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Obtaining high quality textile fibre from industrial hemp through organic cultivation

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Att uppnå högkvalitativ textilfiber från hampa genom ekologisk odling

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Abstract

The urgency to find alternative fabrics to conventionally produced cotton is increasing as vast amounts of agrochemicals are used and a lot of irrigation is required. In this literature survey the potential of organic cultivation practices to produce highly qualitative hemp fibre, suitable for the textile industry, was investigated. The definition of a fibre in the textile context as well as of the qualities that are essential for a textile fibre was necessary as a base for the discussion in this thesis. The quality parameters looked at were fineness, strength, length, friction, and colour. The impact of external growth factors and plant development on these quality properties are discussed. No industrial norms for hemp textile fibres are available. However, there are guidelines available, developed for growers and processors to obtain an even and easily processed fibre material, optimized for textile purposes. Although hemp with high quality fibre with showed to be easily cultivated by organic means to, discrepancies in optimal harvest time with respect to fibre quality, and legislated harvest time (being beyond this point in time) puts the grower in a technical dilemma regarding the fibre quality.

Sammanfattning

Det är angeläget att hitta alternativa textilmaterial till konventionellt producerad bomull, eftersom betydande mängder bekämpningsmedel och bevattning krävs där. Inom ramen för denna litteraturstudie undersöktes potentialen för ekologisk odling för att producera högkvalitativ hampafiber avsedd för textilindustrin. Definitionen för vad en fiber är i textilsammanhang, liksom definitioner för de kvaliteter som är nödvändiga för en textil fiber krävdes som bas för diskussionen i uppsatsen. De kvalitetsparametrar som upptogs i diskussionen var finlek, styrka, längd, friktion och färg. De diskuteras både ur perspektivet gällande yttre växtfaktorer och gällande växtens utveckling, som tillsammans påverkar kvalitetsparametrarna. Industriella operativa normer för hampafiber eftersöktes utan framgång. Däremot finns riktlinjer framtagna för odlare och processenheter för att få ett jämnt och lättbearbetat fibermaterial, optimerat för textila ändamål. Trots att hampa visade sig vara lättodlad i ekologisk odling för att producera fiber av hög kvalitet, så gör skillnader i skördetid för optimal fiberkvalitet respektive den lagstiftade skördetiden att odlaren ställs inför ett fibertekniskt dilemma.

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Introduction

The recent focus and rising awareness on global changing climate has lead us to reconsider our consumption patterns – not only in terms of energy and fuel use, but also about how the things we use in our daily life are being produced, and what product is produced in a more sustainable way than its alternatives. This also applies to the food we eat – we may soon see CO_2 emission price tags on the groceries at the mall. More and more people are also taking an interest in the clothes they wear and the impact of their production on nature. Luckily, the world-wide trade with organically grown crops are on a steady increase of about 15 % annually to reach 280 billion SEK during 2007 (Ryegård, 2007). This is thanks to public demand and legislative decisions taken at the levels of our communities, countries and through multilateral cooperation.

In 2006 the Swedish government took a decision on 20 % of the arable land being used for certified organic cultivation by 2010 (Jordbruksdepartementet, 2006). Industrial hemp is a crop well suited for organic cultivation within the EU to meet the EG legislative demands. Hemp is a good multi use alternative crop as it is able to establish quickly in the field and also has a relatively short growing season. Plant protection measures are minimal partly thanks to the speedy growth making it extremely weed competitive, and partly thanks to the introduction of a new plant family, Cannabaceae, in the crop rotation (Jordbruksverket, 2007a). However it is still susceptible to plant diseases (Clarke, 1999). Hemp has also proven to have positive effects on soil structure – one of the preconditions in organic cropping (Jordbruksverket, 2007a).

The multiple uses of industrial hemp provide for a self-evident place on the market. Literally all parts of the plant can be used. The fibre can for instance serve as reinforcement material in automotive construction and furniture industry. Other markets are high quality paper and packaging, as well as the evident use in the making of clothes and cordage. The woody inner fibre of the hemp stalk, the hurd, can be used for animal bedding, bio mass fuel, compost, paints and sealants, furniture, in plastics and polymers and construction products. The seeds produce a nutritious oil which can be used in cooking and the seeds themselves are edible (Robinson, 1996).

