more. Until the 1930s, hemp was a major crop used for fibres for clothing, sails, ropes and paper, among others. It was subsequently replaced by fossil fibres and cotton. Since the 1990s, hemp has been rediscovered and investments are being made worldwide to realise it full potential.

In the Netherlands, hemp can in principle be grown by anyone, both companies and individuals. Today, hemp is not a commodity. Therefore, it is important for the farmer to have contact with the intended customer before scheduling its cultivation. If the hemp cultivation area increases substantially to meet the growing need for sustainable and circular textiles, insulation and other building products, hemp may get back to its commodity status and traded as any other agricultural product. In such a case, contacting the buyer prior to cultivation may become less important.

This handbook discusses key aspects of hemp cultivation and processing into products. Starting point is the cultivation plan, for which early consultation with the customer is desirable (Chapter 2). It focuses particularly on how seed variety (Ch3), soil conditions (Ch4), cultivation, harvesting (Ch5) and processing practices (Ch6 and 7) affect what such a versatile plant delivers.

Special attention is paid to the processing of hemp into textiles (Ch7). The harvesting and processing techniques of long hemp fibres to produce high-quality textiles are somewhat similar to those used for flax and are currently being developed in Belgium and France.

1.1 Structure and application of the hemp plant

The hemp plant can reach a height of up to 4 m. The diagram below (Figure 1) shows the structure of the hemp plant. On the outside of the stem are the strong bast fibres, commonly known as hemp fibres (Figure 2). The so called primary bast fibres are, a.o., suitable to produce textile fabrics; the secondary bast fibres are shorter, and therefore less suitable for textiles, however they are suitable for use in fibre reinforced composites and insulation. The high strength (and stiffness) result from the high content of cellulose (about 70 wt.%) and the relatively low angle between the main fibre axis and the orientation of the cellulose molecules in the fibre.[1]

On the inside, the stem is composed of a woody core material which, after separation from the bast fibres, is know as shives or hurds. In between the bast fibres and the woody material there is a glue layer which is removed during processing (section 5.4, 6.1, 7.1.1). The stem is hollow inside. At its top there are the flowers, or the seeds later in the season. The weight ratio is approximately 25% bast fibres, 50% shives and 25% for the other crop parts.

An overview of products that can be made from the different crop parts, and their applications, are shown in Table 1.

[1] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8911747/pdf/materials-15-01901.pdf

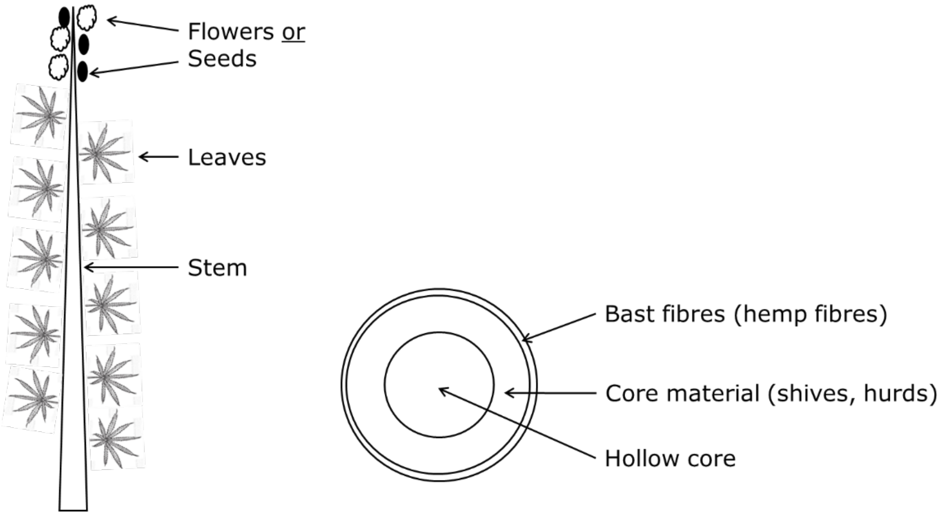

Figure 1 ***Schematic representation of a fibre hemp plant (left) and the cross-section of a hemp stem (right).***

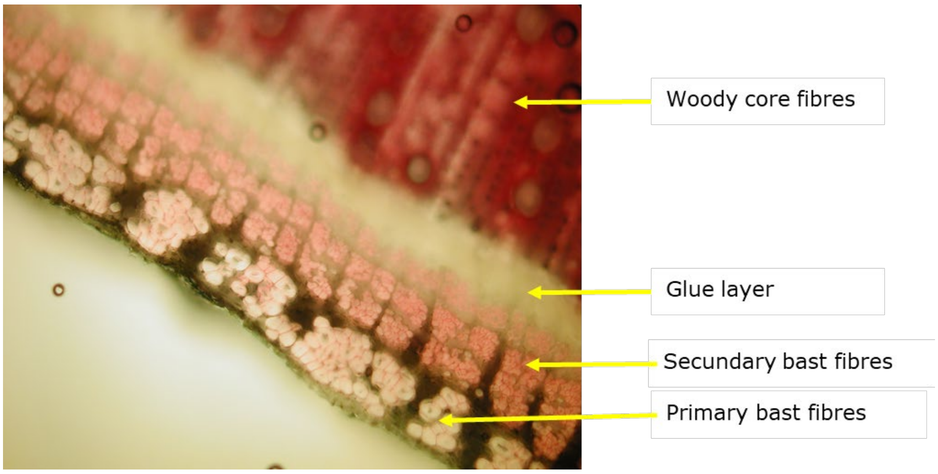

Figure 2 ***Microscopy photograph of the transverse section of a piece of fibre hemp stem.***

Table 1 ***Overview of components from different parts of the fibre hemp plant and their main applications.***

Plant part	Component	Application
Stalk	Bast fibre	Textile; composites; insulation materials; etc.
	Shives / hurds	Animal bedding; building blocks; etc.
Leaves	'Tea leaves'	Infusions; beverages
	Extracts	Neutraceutical and pharmaceutical products; infusions; feed; feed additives; green chemistry products; etc.
Flowers	Extracts	
Seeds	Oil	Food; food supplements; cosmetics; feed; industrial ingredients; etc.
	Press cake	

1.2 Reading guide

This handbook explains the main aspects of hemp cultivation and manufacturing into finished product. The breakdown of topics can be found in the table of contents on pages 5-6 of this report.

At the end of each chapter there are references to more extensive background information, most of which can be accessed via web links. If this information is written in a language other than English, it is indicated. The number of pages of the documents is also indicated.

Videos

6 Videos (Dutch spoken, English subtitles) explain successive aspects from hemp cultivation plan to transformation of hemp into finished products, in accordance with the chapter structure:

- 1- Introduction – what you need to know about hemp
- 2- Hemp in the cultivation plan
- 3- Selection of variety
- 4- Soil and field preparation
- 5- Cultivation and harvesting
- 6- Hemp applications

For subtitles: After starting the video, hover over the image and click on the CC icon at the bottom right of the screen.

To switch between Dutch and English language: click on the wheel at the bottom right of the screen and select the desired language from the lower option 'Captions'.

1.3 Further information

- Textile Exchange, 2023. 'Growing Hemp for the Future - A global fiber guide'
    - Broad overview of information on the construction and structure of the fibre hemp plant, possible applications, figures of hemp cultivation worldwide in 2021, cultivation and processing of fibres into textiles.
    - http://textileexchange.org/app/uploads/2023/04/Growing-Hemp-for-the-Future-1.pdf (60 pages)
- Zimniewska, 2022. 'Hemp Fibre Properties and Processing Target Textile: A Review'
    - Comprehensive information on applications, structure of hemp stem and fibre, chemical composition, physical characteristics, different methods for separating bast fibres and shives, overview of process steps required for making textiles.
    - https://www.ncbi.nlm.nih.gov/pmc/articles/PMC8911747/pdf/materials-15-01901.pdf (29 pages)
- UNCTAD, 2022. 'Commodities at a glance – Special issue on industrial hemp'
    - Comprehensive information on botanical aspects, regulations, cultivation, processing, trade and prices of hemp.
    - https://unctad.org/system/files/official-document/ditccom2022d1_en.pdf (93 pages)
- USDA, 2023. 'Hemp Descriptor and Phenotyping Handbook'
    - Very comprehensive info on the hemp plant.
    - https://www.ars.usda.gov/northeast-area/geneva-ny/plant-genetic-resources-unit-pgru/docs/hemp-descriptors/ (web page, corresponding to approx. 40 pages)

1.4 Disclaimer

This information is intended for all actors in the hemp value chain: farmers, processors, spinners, textile sector, construction sector, education professionals. With reference to this report, the information may be freely used.

The information in this handbook has been compiled with input from the sector, edited by independent researchers at WUR. No rights can be derived from the information given.

2 Hemp in the cultivation plan

Hemp is an interesting crop for a variety of applications, but what exactly do you need to know if you want to grow industrial hemp?

The starting point for cultivation shall be an early consultation with the buyer (§2.1). Considerations on the advantages (§2.2) and needs (§2.3) of hemp cultivation are also necessary. Due to limited needs, fibre hemp fits perfectly into an organic cultivation plan (§2.4). An example of a balance sheet for the cultivation for technical applications (§2.6) shows that the financial picture in an average year might initially be slightly less favourable than for, say, wheat, however this is offset by advantages (§2.2 and 2.3).

The approach towards hemp farming depends on the desired end applications. Here, 2 main product types can be distinguished: 1) Short technical fibre and 2) Long fibre.

1) 'Short fibre' aimed at mostly technical applications such as fibre blankets for building insulation (§6.2), fibre mats for composites for the automotive industry (§6.3) and growing medium for the horticultural sector (§6.4). Fine fibres may also be suitable for textiles (§7.2). The shives and other processing residues can be used for a variety of applications: building blocks (§6.5), animal bedding (§6.6) and food (§6.7). Here again, there are generally 2 sub-options:
    a) Relatively early harvest to obtain relatively fine fibres, and where the yield in tonnes/ha is somewhat lower than with a later harvest. With early harvest, the flowers can also be harvested and field retting (§5.4) is possible; good retting is necessary to properly separate fibres and shives during further processing.
    b) Relatively late harvesting where thicker fibres and higher tonne/ha yields are obtained. This also allows seeds to be harvested. Harvesting later in the season makes it more difficult to sufficiently ret and dry in the field.
        - In drier climates (Germany) or more southern countries (France, Romania), the combination of late harvesting, seed harvesting and field retting is possible. But this option is currently also being explored in the province of Limburg in the Netherlands.
2) 'Long fibre' aimed at high-value textiles (§7.1). And shives with further residues for diverse applications (§6.5, 6.6 and 6.7).
    - Harvesting and processing is similar to that of long flax fibres. Methods for harvesting and processing long hemp fibres have been developed in recent years in countries such as Belgium and France and are ready for scale-up from pilot scale to industrial scale.
    - For growing long fine fibres, early flowering varieties are used which are also harvested early.

For obtaining the 2 different main products, often different seed varieties are used (§3.3 and 3.4), and also the methods of harvesting (§5.3.1 and 5.3.2) and further processing (§6.1 and 7.1.1) differ.

In some countries, it is allowed to grow hemp for the production of flower extracts (the so called CBD oil) which is used as a food supplement. In the Netherlands, this is not permitted (see box in §5.1). In this cultivation, the fibres and shives can be used as a co-product (also see §8.2).

2.1 The selection of fibre hemp cultivation in consultation with buyer/processor

The hemp plant consists of several components (fibres, shives, leaves, flowers/seeds) that can be used to produce textile fibres, food, animal feed, fibre-reinforced composites for cars or construction, and more. The cultivation of hemp needs to be adapted to the final use. The processor of hemp knows the needs of these markets. Those needs can be specific and change over the years. The quality of the different components of hemp depends on several aspects: the seed variety (Chapter 3), the soil conditions and field cultivation (Ch4), the agronomical and harvesting practices (Ch5), and the processing techniques (Ch6 and 7). Since there are only a few processors who can purchase hemp and further process hemp, it is recommended that the choices for hemp cultivation are made together with the buyer.

2.1.1 Contract cultivation for 'short fibres'

A common practice consists in establishing a contract for the cultivation for short fibres between the farmer and the processor; the buyer gives guidance to the farmer on the cultivation and takes charge of the harvest. The farmer engages into a multi-year cultivation plan and agrees to a contract with a seed supplier and a buyer (often the same operator). The supplier recommends the seed that can have the desired yield and suits the soil and climate conditions. Desired yield is expressed both in tonnes per hectare and quality of the various components; for example, fibre length and fineness as demanded by the buyers of the fibre along the value chain.

Preferably, the grower contacts the buyer before January so that the seeds can be ordered on time.

Currently (2023), the maximum distance over which hemp straw can reasonably be transported to a processing plant is about 60 km. Late varieties are grown closer to the factory, early varieties further away so that harvesting machines can be used efficiently. Methods to separate the bast fibres and shives further away from the factory are being developed. This would allow to transport the higher value fibres over larger distances to a facility for further cleaning; the shives are then used locally.

Processors (buyers) of fibre hemp for ‘short fibres’

- HempFlax (Oude Pekela, the Netherlands), Mark Reinders, www.hempflax.com
- Green Inclusive (Drachten, the Netherlands), https://greeninclusive.nl
- La Chanvrière de l’Aube (France), https://lachanvriere.com
- Planète Chanvre (France), https://planetechanvre.com
- Hanffaser Uckermark (Germany), https://www.hanffaser.de/
- Vogtland-Faser (Germany), http://agrar-pahren.de/

2.1.2 Cultivation of long fibres

Flax growers and processors are particularly interested in hemp for long fibre production. The harvesting and processing of hemp for long fibre is similar to flax, with the difference that hemp seems less susceptible to drought (which is expected to become more common with climate change), it can be grown more frequently in the rotation (once every 3 years instead of once every 6-7 years for flax), and no plant protection products are needed so far. After retting and baling, the hemp straw can be sold to a processor and also stored all year round.

Processors of fibre hemp for 'long fibres'

- Vlasbedrijf Bruijns (Heikant, the Netherlands), Sven Bruijns, sven_95@hotmail.com
- Van de Bilt (Sluiskil, the Netherlands), Bart Depourcq, https://vandebiltzadenvlas.com/home/
- Albert Brille (Wevelgem, Belgium), www.albertbrille.be
- Castellins (Wevelgem, Belgium), Laurence Vandecasteele, www.castellins.com
- Debruyne (Ardooie, Belgium), Geneviève Debruyne, www.flax.eu
- La Chanvrière (Saint Lye, France), http://lachanvriere.com/en/notre-chanvre-dans-le-textile/
- Robrecht Engels Vlasbedrijf (Sint-Laureins, Belgium), robrecht.engels@telenet.be

2.2 Benefits of hemp

Hemp is a good substitute for cereals in the crop rotation. It has lower fertiliser requirements. The guideline is 70 - 110 units of active nitrogen[2] per hectare, of which more than 80% is animal manure. In comparison, wheat might require up to 250 kg/ha. The lower fertilization requirements for hemp leaves room to use fertilizer for other crops.

Fibre hemp grows on average 4 cm per day, faster than bad weeds, which are therefore suppressed naturally.

There are currently no known diseases that require plant protection products (herbicides) for both organic and conventional fibre hemp cultivation.

In addition, hemp has a suppressive effect on a number of soil fungi such as Verticillium dahliae and the maize root-knot nematode (Meloidogyne chitwoodi). Hemp also suppresses the northern root-knot nematode (Meloidogyne hapla); complete resistance to this nematode has even been found for some varieties. As a result, subsequent crops are also less affected by these fungi and nematodes.

Added up, hemp requires less labour than other crops such as cereals, beets and potatoes, while a nice yield can be obtained just as well (§2.6).

2.3 Needs for a good growth

Hemp is sensitive to flooding and thrives best on a well-permeable loose soil structure. At the same time, hemp improves the soil structure for crops grown afterwards like potatoes and sugar beet.

High compaction of the soil easily leads to severe retardation of growth.

For optimal growth, the soil needs a pH value between 6 and 7.5.

2.4 Organic cultivation

Fibre hemp is also particularly interesting within an organic cropping plan, partly due to its limited requirements in terms of inputs. In addition, hemp has a different symbiosis with soil organisms than traditional crops such as cereals, beets or potatoes, and therefore may have positive effects on the soil. However, the exact quantitative and qualitative effects still need further investigation.

2.5 Schemes

Fibre hemp is defined as a fibre and oleaginous crop and as such it currently (2023) falls under the Eco scheme in some EU countries. Under such conditions, this is an additional payment on top of the basic premium. However, schemes change regularly; therefore it is recommended to check out applicable schemes through Common Agricultural Policy (CAP) authority in your country and/or through the buyer and/or cultivation supervisor.

Although hemp for textiles is in a transition from pilot to commercial scale-up, prices for long hemp (and flax) fibres are currently (2023) relatively high.

[2] 1 Unit of nitrogen corresponds to 1 kg of the element 'nitrogen' (N) in a fertilizer which is composed of nitrogen compounds.

2.6 Economic model calculation of hemp cultivation for technical applications

An example balance calculation is given below based on data from the KWIN-AGV 2022 manual.[3] This can be found as a customisable calculation model here.

For enquiries, please contact info@hempflax.com or for more info visit https://www.hempflax.com.

	Summer barley / sandy soil					Hemp / sandy soil				
	quantity	unit	price	quantity	amount (€/ha)	quantity	unit	price	unit	amount (€/ha)
Revenu						**Revenue**				
Main product	6.6	ton	250	€/ton	1650	8.5	ton	143	€/ton	1216
Straw	2	ton	100	€/ton	200	1	ha	75	€/ha	75
Gross yield					**1850**					**1291**
Costs						**Costs**				
Starting material	160	kg	0.7	€/kg	112	35	kg	5.5	€/kg	192.5
Fertilizer										
Calcium ammonium nitrate 27% N	27	kg N	2.59	€/kg	70					-
Triple super 43-45% P2O5	0	kg P2O5	1.93	€/kg	0					-
K2O	0	kg K2O	1.4	€/kg	0					-
Slurry	25	m3	5	€/m3	125	25	m3	5	€/m3	125
Plant protection products										
Fluroxypyr-meptyl, metsulfuron-methyl, thifensulfuron methyl (Omnera)	1	kg,l	70	€/L	70	0	kg,l	70	€/L	-
Bifenox (Fox 480)	1	kg,l	56	€/L	56	0	kg,l	56	€/L	-
bixafen, prothioconazool, tebucanazool (Skyway)	1	kg,l	72	€/L	72	0	kg,l	72	€/L	-
Energy										
Diesel	113	liter	1.55	€/L	175	25	liter	1.55	€/L	39
Other product related costs										
Interests charged	153	EUR	3.40%		5	100	EUR	3.40%		3
N-Mineral sample	1	-	36.25	€/Sample	36	1	keer	36.25	€/Sample	36
Drying barley	6.6	ton	3.75	€/ton	25	0	ton	3.75	€/ton	-
Trade costs wheat/barley	6.6	ton	10	€/ton	66	0	ton	10	€/ton	-
Allocated costs					**812**					**396**
Farm balance sheet					**1,038**					**895**

Figure 3 ***Example balance calculation per hectare for hemp based on KWIN data. Weights are 'as is', about 85% dry matter for hemp. Data in red can be adjusted in the online Excel calculation model.***

[3] Kwantitatieve Informatie Akkerbouw en Vollegrondsgroenteteelt 2022, https://www.wur.nl/nl/show/kwin-agv.htm

2.7 More information

- Hempflax. 'Hemp cultivation manual'
  - https://www.hempflax.com/wp-content/uploads/Hempflax-Hemp-Cultivation-Manual.pdf (8 pages)
- Green Inclusive. 'Handleiding hennepteelt 2022' (Dutch)
  - https://greeninclusive.nl/media/1146/handleiding-hennepteelt-2022.pdf (12 pages)
- Grow2Build, 2015. 'De vezelteelt van vlas en hennep' (Dutch)
  - Concise information on desired growing conditions and further processing.
  - https://www.enerpedia.be/websites/1/uploads/files/documents/brochure-vezelvlashennep-2015_2-10-2015_11_16_37.pdf (24 pages)
- Westerhuis, W., 2016. 'Hemp for textiles: plant size matters'
  - Thesis focused on conditions that minimise the formation of so-called secondary fibres. These secondary fibres are relatively short and relatively high in lignin, making them less suitable for use in textiles.
  - https://edepot.wur.nl/378698 (242 pages)
- Van der Werf, H.G.M., 1991. 'Agronomy and crop physiology of fibre hemp. A literature review'
  - Agronomy and crop characteristics of fibre hemp
  - https://edepot.wur.nl/346939 (17 pages)
- Inagro, 2023. 'Hoe hennep telen?' (Dutch)
  - Brief explanation of what industrial hemp is, how it can be grown, harvested and processed, and about economic aspects.
  - https://inagro.be/themas/groene-grondstoffen/hoe-hennep-telen
- Inagro, 2013. 'Vlas en hennep als bouwstof voor biomaterialen' (Dutch)
  - Brochure with brief description of cultivation, harvesting, processing and applications of fibre hemp.
  - https://www.yumpu.com/nl/document/view/13913088/vlas-en-hennep-als-bouwstof-voor-biomaterialen-inagro (8 pages)
- Inagro, 2011. 'Groene grondstoffen – Industriële hennep' (Dutch)
  - Exploration of opportunities for (dual-purpose) hemp cultivation in Flanders; and brief description of diverse application possibilities.
  - https://www.yumpu.com/nl/document/read/8198992/groene-grondstoffen-industriele-hennep-vilt (36 pages)
- List of partner organisations of the General Belgian Flax Association, https://www.vlasverbond.be/NL/partner-organisaties
- List of members of biological linen and hemp association (French), https://linetchanvrebio.org/index.php/les-membres/

3 The choice of the variety

As mentioned in §2.1, hemp is best grown under contract and the buyer of the crop usually supplies the seed and provides cultivation advice as well. When choosing a specific variety a number of factors play an important role: the intended application, the desired quality of the intended material, the yield per hectare, the soil conditions and the climatic conditions (§3.2). For example, different varieties and growing conditions are desired for application in textiles (§3.3) than those highly suitable for technical applications such as composites (§3.4). Also, as for all crops, the seed should be certified (§3.1).

3.1 Certified seeds

The seeds for sowing must be chosen from a list of varieties approved and tested at the EU level (§3.1.1). This list for hemp seeds is aimed at legally maximising the THC (psychoactive substance) content in seeds, leaves and flowers. The maximum THC content is decided by each Member State, however, in order to have the right to the CAP payments, the variety needs to have a THC content that is not higher than 0.3%.[4] Certified seeds are tested and certified according to the national protocols. In the case of the Netherlands it is the Naktuinbouw and the Council for Plant Varieties.

Collecting your own seed from a successful cultivation for a subsequent cultivation is not allowed (except for seed multiplication, which is also managed under contract). In a subsequent cultivation, the THC content could exceed the legal maximum established for CAP payments. Moreover, all hemp sowing seed must have a certificate provided by the national seed certification agency, just like for all other crops. Also, self-harvested seed might contain a higher percentage of male seed, which adversely affects the yield and harvesting process of the next harvest (see also §3.1.3). In addition, the seed might have less germination due to less sunshine hours compared to Mediterranean countries; this often too leads to lower yields.

Figure 4 Hemp seed. Photo: Giesen Crop Research.

3.1.1 EU Catalogue of varieties

In 2022, the European Catalogue of Varieties of Agricultural Crops has around 75 approved varieties of hemp that can be grown in all EU member states. Not all cultivars perform equally well across Europe.

The list of varieties approved at the EU level can be found here: https://ec.europa.eu/food/plant-variety-portal, in the left-hand column under UPOV Species select 'Cannabis sativa L.'.
RVO has an overview list with the varieties authorised in the Netherlands.[5]

[4] https://eur-lex.europa.eu/legal-content/NL/TXT/PDF/?uri=CELEX:32021R2115&qid=1646060944889&from=NL (page 4)
[5] https://www.rvo.nl/onderwerpen/basisbetaling-2022/hennep-2022#toegestane-henneprassen (in Dutch)

3.1.2 Naming of varieties

Hemp varieties usually have a name and a number. The number indicates whether a newer variety exists of a previously bred variety. Compared to another fibre crop such as flax, hemp has a smaller number of varieties. This is a result of the constant search for better and more widely applicable varieties, and hemp is still a relatively new crop.

3.1.3 Sex

There are dioecious and monoecious varieties of hemp. A monoecious plant produces both male and female flowers and fertilises itself. In the Netherlands, the three most commonly cultivated cultivars are USO 31, Felina 32 and Futura 75, all monoecious.

Dioecious varieties have separate female and male plants. Only the female version survives the entire growing season and therefore contributes to yield in fibre and/or seed. Male plants of a dioecious species usually die after flowering and may disrupt the harvesting process by laying transverse during mowing.

Dioecious males, through wind pollination, can also inadvertently fertilise nearby crops of other varieties. Therefore, monoecious hemp species are often preferred.

Examples of dioecious fibre hemp varieties are: Carmagnola Selezionata, Chamaeleon, Dioica 88, Tiborszallasi.

There are also hemp varieties consisting of 50% female plants and 50% monoecious plants. Examples are Fedora 17 and Lipko.

3.2 Soil and climate

Three groups of hemp varieties can be distinguished worldwide: European, American and Asian varieties. Some cultivars, incidentally, thrive on more than one continent. Within Europe, there are three regions where specific varieties have been developed: North-West Europe, Mediterranean Europe and Central-East Europe. Some varieties were purposefully developed for a continental climate with harsher winters and wet hot summers. Others for cultivation under Mediterranean conditions, characterised by dry summers. Again, some varieties are performative in more than one region. Before choosing a cultivar, it is important to understand its suitability for the specific environment in terms of climate, soil and intensity of cultivation support.

Roughly speaking, hemp varieties can be distinguished into early and late flowering, and cultivation and harvesting methods are also determined by this. The time of flowering is not dependent on the sowing time, but on the cultivar, the altitude and the climate. An early harvest is desirable for textiles and flower contents, a late harvest for seed extraction and high fibre yield.

3.3 Varieties for textile production

For textiles as a main application, it is desirable for the fibres to be fine and limitedly glued together. Some varieties produce finer fibres than others, making them more suitable for use in textiles (Table 2). By the time of flowering, the fine bast fibres are largely formed and suitable for harvesting. After flowering, until seed formation, the degree of bonding between fibres increases further, which is undesirable for textile production.

Because the fibre hemp straw needs to be retted in the field for quite some time after harvest (§5.4) before it is stored dry for further processing, it is desirable that the hemp will not be harvested too late in the season. For this reason, varieties that flower early are most suitable;[6] in the Netherlands and Belgium, the risk of retting failure increases with later harvest time.

---

[6] https://www.hogent.be/sites/hogent/assets/File/Teeltfiche_Cannabisness.pdf (in Dutch)

It is also useful that not all plots of hemp flower at the same time, so that as many hectares as possible can be harvested with one harvester. For this, staggered flowering times are desirable.

Early flowering also means that the plants are slightly shorter than after late flowering, resulting in a lower yield in tonnes per hectare. Fibre hemp cultivation is a balance between fibre quality, yield, efficiency of harvesting and proper retting before dry storage to further processing.

Table 2 ***Indicative characteristics of some fibre hemp varieties particularly suitable for textiles.***[7]

Cultivar[8]	**Flowering**	**Straw yield (ton/ha)**[9]	**Fibre yield ('green fibre')**[10] **(ton/ha)**	**Long fibre yield (ton/ha)**	**Fineness (tex)**
USO 31	Early	12.9	4.2	2.1	3.89
Santhica 27	Early	13.5	4.8	1.1	3.19
Bialobrzeskie	Early	13.1	4.7	2.4	2.33
Santhica 70	Late	16.0	5.9	2.7	4.16
Muka 76	Late	16.0	6.1	2.6	3.08
Fibror 79	Late	15.1	5.9	2.3	3.40

3.4 Varieties for technical applications

There are two main differences between hemp for technical applications and textile applications. For technical applications such as composites, insulation material, and growing mediums, the fibres should not necessarily be fine as for textiles. Secondly, the time required for good retting is shorter than time used for textiles, allowing later-flowering varieties to be chosen. Varieties that flower later in the season grow longer and therefore produce higher yields in tonnes per hectare. These plants are taller and thicker, and thus also yield more woody parts, so-called shives or hurds, which are suitable for construction materials and animal bedding, among other applications.

Separating fibres and shives does take more effort for late-harvested varieties than for early ones. Good (field) retting then is of special importance. In areas such as the northern part of the Netherlands, where the field retting is less performative (§5.4) with later harvest time, this creates some difficulties.

In the Netherlands, the three most commonly grown cultivars today are USO 31, Felina 32 and Futura 75. However, new hemp varieties continue to be developed.

Suppliers of certified hemp seeds for cultivation

- Giesen Crop Research (Angeren, the Netherlands), Joris Giesen, www.giesencropresearch.nl
- Enecta (Italy), https://www.enecta.com/pages/enecta-hemp-seed
- Hemp-it (France), https://www.hemp-it.coop/en/ (see the section above on the Seed Catalogue)
- Hempoint (Czech Republic), https://hempoint.cz/en/
- IWNIRZ (Poland), https://www.polishhempprogram.com

3.5 Pre-treatment of seeds for sowing

Typically, seed is treated with plant protection products and possibly nutrients before sale.

[7] Results of field tests in Bottelare (Belgium), crop year 2022, 400 seeds/m² or 70 kg of seed per ha with 70 kg active N/ha.
[8] From the research conducted by HOGENT, is Futura 75 and Dacia give relatively more dust when processed than e.g. Uso and Santhica.
[9] Yield as collected from the plot.
[10] Determined by separating the bast fibres from the stem.

3.6 More information

- Terres Inovia. 'Varietal choice tool' (French)
  - Brief information on sowing timing (in France) and yields of hemp straw, seeds and bast fibre of different hemp cultivars.
  - https://www.myvar.fr/
    - Under 'Culture' please indicate 'Chanvre' (hemp). Under 'Variety', hemp varieties can be selected, and further click the 'Consulter' button.
- Hemp-it, 'Industrial hemp – Varietal catalogue 2023'
  - Comparative info on some qualities of fibre hemp for the purpose of different applications (fibre, shives, seed)
  - https://www.hemp-it.coop/20230306_Catalogue_EN.pdf (14 pages)
- Cibiday. 'Hemp varieties' (Dutch)
  - Background on a range of EU-approved hemp varieties.
  - https://www.cibiday.nl/henneprassen/ (about 50 icons, 1 variety per icon)

4 Soil and field preparation

As for many other crops, the soil type (§4.1) and a proper seedbed preparation (§4.3) greatly influence the growth and yield of hemp. Hemp requires precise fertilisation (§4.2) before sowing. Also, its cultivation has a positive effect on the soil (§4.4). These aspects are explained in the paragraphs below.

4.1 Soil

Hemp can grow well on different types of soil: loam, sandy loam, sand, peat, and clay, provided that some attention is paid to water management (i.e., drainage). Hemp grows best on loose, deep, well-permeable soils with good water retention capacity that are rich in organic matter, with good structure, without deterioration generated by heavy machinery, and with a pH of 6.0 to 7.5. Good drainage is key: wet soils can restrict root and shoot growth in the early stage of cultivation and consequently reduce fibre quality. Wet spots result in uneven plant heights that cause problems at harvest. Limited root growth in early growth also leads to the plant experiencing difficulties during eventual dry periods later on.

4.2 Fertilisation

Hemp requires reasonably accurate fertilisation. Fertilisation that is too low or too high leads to yield reductions. For optimum growth, about 110 units of nitrogen (N), 80 kg of phosphate (P_2O_5) and 140 kg of potassium (K_2O) are recommended per hectare for technical applications (excluding the soil stock from the calculation).[11] This is applied before sowing. Excessive nitrogen application can result in lower yields due to heavy stems lying flat, and stronger competition for light by individual plants leading to uneven plant height and problems at harvest. Excessive N combined with too little K can cause stem breakage.

Hemp grows well on organic fertiliser, such as manure from pigs, cattle, or chickens. It can be chosen to apply 20% of the total with a fast-acting fertiliser in the starting phase for the purpose of rapid growth. N uptake occurs mainly during the first (6-8) weeks, while P and K are mainly taken up later in growth, before flowering and seed formation. The organic farmer would only use animal manure.

For textile applications

Nitrogen application for hemp textiles is lower than for technical applications: 70 - 100 units of active nitrogen (N), 40 kg P_2O_5, 110 kg K_2O and 30 kg MgO per hectare.[12]

4.3 Seedbed preparation

Hemp seed is fine in shape and carries little energy. Therefore, it needs to sprout quickly and uninhibited. This requires a fine top layer for good soil contact to germinate well. Also, the soil should not be compacted. You can compare hemp seedbed preparation to the one used for beet. The structure should not be too coarse, but not too fine either in order to avoid wind erosion of fine sand. It is difficult to give general advice on this; it is advisable to consult with the cultivation supervisor to adapt preparation to local conditions.

A nice even seedbed also ensures regular emergence, ultimately leading to an even product quality during processing.

[11] https://www.hempflax.com/wp-content/uploads/Hempflax-Hemp-Cultivation-Manual.pdf

[12] https://onderzoek.hogent.be/sites/onderzoek/assets/File/HOGENT%20Onderzoeksresultaten%20%E2%80%98Eigen%20Kweek%E2%80%99%20en%20%E2%80%98Hemp4All'.pdf (in Dutch)

Because of its sensitivity to soil structure, good seedbed preparation is crucial.

Figure 5 Seedbed preparation with rotor harrow. Photo: HempFlax.

4.4 Effects of hemp cultivation on the soil

In principle, hemp has a positive impact on soil and soil life. Assuming a good starting situation, the well-developed root system of fibre hemp ensures the formation of soil aggregates and oxygen in the soil.

5 Cultivation and harvesting

Once the cultivation plan has been determined (Chapter 2), the variety selected (Ch3) and the soil properly prepared (Ch4), it is time to actually grow hemp. Sowing aims for a homogeneous and rapid emergence of the crop (§5.1). After this moment, hemp does not require specific crop protection (§5.2).

The method of harvesting depends on the primary use: for textiles, or for technical applications (§5.3). After harvesting, the hemp stalks are left on the field for some time with the intention of weakening the bonds between the bast fibre and the woody core material, under the influence of weather; this is called 'retting' (§5.4). After retting, the hemp is dry-balled and stored for further processing.

If the hemp is harvested late in the season, e.g. for a high crop yield in tonnes/ha, drying after field retting is usually no longer possible in the northern part of the Netherlands.

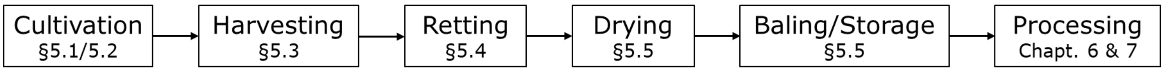

Figure 6 Steps from cultivation to processing of hemp fibre.

5.1 Sowing

Sowing is the most decisive step in the whole cultivation process. A good start for fibre hemp is of importance for root development and an even start is important for homogeneous growth of the plants. For this reason, hemp is preferably sown in warm (10° to 12° Celsius, minimum 8° Celsius) and moist soil. These conditions usually occur in the period from late April to mid-May. However, weather forecasts should be carefully consulted as they might have a major impact. Night frosts during emergence should be avoided.

> ‘Apparent fibre use’
>
> In the Netherlands, hemp cultivation has so far only been allowed in open fields. In addition, the cultivation should only be intended for "apparent fibre use" (“*Kennelijk vezelgebruik”)*. Other plant parts such as leaves, side branches, flowers, seeds and, if desired, roots should be by-products (for now) in market value and volume.

Even though this is not mandatory, the Netherlands Enterprise Agency (Rijksdienst voor Ondernemend Nederland, RVO) advises -due to social sensitivity- to inform the police before sowing; this to avoid any confusion. It is also advisable to ask the municipality and/or province whether there are any objections to growing hemp in certain areas before sowing. Specific requirements might be enforced in other countries.

Sowing conditions depend on the main application (§5.1.1 – 5.1.3).

5.1.1 Sowing for technical applications

For technical applications, 35 kg/ha of seed is sown at a depth of no more than 2-3 cm. A pneumatic sowing machine or mechanical seed drill machine can be used for this purpose. The row spacing is the same as for cereals, 10 - 15 cm. The adjustment depends on the machine; as a guideline, the machine can be adjusted to about 32 kg/ha to sow the desired amount of 35 kg/ha of hemp. It is recommended to check this during sowing. This results in a density of about 100 plants per m^2. Sowing should also be done at a depth as even as possible. Deeper and irregular sowing results in lower yields and irregular plant length.

Hemp would normally emerge after 10 to 14 days. If less than 80 plants per m^2 emerge, sowing is performed again. If plants are given more space, they grow in diameter, obtaining proportionally less fibre and more wood.

Figure 7 Sowing of hemp. Photo: HempFlax.

Figure 8 A regular plant length facilitates harvesting. Photo: HempFlax.

5.1.2 Sowing for textile applications

The main difference with sowing for technical applications is that a higher seeding density is applied for textiles: 70 - 75 kg/ha of seed; about 400 seeds/m^2. A denser sowing is needed for fine textile fibres. Besides that, other varieties are used (§3.3).
Findings from the Hemp4Textiles project (led by HOGENT) demonstrated that with a higher seeding density of 90 - 100 kg/ha (about 650 seeds/m^2) a finer stem was obtained, however, fibres were not finer. A similar result was observed in the HempSys project.[13]

5.1.3 Sowing for seeds and phytocompounds

While in cultivation for fibre purposes it is important to achieve a high plant density and plant height by having the seed rows at short distances (10-15 cm), the experience shows that cultivation for seed and flowers benefits from larger plant spacing (50-75 cm). Under these conditions the plant forms wider branches, generally obtaining more flowers/seed per square metre. The fibres of such plants are short and potentially useful for technical applications. Seed multiplication is not yet competitive under Dutch climate conditions. Cultivation and harvesting for flowers' phytocompounds is not yet allowed in the Netherlands.

[13] https://edepot.wur.nl/522052

5.2 Weed control and crop protection

Once well established, hemp requires no further care. Hemp grows at about 4 cm per day, so that after about 2 weeks the field is dense and weeds have no chance to develop. Hemp does not suffer from any detectable diseases so far; therefore, no plant protection products are needed before or during cultivation. Moreover, the use of plant protection products and further care of hemp after sowing is not allowed if the hemp is used for the greening payment.

After sowing, the crop is left alone until harvest. It can become a resting area for birds (including skylarks) and small mammals.

5.3 Harvesting

Permission for harvesting

In the Netherlands, every farmer will have to declare crops grown in May (depends on Member State). Before harvesting, the Netherlands Enterprise Agency (RVO) must give its permission. On behalf of RVO, the Dutch Food and Consumer Product Safety Authority (NVWA) will visit the field just before harvest to take samples of each crop. Permission for harvesting is obtained after the NVWA randomly checks the THC content - which is a psychoactive substance - in the plant. This content must be below 0.3% in most EU countries (§3.1).

Harvesting time

Hemp is a fast-growing crop that can be harvested 80-100 days after sowing. To obtain a good fine fibre quality, both for technical and textile applications, harvesting in the Netherlands takes place around the time of flowering (Figure 9), from late July to early August. For textiles, the bast fibre has reached the right ratio of strength and fineness around the time of flowering. For technical applications, fineness plays a less important role, but in the northern part of the Netherlands it is not possible to wait until the seeds are fully grown because field retting (§5.4) and drying for storage would no longer be possible for climatic reasons.

Seeds are ripe in the northern part of the Netherlands from about mid-September. By then, the weather in that region is usually so wet that after field retting, it is no longer possible to dry the hemp straw sufficiently to store it in bales. Hemp cultivation in the southern part of the Netherlands is recent and seeds appear to be ripe as early as beginning of September. Considering the regional weather conditions, and if harvesting happens early September, field retting and drying is still possible.

Special harvesters

Harvesting is done with specific machinery, both for technical (§5.3.1) and textile (§5.3.2) applications.


Figure 9 Hemp at flowering stage. Photos: Giesen Crop Research.

5.3.1 Harvesting for technical applications

<u>Harvesting with specific machineries</u>

Machines for harvesting fibre hemp for technical applications (insulation in construction, composites for automotive industry) are adapted to cope with the very strong fibres and to get good feedstock quality for further processing. In this process, the stalk is cut into pieces of 60 cm in length to avoid wrapping around the rotating parts of the machineries, both during harvesting and further processing (§6.1). At harvest, the hemp stalks ('hemp straw') are placed on windrows (Figure 10) for retting purposes (§5.4). A windrow is a row of harvested crop for the purpose of further processing.

<u>Flowers, leaves, seeds</u>

The harvesters also allow separate harvesting of flowers and leaves (Figure 11). These can be harvested for further processing. Seeds are actually not harvested in the Netherlands so far: in order to harvest seeds, the plant needs to be harvested around mid-September in the northern part of the Netherlands, after which the weather is often too wet to allow a correct drying of the stems. In the southern part of the Netherlands, the seeds are ripe by early September and the weather appears to be more favourable to seed production.

Figure 10 Harvesting hemp for fibre for technical applications; stalks are placed on windrows for retting. Photo: HempFlax.

Figure 11 ***Harvesting machine for fibre hemp, where flowers/leaves are harvested separately. Photo: HempFlax.***

5.3.2 Harvesting for textile applications

The plant length is preferably 220 cm or slightly more. Special harvesters mechanically cut the stalks into two pieces of about 1 m and lay them parallel on windrows in the field. This way, the stalks can be processed on a flax scutching line (§7.1.1) after retting (§5.4).

Figure 12 ***Harvesting hemp for fibre for textile applications; stalks are placed on parallel windrows for retting using a Hyler/Cretes harvester. Photos: HOGENT.***

Manufacturer of harvesters for technical applications
- CANN (Oldehove, the Netherlands), https://cannbv.com/

Producers of harvesters for long fibre textile applications
- Hyler (Oostrozebeke, Belgium), https://www.hyler.be/en/machine/hyler-sativa-200a/
- La Chanvrière (France) and Cretes (Wevelgem, Belgium), https://lachanvriere.com/en/francais-revolution-industrielle-dans-le-chanvre-textile/ , https://www.cretes.be/nl/machines/standaard-machines/oogstmachine-voor-hennep
- Depoortere (Beveren-Leie, Belgium), https://www.depoortere.be/DAEAHY

5.4 Field retting

Retting on the field is also known as 'dew-retting'.

Retting: 'loosening' of the bast fibre from the core material in the plant stalk
After harvesting, the hemp straw remains on the land for several weeks. During this period, microorganisms weaken the glue layer between the bast fibre and the woody core in the plant under the influence of water (rain and dew); this process is called 'retting'. During retting, the hemp is turned several times to make sure the retting process is homogeneous and optimal. By weakening the glue layer (pectin layer), the fibre and core

material (shives) can eventually be separated during the further processing step (§6.1 for technical application and §7.1.1 for textiles). The exact duration of retting depends on the weather; decomposition depends on rain, dew, and temperature.

For technical applications, the retting lasts about 2 weeks and the stems are turned every 2 to 3 times. For textiles, the retting duration is up to 5 - 6 weeks and the stems are turned once or twice.

When the retting process proceeds beyond needs, the stems are over-retted: the hemp fibres become weaker and have a lower value. Over-retted hemp results in relatively large share of short fibres during scutching and hackling (§7.1.1, 7.1.3). Conversely, when the straw is under-retted, separating the bast fibre from the core material will require more energy (§6.1), which also results in damages to the fibres.

Figure 13 ***Hemp stalks parallel on windrows during retting. They are turned at least once or twice to optimise the retting process. Photo: HOGENT.***

<u>Determining the retting degree</u>

During retting, the stems turn from green to yellow and finally grey (see Figure 14). The degree of retting can be determined with a relatively simple test (the so-called Fried test)[14]:

- Place a piece of hemp stem of 8 cm length in a slim bottle/flask.
- Add boiling water until so that the entire stem is submerged.
- Vortex the bottle/flask for 10 seconds at 2500 RPM.[15] Additionally, shake firmly vertically for further 5 times.
- Determine the extent to which the bast fibres detach from the core.

Figure 14 ***Hemp stalks (Carmagnola Selezionata), harvested on 8 September 2020, after different retting times: from left to right 15, 22, 29 September, 5, 12 October). Photo: HOGENT.***

[14] http://www.global-sci.org/v1/jfbi/issue/v3n1/pdf/JFBI-3.1.7.pdf?code=dj8Q%2BbIW2DkbGWU3eKlA1A%3D%3D
[15] https://www.ika.com/en/Products-LabEq/Shakers-pg179/Vortex-2-25000258/

5.5 Storage until further processing

When the hemp straw is retted and the glue layer between the fibre and the core material is sufficiently dissolved, the straw is pressed into bales with a moisture content of below 18%. Until the time of further processing (§6.1), the bales of hemp straw are stored dry, usually at the processor's premises.

Figure 15 After retting, the hemp is pressed into bales. Photo: HempFlax.

Silage for pulp and paper

For the purpose of application in pulp and paper, chopped hemp straw can also be ensiled after field retting and drying. From the silage, the hemp can then be transported to the pulp mill throughout the year. This enables decentralised storage at the farmer's premises.

For use in paper, it is useful to remove the leaves and flowers/seeds as much as possible during harvesting as these negatively affect paper quality.[16,17] Too much acidification during ensiling may lead to degradation of the cellulose, and therefore loss of fibre quality.

5.6 More information

- HempFlax, 2022. 'Hemp cultivation manual'.
    - https://www.hempflax.com/wp-content/uploads/Hempflax-Hemp-Cultivation-Manual.pdf (12 pages)
- CAH Dronten, 2002. 'Cultivation manual for hemp grown for fibre'. (Dutch)
    - https://edepot.wur.nl/135333 (24 pages)
- HOGENT, 2020. 'The revival of hemp as a low-impact textile fibre'. (Dutch)
    - Comprehensive report with results of research projects 'Eigen Kweek' and 'Hemp4All' on cultivation, processing and application characteristics of fibre hemp.
    - https://onderzoek.hogent.be/sites/onderzoek/assets/File/HOGENT%20Onderzoeksresultaten%20%E2%80%98Eigen%20Kweek%E2%80%99%20en%20%E2%80%98Hemp4All'.pdf (100 pages)
- HOGENT, 2022. 'Cannabusiness. Summary of hemp cultivation and primary processing results'. (Dutch)
    - Short report with results of harvesting hemp for textile using different harvesters.
    - https://www.hogent.be/sites/hogent/assets/File/Eindverslag_Cannabisness.pdf (9 pages)
- HOGENT, 2023. 'Bio-based materials & circular economy'. (Dutch)
    - Overview of fibre hemp projects at the college
    - https://www.hogent.be/onderzoekscentra/ftilab/projectresultaten-ftilab/
- Inagro, 2022. 'Hemp4Textiles project: Discussion multifactorial hemp trial 2021'. (Dutch)
    - https://inagro.be/nieuws/bespreking-multifactoriele-hennepproef-2021 (webpage, corresponding to 5 pages)

[16] https://edepot.wur.nl/135333
[17] https://edepot.wur.nl/524494

- CREA, 2020. 'Guidelines for dual purpose industrial hemp cultivation'.
    - Introduction on fibre hemp and Guidelines for cultivation of hemp for fibre and seeds with focus on Italy
    - https://www.psrscarabeo.it/wp-content/uploads/2021/06/Dual-Purpose-Hemp-Growing-Guidelines-SCARABEO.pdf (22 pages)
- Cretes, 2021. 'Textile Hemp Harvesting'.
    - Video of harvesting fibre hemp for textile applications.
    - https://www.youtube.com/watch?v=UU9mYpnjnqw (2 minutes)
- Alberta. 'Industrial Hemp Harvest and Storage – Best Management Practices'.
    - Comprehensive detailed info on hemp for food and fibre: Focus on cultivation, harvesting, and retting.
    - https://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/crop15539/$file/HempHarvestStorage.pdf?OpenElement (31 pages)
- Maine Department of Agriculture (USA), 2021. 'Hemp Handbook'.
    - Info on obtaining a licence to grow hemp in Maine, finding seeds and cultivation practices.
    - https://www.maine.gov/dacf/php/hemp/documents/hemphandbookmarch2021.pdf (13 pages)
- Manitoba Ministry of Agriculture (Canada), 2023. 'Industrial Hemp Production and Management'.
    - Info on seed selection, plot selection, cultivation, harvesting, and fibre production.
    - https://www.gov.mb.ca/agriculture/crops/crop-management/hemp-production.html (webpage corresponding to 10 pages)

6 Industrial processing into technical applications and food products

Hemp is used in a wide variety of applications. Besides the choice of the variety (Chapter 3), the cultivation practices, and the harvesting methods (Ch5), also processing has a direct influence on the quality of hemp, depending on its intended applications. The first processing step consists in the separation of the hemp straw into the bast fibres and the woody core material, called shives or hurds (§6.1). Subsequently, different products can be produced, starting from these two raw materials.

The vast majority of hemp production in Western Europe is used for technical applications (§6.2 – 6.6).

The use of hemp for textiles is relatively small-scale and mainly takes place in China and Eastern Europe. However, processors are working on the development of the complete value chain for textile fibre processing in Western Europe. More information on textile applications is given in Chapter 7.

Processing of flowers, leaves, and seeds into food products is still a relatively niche market (§6.7).

The sections below discuss processing of hemp into different technical products and their important characteristics.

6.1 Separation of bast fibres and core material (shives)

In the first processing stage, the hemp bast fibres are separated from the core material. The core material obtained after separation is called 'shives' or 'hurds'.

This process is to some extent identical for all technical applications. The main parameter is the degree to which the bast fibres are separated from the shives.

Bale opening
The bales of retted hemp straw are taken from the storage and fed into the processing line, starting from the bale opener (Figure 16). The bale opener also removes possible contamination of materials from the land; such as sand and stones.

Figure 16 Bale opener. Photo: HempFlax.

Separation of the bast fibre from the woody core
A hammer mill is used to separate the bast fibres from the core material (shives or hurds). Hempflax uses a patented proprietary design hammer mill.

Subsequently, the fibres and shives are separated by means of a rotating sieve drum through which the fibres and shives are pushed; the shives fall through the sieve, the bast fibres stay in the sieve drum and leave the drum at the end of the line. After this, the bast fibres are reasonably clean, but they still contain a small amount of shives.

Figure 17 Duvex sieve drum for separating bast fibres and shives. Photo: Cretes.

Further cleaning and refining
The quality of the fibres coming from the previous separation step is already suitable for paper making. However, further cleaning is needed if the fibres are intended for composites and textiles. To this end, several additional refining and cleaning steps are available (Figure 18). Depending on the settings of the processing line and the input quality of the straw, different output quality can be obtained. The finest and longest fibres are suitable for textiles. Within the range of fibres suitable for textiles, there are again different qualities (Chapter 7).

For textile applications, the fibres go through a scanner which – based on colour – detects and removes undesired parts such as knots from twines which were used for baling.

Figure 18 Refining and cleaning hemp fibres. Photo: HempFlax.

Many of the machines used by Hempflax were originally developed for processing other kind of fibres, and over the years have been modified by Hempflax for optimal processing of hemp.

With the addition of a bio-enzymatic treatment, the fibres can be made even finer, making it suitable for use in nappies, sanitary towels and cleaning wipes.

Figure 19 Clean hemp fibre. Photo: HempFlax.

<u>Manufacturers of hemp processing lines</u>

- Cretes (Wevelgem, Belgium), https://www.cretes.be/nl/machines/volledige-lijnen/hennepverwerking
- Tatham (Bradford, United Kingdom), https://www.tatham-uk.com/

6.2 Insulating mats for the construction industry (fibres)

The hemp bast fibre can be processed into a mat, eventually bound with a small amount of plastic fibre. For fire retardancy, some soda (an additive also permitted in food) is added.[18] Hemp fibre is mixed with finer jute fibres to improve the insulation value.

The density of such mats is approx. 35 – 40 kg/m^3. The insulation value lambda, λ, is approx. 0.04 W/m.K, comparable to insulation materials made of flax, cotton, wood fibre, or cellulose pulp.

A fibre mat can also be 'bonded' by so-called needling of the fibre mat. The density of such mats is higher, approx. 130 - 175 kg/m^3. These mats are suitable for sound insulation under floating floors and as a growth substrate for horticulture (§6.4).[19]

Figure 20 Hemp-based fibre mat for thermal insulation of buildings (left) and for sound insulation, e.g. under floating floors (right). Photos: Thermo-Hanf.

[18] https://www.thermo-hanf.de/en/products/thermo-hemp-combi-jute-insulation-mat/
[19] https://www.thermo-hanf.de/en/products/building-materials/thermo-hemp-footfall-sound-insulation/

6.3 Biocomposites for the automotive sector (fibres)

Hemp bast fibres are extremely strong and at the same time have a low density. This makes the fibres suitable for fibre-reinforced polymers ('biocomposites'). The fibres are mixed with a plastic and hot-pressed into a (moulded) product. Instead of plastic, the fibres can also be bonded with a resin. The fibres reinforce the polymer, thus requiring less material for the same functionality (strength). Relatively short fibres already give a good reinforcement of the material.

Bio-based fibre composites are widely used in cars, for example in door panels and trunk shelves. A big advantage in cars is that the low density of biofibres makes the car slightly lighter, which saves on fuel consumption. In addition, complex shapes can be made relatively easily. Also, in case of collision, no sharp edges arise as would occur with glass fibre composites. The good formability also makes these composites suitable as facade cladding.

Figure 21 Biocomposite facade panels; on the left containing an air-to-heat pump; on the right as cladding of the 1st floor. Photos: NPSP.

6.4 Growing medium and ground cover for horticulture (fibres)

Mats made of hemp fibres are very suitable as a growing substrate in horticulture. The fibres have good water retention capacity, and the open structure ensures air supply to the roots.[20] These mats are particularly suitable for shortly growing crops. And also as ground cover to suppress weed and moss growth.[21]

By needle punching of the fibres, no binder is needed; the mat is therefore 100% hemp fibre. As a result, the mats are also fully biodegradable in soil and composting.

Figure 22 Needle punched hemp fibre mat as a growing medium for horticulture. Photo: HempFlax.

---

[20] https://www.hempflax.com/en/applications/horticulture/growing-medium/
[21] https://www.hempflax.com/en/applications/horticulture/hempflax-garden-mulch/

6.5 Building blocks/mortar for construction (shives)

Hemp shives can be mixed with lime mortar and made into non-structural building blocks or prefabricated panels. The material is suitable for internal walls and can also be used for external walls if finished with, for example, lime plaster. The material has thermal and sound-insulating properties, fire class B resistance (fire-resistant for 2 hours or more) and moisture-regulating properties. Its high thermal capacity makes it particularly suitable for low-temperature heating (heat pump).

Producers:
- Building blocks: IsoHemp (Fernelmont, Belgium), https://www.isohemp.com/nl

Examples:
- Exterior walls, interior walls and roof made of lime hemp. https://hempcollective.nl/2018/11/14/opening-prefab-hennephuis/
- Noise barrier of hemp shives and lime (50:50), enclosed with coconut fibre non-woven. https://hempcollective.nl/2020/06/30/geluidsscherm-van-hennepvezel/

6.6 Animal bedding (shives)

Hemp shives can be made virtually dust-free, reducing the risk of allergic reactions and respiratory problems in animals. The natural antibacterial properties of the hemp plant help prevent diseases and infections. The shives can also absorb a lot of moisture, and are fully biodegradable in soil and composting.[22]

Figure 23 Hemp shives as animal bedding. Photo: HempFlax.

6.7 Use in nutrition (seeds, leaves and flowers)

The cultivation of hemp in the Netherlands mostly focuses on bast fibres and shives. Separating these properly requires good retting of the stalks, as well as sufficient opportunities to dry the stalks before baling and storing for further processing. With the northern Dutch climate, this requires harvesting around the flowering period, which means that no seeds can be harvested. For textile applications, harvesting is also done around flowering.

For good seed formation, many hours of sunshine are desirable. There are developments to grow hemp in the southern part of the Netherlands, investigating whether weather conditions there are suitable to achieve sufficient retting after later harvesting such that the seeds are mature and can be harvested.

To the extent that the seeds can be harvested (this is quite possible in more southern countries), they are used in food, for instance in muesli. Oil can also be pressed from the seeds. Leaves and flowers are used to make tea. Flowers, leaves, seeds, oil from seeds and seed parts are also used to add flavour to beer.[23]

---

[22] https://www.hempflax.com/toepassingen/animalcare/
[23] https://en.wikipedia.org/wiki/Hemp_beer#cite_note-8

In all dry products, the THC content should be below 3 mg/kg; in hemp oil a maximum of 7.5 mg/kg is foreseen as per EU legislation.[24,25]

Feed

Hemp leaves are high in protein and in principle suitable as animal feed. The flowers or the whole plant can also serve as animal feed. The use of leaves and seeds as animal feed is currently not allowed in the Netherlands. For the marketing of feed materials it is advised to verify the national legislation and to follow the requirement established in EU legislation.

Medicinal cannabis

To cultivate, process or research cannabis with increased THC content, a specific licence is needed in the form of an exemption from the Opium Act. This is done only after obtaining permission from the Medicinal Cannabis Agency, an agency of the Ministry of Health. In the Netherlands, medicinal cannabis is only produced through protected cultivation on a pharmaceutical basis through greenhouse cultivation or in cultivation cells. At the same time, this is only done after ordering on doctor's prescription through pharmacists who submit their application to the agency.

[24] https://eur-lex.europa.eu/legal-content/NL/TXT/PDF/?uri=CELEX:32022R1393&from=EN

[25] EIHA press release on EU-wide regulation on maximum THC levels in hemp seeds and derived products, https://www.linkedin.com/feed/update/urn:li:activity:6909105573296775168/

7 Industrial processing into textiles

Hemp has been an important crop for clothing and upholstery textiles for a long time. From the 1930s, hemp fibres were gradually replaced by cotton and fossil-based fibres. With stronger focus put on sustainability in the recent years (§4.2, 5.2), hemp for textiles is being reconsidered as a viable alternative. This development is accelerating due to the increasing demand for flax textiles and the decreasing production of flax due to drought sensitivity combined with the low rotation frequency of flax cultivation.

The processing and textile applications of hemp are basically similar to flax. After the hemp stalks are retted, dried and baled, the parallel stalks can be further processed into long fibres, and eventually yarns. The industrial processing of hemp into textiles can be distinguished in two: the production of yarns based on long fibres (§7.1) and on short fibres (§7.2). These short fibres are then either a by-product of the long fibre processing (§7.1.1, 7.1.3), or a product of technical fibre production (§6.1).

The obtained yarns can be processed into fabrics by weaving (§7.4.2) or knitting (§7.4.3). After weaving or knitting, further finishing (§7.4.4) and post-treatment (§7.4.5) are often required. These processing steps are common for any type of fibre, both plant based as well as synthetic.

7.1 Production of yarn with long hemp fibres

Yarn production in general involves a series of processes. After harvesting, retting and drying, the successive steps are breaking and scutching (§7.1.1), possibly softening (§7.1.2), hackling (§7.1.3), preparation for spinning (§7.1.4) and finally spinning (§7.1.5, 7.2).

Figure 24 shows a schematic overview of the main processing steps (dark blue/dark grey) and the resulting (intermediate) products (light blue/light grey), starting with the hemp straw that is harvested. This diagram also indicatively shows how many kg of product are usually obtained during each step.

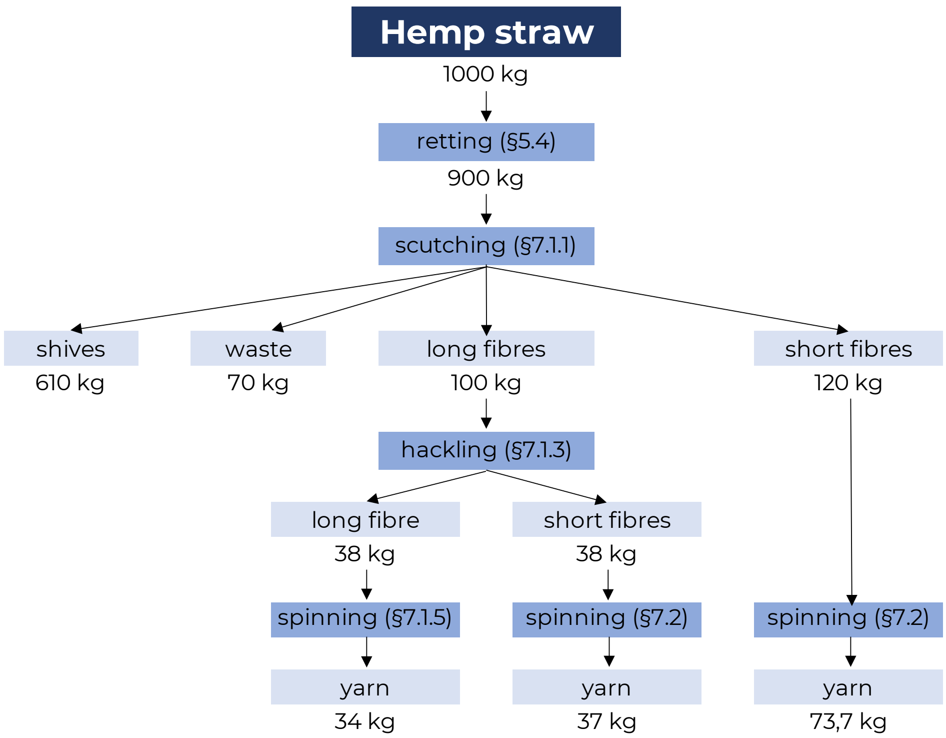

***Figure 24** Overview of main processing steps and intermediate products for making yarn from fibre hemp stalks (straw).*

7.1.1 Scutching

Scutching consists of a number of steps. The schematic structure of a scutching line is presented in Figure 25. The bale with parallel hemp stalks is unwound (Figure 26) and the stalks are broken. In this process, the woody core is broken into so-called shives so that they can be more easily separated from the bast fibres. This process already removes most of the shives from the bast fibres.

The bast fibres are then passed through turbines equipped with counter-rotating blades (Figure 27). The blades continuously strike the fibres, separating the shives and also short fibres (also called 'tow' or 'scutching tow') from the long fibres (Figure 28). The scutching opens the fibre bundles, making them finer and softer. The speed of the rotating blades for scutching hemp is lower than for flax.

The long fibres will be hackled (§7.1.3) for producing fine yarns. The short fibres (tow), after further cleaning, can be used to produce coarser yarns (§7.2) or they can be cottonised (§7.3) into fibres approximately the size of cotton. Other applications of the short fibres include insulation material (§6.2) or composites (§6.3). The shives can be used in building blocks (§6.5) or animal bedding (§6.6).

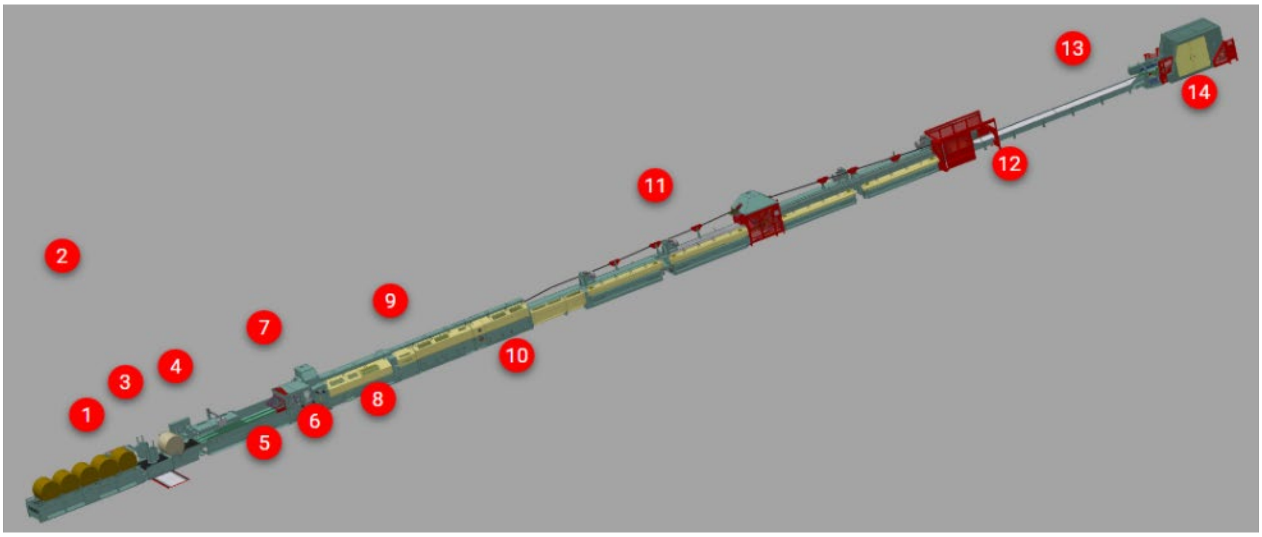

Figure 25 Schematic representation of a scutching line. Scheme: Depoortere.[26]

The main steps include:
- Tilt table (2): Bales of hemp straw are tilted from the flat position to the side position, in the right direction to be unrolled for scutching.
- Reserve tables (1): Storage of bales that will be scutched (see also Figure 26).
- Preparation table (3): Removal of twine so that the bale can be unwound.
- Unrolling machine (4): Unrolling the bale into a layer of hemp straw.
- Feeding table (5): Control the feed speed.
- Deseeding machine (7): Parallelising the stalks and extracting the seed heads.
- Divider (9): Refining the layer of stalks ('swath') by progressive acceleration, by means of star wheels where speed of every following star wheel is higher in comparison to the previous.
- Breaker (10): Breaking the woody part of the stalks.
- Scutching drums (11): Blades continuously beat against the fibres separating the shives and short fibres from the long fibres (see also Figure 28).
- Mills with leather blades (12): the mills clarify the fibres.
- Uproller press (14): Fibres are packed into round bales, with a web weight of about 1 kg/m.

[26] https://www.depoortere.be/machineCategory/2/display/Zwingelmachines (English translation available on website)

Figure 26 Feeding bales into the scutching line: breaking + scutching. Photo: HOGENT.

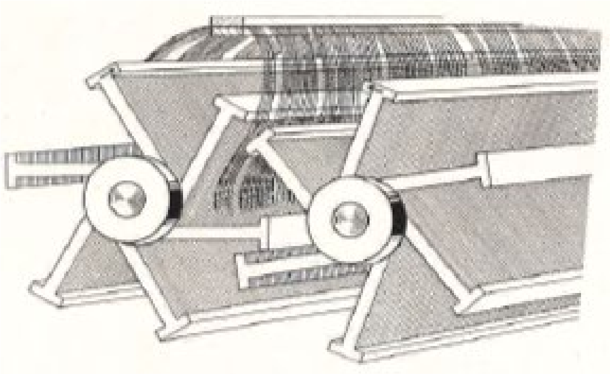

Figure 27 Scutching turbine. Copied from Dijkmeijer.[27]

Figure 28 Scutched long fibres leave the scutching line. Photo: HOGENT.

The quality of scutched hemp fibre (and flax) is divided into classes according to the expected yarn fineness which can be achieved by wet ring spinning (Table 3).

Table 3 Quality grades of scutched long hemp fibres corresponding to expected yarn fineness by wet ring spinning.

Class	Nm	Class	Nm
2	12 – 15	4+	26
3	15 – 18	5	28
3+	18 – 20	6	36
4	24	7	39

[27] E. Dijkmeijer, Textiel Deel 2 Spinnen en weven. (Dutch)

Processors of fibre hemp for 'long fibres'

- Albert Brille (Wevelgem, Belgium), www.albertbrille.be
- Castellins (Wevelgem, Belgium), Laurence Vandecasteele, www.castellins.com
- Debruyne (Ardooie, Belgium), Geneviève Debruyne, www.flax.eu
- Devogele S.A.S. (Coulommiers, France), etsdevogele@hotmail.fr
- La Chanvrière (Saint Lye, France), http://lachanvriere.com/en/notre-chanvre-dans-le-textile/
- Linière du Ressault - Ets Lamerant S.A. (Le Neubourg, France), lin.ressault@orange.fr
- Robrecht Engels Vlasbedrijf (Sint-Laureins, Belgium), robrecht.engels@telenet.be
- Teillage Bellet & Cie S.A.R.L. (Raffetot, France), teillagebellet@orange.fr
- Teillage Vandecandelaere (Bourbuebus, France), pberghman@vandecandelaere.com
- Vlasbedrijf Bruijns (Heikant, the Netherlands), Sven Bruijns, sven_95@hotmail.com
- Van de Bilt (Sluiskil, the Netherlands), Bart Depourcq, https://vandebiltzadenvlas.com/en/home/

Constructors of scutching lines

- Depoortere (Beveren-Leie, Belgium), https://www.depoortere.be/Machines-de-teillages
- Cretes (Wevelgem, Belgium), https://www.cretes.be/en/machines-index/turnkey-processing-lines/hennep-voor-textiel
- Valtech group (Menen, Belgium) https://www.valtechgroup.eu/en/projects/complete-flax-breaking-scutcher-for-long-fibre-flax
- Vanhauwaert (Kuurne, Belgium), https://www.vanhauwaertmachines.com/en/bast-fiber-processing

7.1.2 Softening

The long and short hemp fibres may eventually be softened and made more flexible. This can be done mechanically with a roller or by using additives. Softening can take place at different points in the process: on fibres, continuous hackling sliver or passage sliver, yarn, fabric or knitwear.

Mechanical softening

This operation can be carried out using the hemp softener (Figure 29). This device consists of 14 pairs of fluted rollers arranged in a semi-cylindrical shape. Three rollers rotate forward and two in the opposite direction. During this continuous process, the fibres are cleaned from the last woody particles and other contaminants. Thanks to this process, the fibres will also split better during further processing.

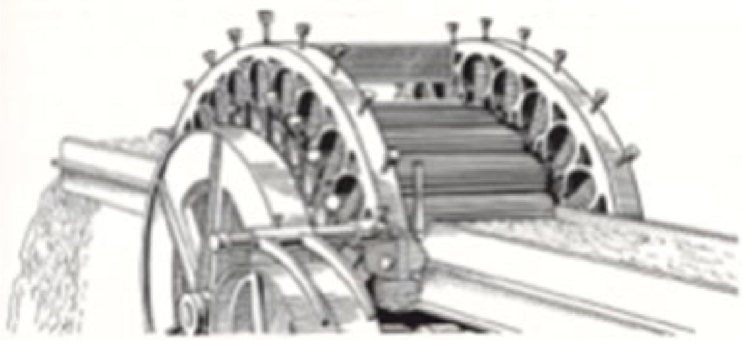

Figure 29 Hemp softener.

Softening with use of additives

Several textile chemicals suppliers have launched products to soften fibres. Note that these products sometimes contain silicones. The disadvantage of using additives is that this operation is sometimes done in an aqueous solution and the fibres have to be dried again before further processing.

7.1.3 Hackling

Scutching is followed by hackling, which is actually a kind of combing. During this process, the fibres are repeatedly pulled through fine pins to remove remaining woody particles and to separate the short fibre from the long fibres; please note that these ‘short fibres’ are longer, finer and cleaner than the short fibres obtained during scutching. Subsequently, the long fibres are levelled out, spread on top of each other and processed into a continuous sliver of hackled hanks of line fibres. This sliver is given a slight twist to maintain consistency in the following preparatory operations of the (ring) spinning. The hackled sliver is turned into bales.

Figure 30 Bales of hackled sliver (left); combed hackled sliver (right). Photos: HOGENT.

7.1.4 Spinning preparation

Prior to wet spinning, a few more production steps take place (Figure 31). After selecting the batches of hackled sliver, a plan is made for mixing, drafting and doubling the slivers ('mixing plan'). Then, hackled sliver from selected bales are drafted on a drawing frame and reassembled into a new sliver (Figure 32). This drafting and doubling process takes place at least 4 times and aims to obtain a more homogeneous sliver with further refined fibres. The sliver is lightly twisted using a roving frame (Figure 33) into roving that is wound onto a rove bobbin after which the fibre is suitable for further refining and wet spinning (§7.1.5).

Figure 31 Process steps from hackled sliver to spinning.

Figure 32 Drafting and doubling of hackled sliver into sliver (left); top view (centre); sliver in barrel (right). Photos: HOGENT.

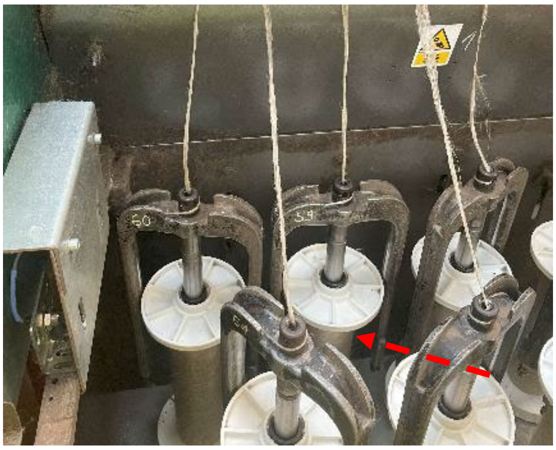

Figure 33 Roving frame for processing sliver into wick on rove bobbin. Photos: HOGENT.

If necessary, the wick or rove bobbin can be demineralised, alkaline boiled and/or bleached before wet spinning.

Demineralisation contributes to:
- ✓ Removal of iron which can lead to holes in the fibre and thus in textiles due to rusting and possible washing out during washes.
- ✓ Removal of other metals to avoid possible negative effects in subsequent processes (e.g., dyeing).
- ✓ Higher degree of whiteness after peroxide bleaching.
- ✓ Lower hardness of the fibres, yarns and ultimately the fabric.

Demineralisation takes place before or after alkaline boiling.

Alkaline boiling contributes to:
- ✓ Removal of secondary substances (hemicellulose, pectin, lignin, natural fats and waxes).
- ✓ Spinnability due to smoother fibres as a result of removing lignin and pectin.

Bleaching contributes to:
- ✓ Removal of natural dyes, or coloured impurities
- ✓ Increasing hydrophilicity

Figure 34 Machine for boiling and bleaching of roving. Photo: Loris Bellini.

<u>Companies pretreating hemp for spinning</u>
- Fibres: Safilin (France), https://www.safilin.fr
- Fibres: Schrurs (Ieper, Belgium), Serge Schrurs, http://www.schrurs.be/index.php?lang=NL
- Fibres: Van Riel (Temse, Belgium), Alain Van Riel, https://www.vanrieltemse.be/en
- Bobbins: Masureel (Wevelgem, Belgium), https://www.masureel-group.com

7.1.5 Spinning of long fibres

The long fibres have the highest quality; they are stronger, finer, less hairy, and more regular than the shorter fibres. The fibre fineness is a result of splitting during scutching (§7.1.1), hackling (§7.1.3) and further pre-processing (§7.1.4). This allows the long fibres to be spun into much finer yarns than the shorter fibres. During spinning, the fibres on a rove bobbin are further refined and twisted around each other, giving the yarn (also called 'thread') its strength.

The long fibres are usually wet spun via the ring-spinning system (Figure 35). The wick ('rove' at the top of the figure) passes through a hot water bath at 60-70 °C, which softens the remaining glue (pectin) between the fibres and allows the fibres to move more freely during the spinning process and therefore position/orient themselves more ideally in the yarn. Subsequently, the fibres pass through the drafting zone where the rove can be refined to the desired yarn fineness, up to 18 times. Finally, the fibres are spun into yarn by a rotating guide ('wire traveller' at the bottom of the figure) which creates a twist in the yarn; each rotation creates one twist in the yarn.

The production speed in ring spinning is limited by the fact that winding the yarn is linked to twisting the yarn. On a ring spinning machine, a twist can be given from about 300 to 700 rotations per minute. Wet spinning of bast fibres is a more cost-intensive technology than spinning short staple fibres using rotor spinning (§7.3.2).

The thickness of a yarn is indicated by the so-called yarn number (§7.1.6). The finest yarns are obtained when the fibres are bleached prior to spinning. Wet spinning produces fine, smooth, regular but fairly hard touch and shiny yarns that are processed into clothing and interior (home) textiles. Wet-spun yarns can be obtained with yarn numbers in the range Nm 26 to 39.

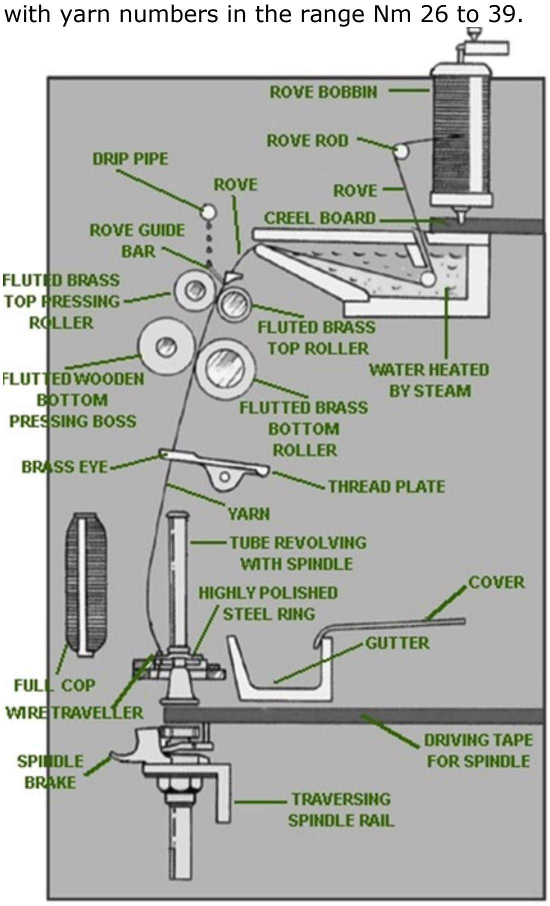

Figure 35 Schematic representation of wet ring spinning. Copied from Janssens.[28]

[28] Els Janssens, 'Garentechnologie 1: mechanisch spinnen', Cursus 2019-2020. https://issuu.com/communicatie-hogent/docs/garentechnologie_1 (in Dutch)

***Figure 36** Wet ring spinning of long bleached fibres. The arrow indicates where the yarn passes through the hot water bath. Photo: HOGENT.*

In the process of semi-wet spinning, the yarn passes over a copper dip roller after the drafting zone (Figure 37). The roller rotates in a water bath. The water makes the yarn slightly smoother but it retains the character of dry-spun yarn: fluffier, weaker, coarser and no 'eternal' lustre.

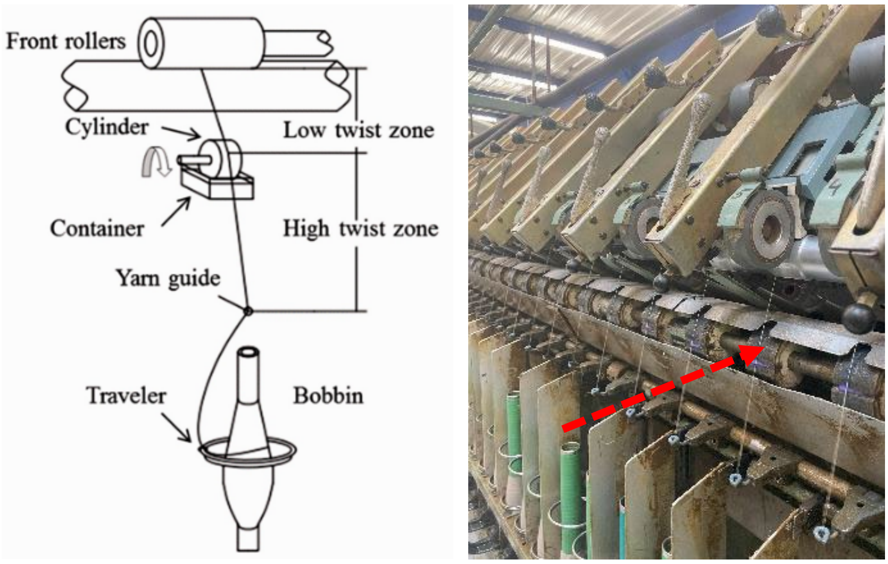

***Figure 37** Schematic representation of semi-wet spinning (left, copied from Kahn)[29] and semi-wet ring spinning machine (right). The arrow indicates the dip roller. Photo: HOGENT.*

Typical applications of long fibre yarns are clothing and interior textiles.

Spinners of long fibres

- Safilin (Béthune, France & Poland), Olivier Guillaume, https://www.safilin.fr
- Linificio & Canapificio Nazionale (Villa d'Almé, Italia), Pierre Luigi Fusco, https://www.linificio.it
- CAVVAS (Cluj, Romania), https://cavvas.com

[29] Khan et al., Journal of Textile Science and Technology, 2020, 6, 19-39, https://www.scirp.org/pdf/jtst_2019122416553807.pdf

Manufacturers of ring spinning machines for 'long fibres'

- Tongda (Weifang City, China), https://www.china-tongda.com/product/flax-spinning-machine.html
- Linimpianti (division of Linificio, Italy), https://www.linificio.it/linimpianti/
- Sermates (Cologne, Italy), https://sermates.com/

7.1.6 Yarn numbering and naming

The thickness of yarns, also known as 'yarn number', is expressed in a wide variety of ways. Table 4 shows how a selection of most common yarn number quantities, indicated on the diagonal, can be converted. The procedure is as follows: 1) On the left vertical axis, select the unit in which the yarn thickness is given; 2) In the top row, select the desired (to be determined) unit; 3) Select the formula for conversion in the box that 'connects' both units; 4) Calculate the yarn number in the desired unit.

Calculation example

The conversion of a yarn with thickness '30 tex' to 'Nm' is as follows:

- The formula is: 'yarn number in Nm' = 1000/'yarn number in tex'
- Yarn thickness of 30 tex corresponds to 1000/30 = Nm 33

Table 4 Relationship between yarn numbers. Magnitudes are shown on the diagonal.

		To be determined						
Given		**Nm**	**Tex**	**Den**	**Ne_k**	**Ne_v**	**Ne_w**	**Ts**
	Nm	**Metric number**	1000 / Nm	9000 / Nm	0,59 x Nm	1,65 x Nm	0,89x Nm	29,03 / Nm
	Tex	1000 / tex	**Tex**	9 x tex	590,5 / tex	1653,5 / tex	885,8 / tex	34,45 / tex
	Den	9000 /den	den / 9	**Denier**	5314,9 / den	14882 / den	7972,3 x den	den / 310,03
	Ne_k	1,69 x Ne_k	590,5 / Ne_k	5314 / Ne_k	**English cotton number**	2,8 x Ne_k	1,5 x Ne_k	17,14 / Ne_k
	Ne_v	0,60 x Ne_v	1653,5 / Ne_v	14882 / Ne_v	0,36 x Ne_v	**English linen number**	0,54 x Ne_v	48 / Ne_v
	Ne_w	1,13 x Ne_w	885,8 / Ne_w	7972,3 / Ne_w	Ne_w / 1,5	1,87 x Ne_w	**English wool number**	25,1714 / Ne_w
	Ts	29,03 / Ts	34,45 / Ts	310,03 Ts	17,14 / Ts	48 / Ts	25,7143 / Ts	**Scottish jute number**

The pretreatment is reflected in the yarn's name designation: the term grey or 'ecru' is used if the fibres have not been boiled or bleached; the term 'bleached' is used if the fibres have undergone some form of bleaching.

7.1.7 More information

- SSUCHY project, 2019. 'SSUCHY HEMP processing: from plants to aligned fibres'
    - EU project on hemp cultivation and processing up to hackling sliver.
    - https://www.ssuchy.eu/ssuchy-hemp-processing-from-plants-to-aligned-fibres/
- HOGENT, 2023. 'Hemp4Textiles: Fibre hemp for textile applications'
    - Research project aiming at optimising cultivation technique, harvesting, retting and primary processing for the production of long hemp fibres for textile applications. This Vlaio project is coordinated by HOGENT in collaboration with UGent – Faculty of Bio-engineering Sciences, INAGRO, several actors from the agricultural sector, primary processors (flax scutching companies), constructors of harvesting and processing equipment, and textile sector. Duration 2021-2024.
    - https://onderzoek.hogent.be/projecten/hemp4textiles-vezelhennep-voor-textieltoepassingen1/ (English at bottom half of webpage)
- HOGENT, 2023. 'Hemp4Circularity: Hemp as a driver of circularity in the textile industry: from field to recycled fibre' (Dutch)
    - This European Interreg project aims at applying long fibre hemp textiles at industrial scale in the European textile value chain. The project is a collaboration between companies and associations from 4 North western European countries and aims to accelerate the growth and independence of processors and manufacturers in these countries. Further, Hemp4Circularity focusses on sharing knowledge and expertise.
    - https://onderzoek.hogent.be/projecten/hemp4circularity-hemp-as-a-driver-of-circularity-in-the-textile-industry-from-field-to-recycled-fibre/

7.2 Spinning of short fibres from the scutching and hackling line

Scutching tow is used for making coarser yarns with a dry spinning process. Dry spinning is based on the same principles as making roving yarn (§7.1.4), but using a finer flyer, spindle and cop. Before spinning, the scutching tow is combed, made into sliver and drawn and doubled, like is done for long fibres. Based on scutching tow, yarns with a fineness of Nm 3 to 7 can be spun.

The successive steps are:

- Prepare mixing plan for bales of scutched short fibres.
- Roller card: The fibres are split by the sharp needles of the carding machine and made into a carding sliver. The shives that were still attached to the fibres and the fibres that are too short 'fall out of the main stream of fibres' and are collected in the dust container under the large carding drum.
- Drawing: The fibres are laid in parallel.
- Comber: Extra treatment for more regular yarn. The fibres are further parallelised to form combed sliver. Production is about 8 kg/hour where there is a loss of 20% comber noils or combers.
- Drawing frame: The combed sliver is drawn and doubled, thus obtaining carded sliver which is collected in a rotating drum. During the successive 3 to 4 passages, a smaller number of doublings is applied each time and the combing zone becomes finer at each passage, as well as delivered roving.
- Roving frame: the slivers are further refined into wicks with a slight twist
- Dry spinning: Based on the principle of roving preparation, but with a finer flyer, spindle and cop.
- Semi-wet spinning: Performed on similar spinning machines as for dry spinning. The difference is that the wick is moistened after drawing by feeding it over a copper, continuously wetted roller. This water makes the formed yarn smoother but it retains the character of a dry–spun yarn.

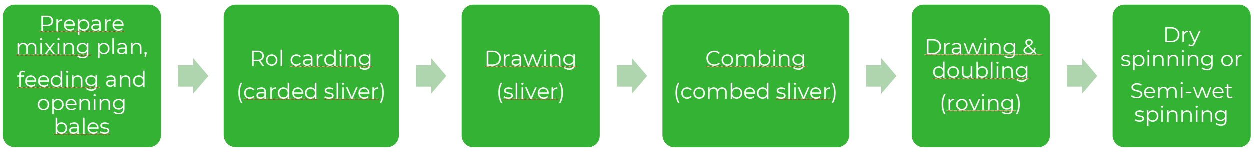

Figure 38 Processing steps from scutching tow (dry spinning) and hackling tow (semi-wet spinning) to spinning into rope works.

Hackling tow fibres are longer and cleaner and finer than scutching tow, and can therefore be processed into finer yarns that are slightly more regular and stronger. To achieve this, it is necessary to partially dissolve the pectin from the hemp fibres so that the elemental fibres can slide better relative to each other, and thus finer yarn numbers can be spun. Hackling tow is usually semi-wet spun and yarns with a fineness of Nm 6 to 15 can be obtained.

Typical applications of yarns based on short fibres of the scutching line are ropes and coarser/heavier textile fabrics. The finer fibres of hackling tow are used in clothing, knitting yarn or upholstery.

Spinners of 'short fibres' (scutching and hacling tow)

- Lambrecht Spinning (Okonek, Poland), Raymond Libeert, https://www.lambrecht.pl/
- Safilin (Béthune, France & Poland), Olivier Guillaume, https://www.safilin.fr (hackling tow)
- Linificio & Canapificio Nazionale (Villa d'Almé, Italy), Pierre Luigi Fusco, https://www.linificio.it (hackling tow)
- Cavvas (Cluj, Romania), https://cavvas.com/
- Utexbel (Ronse, Belgium), Jean-Luc De Rycke, https://utexbel.com/nl/

7.3 Production of yarn from cottonised hemp fibres

The wet, semi-wet or dry ring spinning processes are relatively slow. Rotor spinning (also called 'open-end spinning') is much faster. This requires short fibres of a few cm length. Among biobased fibres, cotton is a well-known example that can be spun this way. However, the 'short fibres' coming from the scutching and hackling processes (§7.1.1, 7.1.3) are still too long for rotor spinning. These hemp fibres can be made shorter and finer by means of cottonisation (§7.3.1), so that they can be spun into yarn like cotton by rotor spinning (§7.3.2).

7.3.1 Cottonisation

Cottonisation is a process that gives the relatively long fibre bundles of hemp the texture and consistency of short staple fibres, such as cotton, so that they can be spun, woven and knitted on cotton-specific systems. The physical properties that can be changed by cottonisation are length, fineness, and diameter.
Hemp fibres contain less cellulose than cotton fibres, so they do not have the same softness as cotton fibres. This makes hemp fibre a less popular fibre in the textile industry. Cottonising can (partially) overcome this disadvantage, making hemp fibres more similar to cotton fibre.

The raw material for cottonisation is the whole bast fibres intended for technical applications (§6.1), and/or the short fibres released from the scutching and hackling line (§7.1.1, 7.1.3). During cottonisation, the pectin and lignin bonds between the plant cells in the bast fibre bundle are weakened such that these plant cells can be isolated as fibres, with dimensions similar to cotton or wool.

During cottonisation, it is important not only to make the hemp fibres finer, but also to maintain their strength. If pretreatment is too harsh, the fibres can lose their quality and become less useful for spinning. Cottonised fibres are usually blended with cotton or Tencel to facilitate spinning and achieve better yarn strength. Cottonised hemp fibres can also be used to compensate for the decreased strength of recycled fibres in a 'new yarn'. Conversion yield of cottonisation is about 80 – 85%.

There is no single set procedure to cottonised hemp. Companies have their own approaches to deliver best possible fibre products.

Methods of making cottonised hemp fibres include:
- Mechanical, after alkali pretreatment
- Steam explosion
- Electroshock treatment

Methods under development:
- Oxidation with ozone
- Acoustic cavitation using ultrasound
- Microwaves

<u>Producers of hemp cottonised fibre</u>
- Schrurs (Ieper, Belgium), Serge Schrurs, http://www.schrurs.be/
- Jos Vanneste (Harelbeke, Belgium), Alex Vanneste, https://www.jos-vanneste.com/
- Bast Fiber Tech (Canada), using fibres from HempFlax, https://www.bastfibretech.com/

7.3.2 Spinning of short staple fibres

The cottonised staple fibres can be spun on cotton or wool spinning machines, both by ring spinning as well as by rotor spinning. Ring spinning is a widely used method for spinning short textile fibres; it produces a fine, high-quality spun yarn that causes few problems in the subsequent production process. It is the best method for spinning yarn for knitted fabrics and for mixing different types of fibres ('blended fabrics').

Ring spinning of short staple fibres follows the same principle as ring spinning of long fibres (§7.1.5). Short staple fibres are most often dry spun; eventually, if the yarn becomes too hairy, a dip roller with water is used to obtain a more smooth yarn. With ring spinning of staple fibres, yarns with fineness in the range Nm 5 - 36 can be obtained.

Rotor spinning, also called open-end spinning, is 4 to 10 times faster than ring spinning. However, the resulting yarn feels slightly more rough, is slightly weaker and less resistant to abrasive movement than ring-spun yarn. An advantage is that the yarn is less transparent and evenness is more uniform than in ring spinning.

Table 5 Comparison of yarn properties of ring-spun and rotor-spun yarns.

Ring-spun	Rotor-spun
Regular twist	Core twist – less beautiful twist
Higher strength	Lower strength
Soft touch	Hard touch
Longer and finer fibres	Mostly short fibres
Fineness 5 – 600 tex	Fineness 25 – 295 tex
Longer process	Shorter process
Speed spinning 25 m/min	Speed spinning 300 m/min
Limited automation	Higher level of automation
Fine fabrics for textile and upholstery, sewing threads, high quality terry cloth, knitwear	Coarser fabrics for clothing, denim, interior fabrics, terry cloth, knitwear, household textiles

Typical applications of cottonised hemp fibre yarns: clothing (T-shirts, jeans), tablecloths, towels, bedlinen, hygiene products.

7.3.2.1 Rotor spinning

In rotor spinning, also known as open-end spinning, twist is introduced into the fibres without the roving rotating itself. Thanks to very large centrifugal forces, the fibres are pressed against the rotor wall and move from the collection surface of the rotor to the rotor groove. In the groove, a layer of fibres is formed, whereby an x-fold doubling is achieved and a regular yarn is obtained. The yarn is actually spun in the rotor groove and leaves the rotor through a spinning tube.

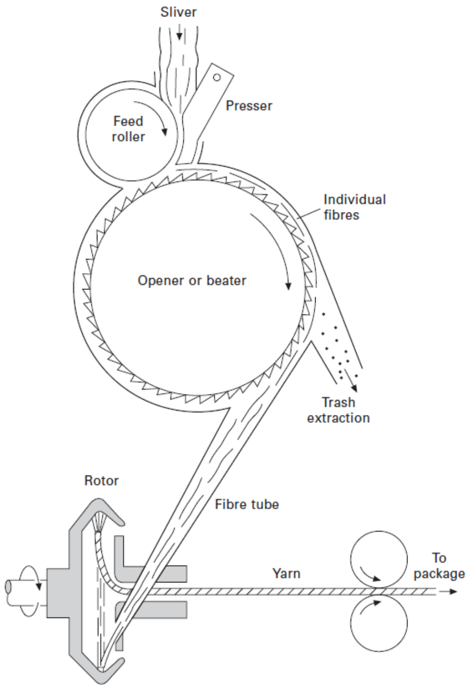

Figure 39 Basic features of rotor (open-end) spinning. Copied from Carl A. Lawrence.[30]

The production rate in rotor spinning is much higher than in ring spinning (Table 5). This is because introduction of the twist is completely independent from winding the yarn on a bobbin. The rotation speed is also higher than for ring spinning, about 6,000 - 9,000 rotations per minute, versus 300 - 700 for ring spinning.

Rotor spinning is a dry spinning process and is mainly applied to short staple fibres. A more regular and less hairy but weaker yarn is produced than in ring spinning of staple fibres.[31] With rotor spinning of staple fibres, yarns with fineness in the range of Nm 5 - 12 can be obtained.

Figure 40 Semi-automatic rotor spinning. Photo: Rieter.

[30] Carl A. Lawrence, 'Fundamentals of spun yarn technology', 2003 CRC press, www.eopcw.com/find/downloadFiles/237
[31] https://www.rieter.com/fileadmin/user_upload/products/documents/systems/fiber-preparation/varioline/rieter-bast-fibers-processing-brochure-2261-v2-94769-en.pdf

Spinners of 'staple fibres' using rotor spinning ('open-end spinning')
- Utexbel (Ronse, Belgium), Jean-Luc De Rycke, https://utexbel.com/nl/
- ESG (Spiere-Helkijn, Belgium), Julie Lietaer, https://www.esg-group.eu/en/about-us
- Recycled fibres: Spinning Jenny (Nijverdal, the Netherlands), Liset Pander, https://spinningjenny.nl/

Spinners of 'staple fibres' using ring spinning
- Utexbel (Ronse, Belgium), Jean-Luc De Rycke, https://utexbel.com/nl/

Manufacturers of 'short fibre' spinning machines
- Rieter (Switzerland), rotor and ring spinning, https://www.rieter.com/
- Schlafhorst (Switzerland), rotor spinning, https://saurer.com/schlafhorst-systems-rotor-spinning-1#
- Sermates (Cologne, Italy), ring spinning, https://sermates.com/
- Trützschler (Mönchengladbach, Germany), ring and rotor spinning, https://www.truetzschler.com/en/spinning/

7.3.3 More information

- HOGENT, 2020. 'Yarn technology 1: Mechanical spinning' (Dutch)
  - Very broad information on yarns: types, structure, spinning methods (traditional, new and advanced), and properties.
  - https://issuu.com/communicatie-hogent/docs/garentechnologie_1 (141 pages)
- Carl A. Lawrence, 'Fundamentals of spun yarn technology', 2003, CRC Press
  - Very comprehensive information on fibre raw materials, raw material preparation, spinning principles and techniques, yarn structure and properties, and background information on relationships between raw materials, processing and properties.
  - www.eopcw.com/find/downloadFiles/237 (500 pages)

7.4 Textile fabric production

Textile fabrics can be woven or knitted. For hemp the same techniques can be used as for flax (and other fibres). There are different ways of weaving: Flat weaving (§7.4.2.1), Jacquard weaving (§7.4.2.2) and terry cloth weaving (§7.4.2.3). For knitting, 2 techniques are available: Weft knitting (§7.4.3.1) and warp knitting (§7.4.3.2). Prior to weaving, some preparatory activities are required (§7.4.1). After weaving, often finishing of textiles (§7.4.4) and after-treatments are applied (§7.4.5).

7.4.1 Weaving preparation

Before weaving, the warp yarns should first be wound in desired number and length on a so-called warp beam.

Making a warp is done in two steps. First, the desired number of warp yarns are wound onto a drum to the desired length using a so-called sectional warping machine or cone warping machine (Figure 41). Next, the yarns are rewound full-width onto the warp beam of the loom.

Figure 41 Cone warping machine. Photo: Masureel.

The warp yarn should be sufficiently strong and smooth to weave without difficulty. If the yarn is too fluffy or weak for the desired weave, the warp of the loom is sized with sizing agents. These are removed again after weaving, called desizing (§7.4.4). Wet-spun hemp yarns do not require sizing.

Next, the warp yarns have to be inserted through healds or heddles into 2 or more shafts. This is done according to a predetermined pattern. Finally, the warp yarns have to be threaded through a reed of the loom. This reed is an elongated frame and serves to keep the warp yarns parallel, to guide the weft rapier and to strike the applied weft.

7.4.2 Weaving

Weaving is a technique by which yarns are interwoven rectangularly to form fabrics. The longitudinal yarns are called warp yarns and the yarns woven perpendicularly through them are called weft yarns. Using the shafts, the warp yarns can be moved apart from each other ('lifted'), creating an opening into which the weft yarn can be inserted. After each weft, another group of warp yarns is lifted using the shaft and the next weft yarn is inserted into the opening.

Depending on how the warp yarns are inserted through the different shafts and the order in which the shafts lift the warp yarns, different patterns can be made. Some examples are given in Figure 42.

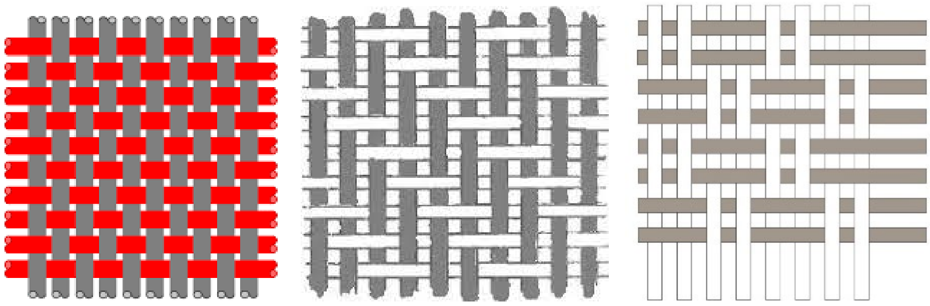

Figure 42 Plain weave (left), twill (centre) and panama weave (right). Copied from Motiv[32] and J. Nientker.[33]

Inserting the weft into the shed opening can be done in various ways, namely by means of a weaving shuttle (in the past), rapiers, projectile, air jet and/or water jet.

Wet-spun hemp yarn can be woven on rapier loom or rapier weaving machine; weaving with an air jet loom causes more problems. Cottonised fibres, ring spun or rotor spun, both can be woven on gripper or air jet looms.

Figure 43 shows the principle of weft transfer according to the double rapier system. The weft (red) is in the insert gripper (left) and the top of the weft forms a bridge, so to speak, in the gripper head. The receiving gripper (right) moves in the insert gripper where the "hook" of the receiving gripper moves past the weft yarn. At the moment the receiving gripper returns to the right, the "hook" of the receiving gripper grasps the weft, clamps it and transports the weft further through the opening.

[32] Motiv, 'Aankoopwegwijzer voor circulair textiel 1 – Module 3B: Doeken uit textile'. (in Dutch), https://data.secureserver.be/databases/bedrijven.nsf/webopen/downloads/$file/GDCA3Bdoeken.pdf
[33] Joke Nientker, 'Fragment stof AM-1993-65-5, van textielloodje uit scheepswrak Aanloop Molengat', 2011. (Dutch)

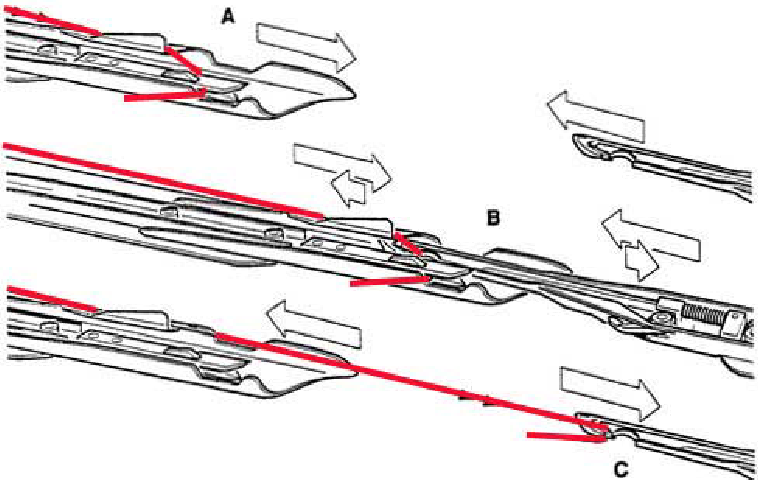

Figure 43 Double rapier system. Copied from G. De Smedt.[34]

Yarn based on cottonised hemp fibre can be woven using an air jet loom. In this process, the weft is fed through a 'pre-winder' via several air blowers in relay procedure through the shed opening. After the weft is struck by the reed the cycle begins again. The weft is cut on both sides of the fabric.

7.4.2.1 Flat weaving

Flat weaving is weaving in which the warp and weft yarns are visible 50:50 at both top and bottom side of the fabric. It is a very old technique and many variants exist (see Figure 42, among others).
The yarns used to weave textiles can be based on natural material, such as wool, flax, cotton, hemp or silk, or on man-made fibres, such as artificial silk, nylon (polyamide), polyester, acrylic, aramid or elastane.
Mixed fabrics consist of a combination of two or more of these fibres.

7.4.2.2 Jacquard weaving

The Jacquard weaving loom differs from an ordinary loom with shafts to the extent that each warp thread can be lifted individually. This technique allows very intricate patterns to be woven, for example a floral pattern in a tablecloth. The production capacity of this machine is lower than for a conventional air loom.

7.4.2.3 Terry cloth weaving

For the various uses of terry cloths, the ability to absorb moisture is important to a greater or lesser extent, depending on the use of the product.

Cotton is therefore most commonly used for towels. Hemp (and flax) absorb more moisture than cotton, have better strength in the dry state and have a greater gloss effect. Despite these advantageous properties, hemp (and flax) is still little used in towels, presumably due to its limited availability and higher cost.

The less the fibres are twisted, the better they will absorb moisture. In a yarn with a lot of twist, there are fibres in the middle of the yarn that are shielded by fibres on the outside and therefore do not come into direct contact with moisture. As a result, its ability to absorb moisture is less than yarns with less twist where all the fibres come to the yarn surface. Yarns based on cottonised fibres absorb moisture better than classic wet-spun yarns.

To produce terry cloths it is possible to use pile yarns[35] with relatively low twist because they are not subjected to much tension and resistance during the weaving process (Figure 44). Nevertheless, minimal twist is necessary to avoid breaking of yarns or fluffing too much during the weaving process.

---

[34] Geert de Smedt, 'Weven', Cursus 2020-2021. (Dutch)
[35] https://en.wikipedia.org/wiki/Carpet https://nl.wikipedia.org/wiki/Tuften

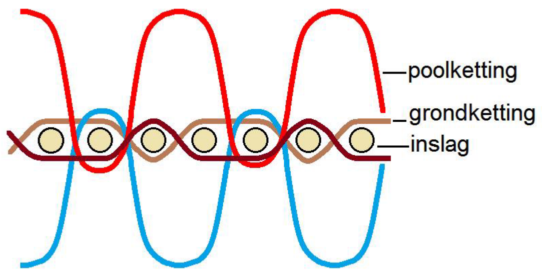

Figure 44 Cross-section of a classic terry cloth with a pile warp (red and blue) every 3 wefts (beige, perpendicular to image); ground warp (brown). Copied from Motiv.[32]

7.4.3 Knitting

For knitting, it is important that the yarn is flexible. These are generally rotor-spun staple fibres. Knitting with wet-spun yarn is difficult because the yarn is not sufficiently flexible. However, by softening the yarn and giving it the necessary treatments, it is possible to knit with wet-spun hemp yarn.

Important properties of yarn in knitting include yarn number, strength (Table 6), elongation, coefficient of friction, irregularity, twist (Figure 45), hairiness, stiffness and shrinkage.

Table 6 Specific tensile strength (cN/tex) for knitting yarns.

Fibre raw material	Weft knitting	Warp knitting
Hemp and flax long fibre	17 – 18.5	19.5 – 23
Hemp and flax short fibres	10 – 12.5	13.5 - 17
Carded cotton	7 – 12	9 – 15
Combed cotton	11 – 15	14 - 22
Wool	3 – 4.5	4 – 5.5

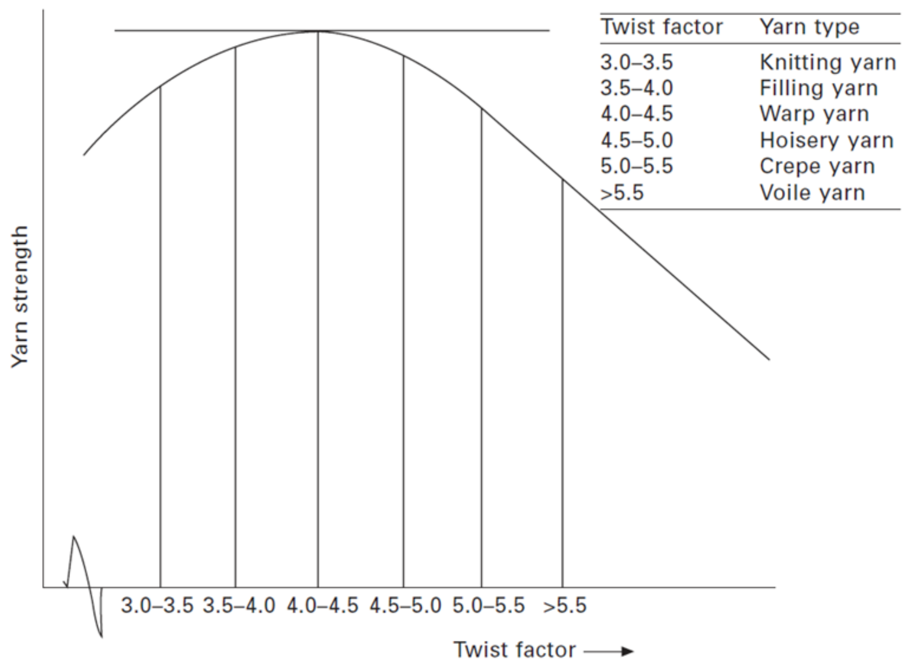

Figure 45 Classification of yarn type according to twist factor. Copied from C.A. Lawrence.[36]

[36] Carl A. Lawrence, 'Advances in Yarn Spinning Technology', 2010 Woodhead Publishing Series in Textiles, https://www.sciencedirect.com/book/9781845694449/advances-in-yarn-spinning-technology#book-description

In knitting, we distinguish weft knitting (§7.4.3.1) and warp knitting (§7.4.3.2).

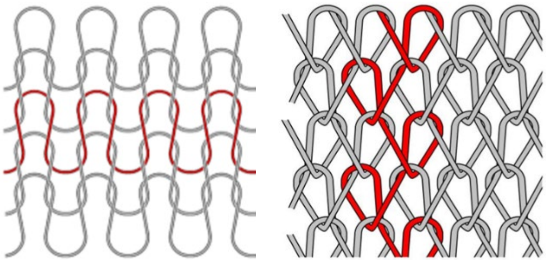

Figure 46 Schematic representation of weft knitting (left) and warp knitting (right). Copied from Motiv.[32]

Knits made of hemp yarn are still hard to find; typical applications of knits are: T-shirts (weft knitting - circular), jumpers (weft knitting), mattress duck (warp knitting)

<u>Suppliers of hemp knitting yarn</u>

- Etsy, https://www.etsy.com/listing/1044487407/lilac-just-hemp-yarn
- Hobbydoos, https://www.hobbydoos.nl/winkel/producten/lang-yarns-canapa
- Linificio, https://linificio.feeltheyarn.it/en/prodotto/canapa-2/
- Safilin, https://www.safilin.fr/?lang=en
- Wolplein, https://www.wolplein.nl/wol/hennep

7.4.3.1 Weft knitting

Weft knitting is the technique where the yarns that form the loops run across the full width of the fabric. A weft knitted fabric can be formed with one yarn.

Weft knitting is easier when using a circular knitting machine than a linear knitting machine because the yarn does not have to change direction.

Advantages of knitted fabrics:

- More voluminous
- Softer
- More elastic
- Cheaper than woven

Disadvantages:

- Less strong than woven fabric
- More difficult to process during confection

7.4.3.2 Warp knitting

Warp knitting is a technique in which the yarns forming the loops run in length direction of the fabric. The loops are connected laterally by moving the warp yarns sideways. The loops are formed simultaneously across the width of the knit. This requires several yarns, usually wound on a warp beam.

Advantages of warp knitted fabric:

- Does not fray (unravel)
- Does not ladder
- Less stretchable than weft knitted fabric
- Coarser yarns can be used
- Higher production rate

Disadvantages of warp knitting:

- Less stretch than weft knit
- Not applied for small production quantities

- More expensive than weft knit because a warp has to be made

7.4.4 Finishing in the production process

Finishing comprises a series of treatments performed on textile materials to improve properties or add new properties. Finishing can take place at 3 points in the process from hemp fibre to textile (cloth).

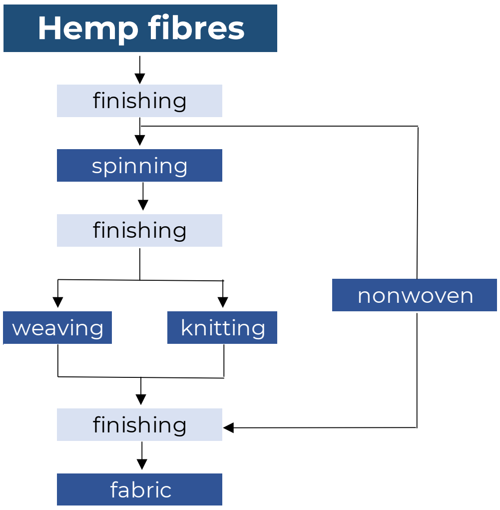

Figure 47 Places in het the processing of hemp fibres into textile fabric where finishing can take place.

Overview of finishing processes:

Singeing
Protruding fibres are burned from the fabric. This is mainly applied to fabrics made of cellulose fibres such as cotton, hemp and flax. This makes the fabric smoother and softer and prevents 'pilling' and hairiness during subsequent processes.

Desizing
Removal of sizing agents applied to warp yarns as an aid to weaving (§7.4.1). The sizing agents are removed to facilitate the absorption of dyes and finishing products in subsequent process steps. Enzymes can possibly be used for this purpose.
Twined yarns do not need to be sized and therefore do not need to be desized.

Washing
Washing is performed with detergent (soap) to remove contaminants, spin oils or water-soluble products from the previous processing.

Extraction
Removal of natural substances such as fats, waxes and pectin; by pressure cooking with sodium hydroxide, or by enzymatic hydrolysis.

Bleaching
Removal of natural pigments present in natural fibres. Bleaching is necessary if one want to apply light shade dyes.

Mercerisation
Increasing the lustre or bloom, strength and dyeability of yarns and fabrics made of hemp (and flax and cotton). The fabric is treated under tension with a high concentration of sodium hydroxide.

Dyeing
Dyeing of hemp can be done in the same way as for flax and cotton; one can use the same dye classes (Table 7) and dyeing machines.
Several machines can be used for dyeing hemp textiles. The choice of dyeing machine depends on the textile material (yarn, woven fabric, knitted fabric, non-woven), the choice of dye class and the desired end result. Dyeing can be discontinuous, semi-continuous or continuous.

Dyeing is done in several stages:
- Preparation of the dye bath
- Colouring
- Fixing
- Washing and rinsing
- Dehydrating and drying

Table 7 Dye classes, dyeing principles and properties of textile dyeing methods.

Dye class	Dyeing principle	Features
direct	Diffusion of the dyes from an aqueous solution into the fibre. They bind to the fibre by weak secondary bonds.	Poor wet- and sweat resistance. Lightfastness varies depending on colour. Large colour spectrum.
vat	Insoluble dyes are made temporarily soluble so they can dye the textile material. After penetrating the fibres, the dyes are converted back to the insoluble form.	Good lightfastness. Smaller colour spectrum with dull shades (few red tones). Expensive dyes.
sulphur	Idem as vat	Less good light and chlorine fastness. Narrow colour spectrum with only dull shades but contains a nice black. Cheap dyes.
reactive	The dyes form a strong chemical bond with the fibre. Also suitable for printing.	Very good washing and rubbing resistance. Moderate light and bleach fastness. Large colour spectrum (slightly less than direct) with brilliant shades. More expensive dyeing process.
pigments	Pigments are bonded with an agent to the outside of the fibre. They are mainly used in printing.	Good light fastness. Moderate washing and rubbing resistance.

7.4.5 Aftertreatment

Softening
After pretreatment and dyeing, most textile materials are hard and brittle. Applying softeners gives them a soft and pleasant grip. Examples of softeners are hygroscopic products and lubricants; these are applied by impregnation.

Making crease/ wrinkle recovering
Fabrics made of hemp, flax, cotton and viscose can be made less sensitive to wrinkling. This is done by applying chemicals that cross-link or bind with the fibres to form a layer that makes the textile less sensitive to wrinkling. Application can be done by impregnation or coating.

Calendering
Fabrics are pressed between two or more pressing drums to make them more closed, glossy and smooth or to give them a relief pattern.

Sanforising
Making shrink proof, named after its inventor Sanford L. Cluett. Under the influence of moisture and heat, the compressive shrinkage of the ensures the shrinkage is fixed.

Liquid ammonia treatment
This treatment (Figure 48) is an alternative to mercerizing, caustifying of cellulose textiles where an overall substrate improvement is sought in terms of: better dyeability, more lustre, higher dimensional stability, improvement of basic physical properties (e.g. strength, abrasion) and better touch. Traditional processes based on high concentrations of sodium hydroxide may lead to undesirable substrate degradation and

ecological impact (wastewater). Treatment of the textile in liquid ammonia (Beau-Fixe®) involves a continuous 4-step process and can be performed in contract at Veramtex (Brussels).

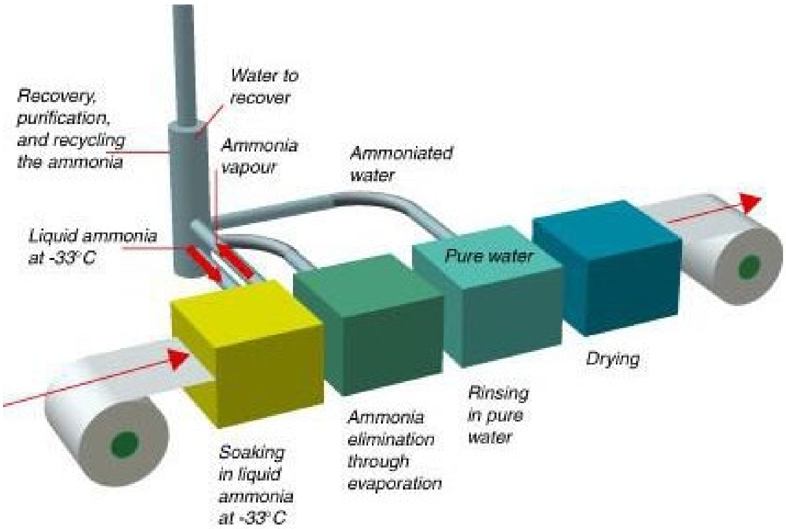

Figure 48 Process for liquid ammonia treatment of textiles (Beau-fixe®). Scheme: Veramtex.[37]

Figure 49 Effect of liquid ammonia treatment on shape stability of hemp tissue. Photo: HOGENT.

Suppliers of hemp textile products

- Ecotex (Roermond, the Netherlands), clothing and fabrics, https://www.ecotex.nl/
- Hempishop (Rijsbergen, the Netherlands), clothing, bags, oil, and food, https://www.hempishop.nl/
- Stoffen.net, fabrics, and knitting yarns, https://www.stoffen.net/
- Ida & Volta (Gentbrugge, Belgium), clothing, https://www.idavolta.eu/
- La Redoute (France), bed and table linen, lampshades, and rugs, https://www.laredoute.be/nl
- Ornament (Gent, Belgium), clothing, hats, and socks, https://ornament-hemp.com/
- Yak & Yeti (Belgium), accessories, https://yakenyetifairwear.be/

7.4.6 More information

- Motiv, 2018. 'Aankoopwegwijzer voor circulair textiel 1 – Module 3B: Doeken uit textiel' (Dutch)
    - Explanation of structure and production techniques of fabrics and knits.
    - https://data.secureserver.be/databases/bedrijven.nsf/webopen/downloads/$file/GDCA3Bdoeken.pdf (36 pages)

[37] https://www.veramtex.com/beaufixe_en_GB.html

7.5 Environmental impact

The many processes required to make textiles affect the environmental impact of textile products. In particular, high-temperature processes, use of chemicals and drying generally have a high environmental impact.

However, environmental impact data as published are often difficult to compare because, for example, the functional unit is not comparable, assumptions made are different, etc.

Publicly accessible information on environmental impact of hemp yarns and textiles:

- Cherret et al, 2005. 'Ecological Footprint and Water Analysis of Cotton, Hemp and Polyester'
  - https://www.sei.org/publications/ecological-footprint-water-analysis-cotton-hemp-polyester/ (at the bottom of the webpage is a link to the report; 45 pages)
- Van Eynde, 2015. 'Comparative Life Cycle Assessment of hemp and cotton fibres used in Chinese textile manufacturing'
  - https://www.scriptiebank.be/sites/default/files/VanEyndeHannes_KUL_Eindwerk.pdf (158 pages)
- Van der Werf & Turunen, 2008. 'The environmental impacts of the production of hemp and flax textile yarn'
  - https://blogs.ubc.ca/ecohealth449/files/2011/01/Hemp-yarn.pdf (10 pages)
- EIHA, 2011. 'Hemp Fibres for Green Products – An assessment of life cycle studies on hemp fibre applications'
  - https://www.votehemp.com/PDF/11-07-07_META-LCA_Hemp_Fibre_Products.pdf (20 pages)

8 Developments

Although hemp fibre is an old crop, there are still a number of developments. Textile recycling in particular requires attention (§8.1). An alternative route for making yarn from hemp is through making viscose (§8.2).

8.1 Recycling

Recycling of textiles is still limited. A small part of clothing is resold in vintage shops and exported abroad. A small part is used in insulation felt and a somewhat larger part is used in cleaning cloths, in total about 12%.[38] More than half of discarded textiles are currently incinerated (with energy recovery).

Increasingly, high-value recycling from textile to textile is being looked at. This is reasonably possible if the textile consists of a single material or group of materials, such as cellulose, polyester, polyamide. These are so called mono-material streams.[39] However, textiles today are mostly made of a mixture of 2 or more different raw materials; for example, cotton-polyester, cotton-elastane, cotton-polyester-elastane; or provided with a coating or other post-treatment agent. High-quality recycling requires the ability to properly separate these different raw materials from textiles. This is greatly complicated by the fact that the different fibre materials in textiles are intimately mixed or have a finish or coating that makes recycling expensive and energy-intensive.

High-quality recycling is desirable partly because demand for cotton exceeds supply. Instead, synthetic fibres are more and more blended in. However, these synthetic fibres are often plastics of fossil origin, difficult to separate as blended fibres and thus not very circular.

Using fibres from one group of materials such as cotton, viscose, flax and hemp enables recycling in 2 ways: mechanical and chemical. In mechanical recycling, fibres are isolated from textiles. With each recycling, the fibres become slightly shorter, reducing the quality of the final product. Hemp fibres (and flax), on the other hand, are on average very long and therefore expected to be recyclable more often.

Several cellulose-based materials (cotton, viscose, bamboo, flax and hemp), also when unsorted, can be chemically recycled into cellulose products such as lyocell or viscose (§8.2).

Good recycling starts with proper design of material, fabric and garment, as well as sorted reuse or disposal policies. And, of course, consumer behaviour is also key.

Infinite recycling is not possible; the quality of the raw material gradually decreases through use and recycling processes. This means that new raw material will always remain necessary, in smaller quantities though. Efficient use of raw materials therefore also requires a long lifetime in the use phase.

Companies active in textile recycling

- SaXcell (Enschede, the Netherlands): Regenerated cellulose from cotton 'waste', https://saxcell.com/
- Spinning Jenny (Nijverdal, the Netherlands): Spinning with recycled fibres, https://spinningjenny.nl/
- Sympany (Utrecht, Netherlands): Collection and recycling of used textiles, https://www.sympany.nl
- Wolkat (Tilburg, the Netherlands): Collection, sorting, recycling, spinning and weaving, https://wolkat.com
- Procotex (Dottignies, Belgium): Mechanical recycling into fibres, https://en.procotex.com/
- Van Riel (Temse, Belgium): Collection, sorting and recycling of 'waste' from spinners, weavers and tufters, https://www.vanrieltemse.be/nl/
- https://www.textielrecycling.nl/over-ons/de-leden/
- Purfi Manufactering (Waregem, Belgium): Collection, sorting, reverse spinning, https://purfi.com/

[38] https://edepot.wur.nl/517183
[39] https://edepot.wur.nl/553932

8.2 Viscose

The most elegant route for making textiles from hemp is using the long fibre, which may be shortened for spinning in combination with wool or cotton. An alternative route is to process the hemp plant in a way that viscose can be made from it. Viscose is the common name, and together with acetate, rayon, modal, supra and lyocell belongs to the family of artificial silks or man-made cellulose fibres.

Viscose is made from cellulose, so far mainly obtained from wood. Hemp has a high cellulose content, which also makes it a suitable raw material for making viscose.

The cellulose is extracted from the plant by pulping, a process somewhat similar to making pulp for paper. In that process, lignin, hemicellulose and pectin are chemically separated from the cellulose and removed from the pulp. The cellulose fibre is then cleaned and bleached (e.g. with enzymes) prior to synthetically spinning into viscose from an acid bath. The viscose fibre can then be processed as a continuous filament or as a short staple fibre (shortened to the length of cotton or wool) into yarn and then textiles. The properties of viscose are well known and widely accepted by consumers in, for example, women's clothing and furnishing fabrics.

The price of viscose is about half that of yarn based on long hemp fibre. That price ratio also applies to the price of pulp relative to hemp fibre. Nevertheless, the route to viscose could potentially be interesting in combination with flower and seed production; with plants that are less suitable for extracting good quality fibres; and when the plants are harvested early or very late. In fact, fibre production is then a by-product of flower/seed production. An advantage is that, unlike for fibre production, the entire stem is pulped to obtain cellulose for viscose. A further advantage of early harvest (for flowers) is that the percentage of lignin is still low, which facilitates pulping.

If hemp fibres have become too short or weak after use and mechanical recycling, the fibre can be a good feedstock for viscose; this is then called 'chemical recycling'.

This route has hardly been developed yet for raw materials other than wood. This is because of the high production volumes in pulping; a pulp mill or a viscose mill has a production volume of at least 100,000 tonnes per year, a multiple of a usual fibre hemp processing plant. Currently, there are only a handful of viscose production mills; a few more plants are expected to be built in the coming years.

Where previously used solvent systems were not very sustainable, a process with solvent reuse in a closed system has been developed and is in use now for several years (Lenzing).

Annex 1 Glossary Dutch-English-French

Dutch	English	French
baal	bale	ballot - balle
bast	bast	liber - la filasse
bleken	bleach	blanchir
bobijnen	wind	bobiner - enrouler sur bobines
breken - braken	breaking	casser
canvas	canvas - duck - tenting	canevas
dauwroten	dew retting	rouissage à la rosée
dikte	thickness	grosseur - épaisseur
droogspinnen	dry spinning	filer à sec
garen - draad	yarn - thread	fil
garendikte	count	titre
hekelen	hackling	
hekelklodden	tow	étoupe
Hekellint - hekelband	line fibre	ruban
hennep	hemp	chanvre
hennepstengel	hemp stem	tige de chanvre
hennepvezel	hemp fibre	fibre de chanvre
inslag	weft	trame
kaarden	carding	cardage
kammen	comb	peigner
keperbinding	twill weave	armure croisé
keren	turning	retournage
kettingboom	warp beam	ensouple de chaîne
kettingbreien	warp knitting	tricot Rachel
kettingscheren	warping	ourdir
kleurechtheid	colour fastness	solidité des couleurs
korte vezels	scutching tow - hackling tow	remorquage teillé - fibres courtes
kreukvrij	non-creasing	infroissables
lont	sliver	mèche
mengen	to blend	mélanger
ontbasten	decorticating	décortiquer
ontgommen	degumming	dégommage - désencollage
oogsten	harvesting	récolter
open-end-spinmachine	rotor spinning frame	métier à filer open-end
oprollen	roll	enroulage
overspoelen	to rewind	rebobiner
pectine	pectin	pectine
platbinding	plain weave	armure toile
reinigen	cleaning	nettoyer
rekveld	drafting zone	zone d'étirage - le champ d'étirage
ringspinmachine	ring spinning frame	métier à filer à annaux
rondbreien	circular knitting	tricotage circulaire
roten	retting	rouir
rotorspinmachine	rotor spinning frame	métier à filer à rotor
rotorspinnen	rotor spinning	filature à rotor
ruwen	to fleece	gratter - pelucher - lainer
scheerrek	beaming creel	cantre d'ourdissage
scheven - lemen	hurds - straws (shives for flax)	pailles - chénevotte
slijten	pulling	arrachage
spinnen	spinning	filager
spinnerij	spinning mill	filature
spinolie	batching oil	huile dénsimage
spinsnelheid	discharge speed	vitesse de déroulement

spoel - bobijn	bobbin	bobine
stapelvezel	staple fibre	fibre de coupe - fibre coupé
sterkmachine	sizing machine	encolleuse
strengverven	to dye rope	teindre en écheveau
stukverven	to dye in piece	teindre en pièce
teelt	culture	culture
torsie	twist - torsion - torque	torsion
ververij	dyeing plant	teinturerie
vlas	flax	le lin
vochtopnemend	moisture absorbant	hydrophile
voorbehandeling	pretreatment	prétraitement
voorgaren	roving yarn - roving	fil de mèche - la mèche
weefgetouw	loom	métier a tisser
weefsel	fabric	tissu
weverij	weaving mill	tissage
in zwad	(oriented) swathes	dans un andain orienté
zengen	to singe	brûler - flamber
zwingelen	scutching	teillage
zwingellijn	scutching turbine (line)	turbine de teillage

To explore the potential of nature to improve the quality of life

Wageningen Food & Biobased Research
Bornse Weilanden 9
6708 WG Wageningen
The Netherlands
E info.wfbr@wur.nl
wur.nl/wfbr

Report 2509

The mission of Wageningen University & Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 7,600 employees (6,700 fte) and 13,100 students and over 150,000 participants to WUR’s Life Long Learning, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.