However, there are certain restrictions concerning hemp cultivation due to associating hemp with marijuana tetrahydrocannabiol, THC, known as the psychoactive compound in drugs made from marijuana. Only certain bred varieties of hemp containing a low level of THC are allowed in legal cultivation of industrial hemp. Wild growing hemp and hemp for drug production contain 3–20 % of THC (NAIHC, 1997). From a public point of view, what most people first think of when they hear about hemp and *Cannabis* is the use of it as a drug. General opinion often makes growers hesitant to try something new such as hemp despite it being a perfectly sound crop from a modern perspective. The ban to grow hemp in Sweden was revoked only in 2003. Growing industrial hemp within the EU today requires a specific application for a cultivation subsidy and only listed varieties with a THC level below 0.2 % are allowed (Jordbruksverket, 2008). Even the time of harvest is regulated – At harvest the crop must contain more mature than immature seeds, as most pollen will then be shed, thus preventing collection and illegal breeding (Barron et al., 2003). The seeds from an own cultivation are not to be sown. Since 2007 hemp is classified as an energy crop (Jordbruksverket, 2008).

Other limitations with hemp, concerning breeding, is the species being dioecious. Some approved cultivars have been bred from naturally existing monoecious specimens and interbred to produce uniform plants necessary for a reliable and even yield, especially for seed production (Bócsa and Karus, 1998).

Depending on what product (e.g. fruit, oil, fibre) is desired from a plant and what part of the plant is used (e.g. stem, leaves, seeds, root, flowers) different cultivation practices come into play in order to optimize yield and quality. The objective of this literature study was to investigate whether it is possible to obtain a high quality hemp stem fibre according to textile industry standards, with respect to textile quality parameters such as fibre length, fineness, strength, friction and colour by means of organic cultivation practices. The objective was also to see where the possible bottlenecks and difficulties may lie, provided the afore-mentioned production is possible. Focus is put on European preconditions. The questions initially asked were:

- What quality parameters are present for hemp fibre and how are they defined?
- What quality standards are set by the industry for textile use of hemp fibre?
- Which growth stages are crucial in obtaining high quality fibre?

- What growing conditions are optimal to meet these standards and demands?
- Which are the criteria for organic cultivation in Europe and Sweden?
- Can the standards and demands be met through organic cultivation, and what special implementations need consideration?

Materials and Methods

This Bachelor thesis and literature survey is based on information from current and state of the art sources on hemp fibres and organic cultivation. Scientific reports and articles, study reports, books and authority reports were gathered using university linked databases and search engines on the Internet. Sources of Information were also retrieved from my supervisor Bengt Svennerstedt at the Department of Agricultural Biosystems and Technology, Swedish University of Agricultural Sciences (SLU).

Results and Discussion

The hemp plant – Botany, Origin and Classification

Botany

Cannabis sativa shown in figure 1, is an erect annual herb with palmate leaves. It normally reaches a height of up to 5 m during a period of 4–6 months (Bócsa and Karus 1998). Cultivated varieties in Northern and Western Europe usually grow 2.0–3.5 m tall (Bruce *et al*., 2005). The primary root reaches 40–250 cm down and branches out with 60–80 cm long secondary roots. The major part of the root mass is located at a depth of approximately 30–50 cm (Bócsa and Karus, 1998). The flower initiation response occurs when the plant is subjected to short days of less than 12–14 h. Before that the plant grows more vigorous as a response to increasing day length (Clarke, 1999). Hemp's characteristic scent arises from THC exudating glandular trichomes covering the lamina (Bócsa and Karus, 1998).

Figure 1. Left: Industrial cultivation (Wikimedia Commons, 2000). Right: Characteristic leaf of *C. sativa* (Wikimedia Commons, 2008).

The species is dioecious, but monoecious specimens with both sexes on the same plant occur in the wild and are utilised in breeding and cultivation. Just before flowering, the leaf arrangement changes from opposite to alternate (Bócsa and Karus, 1998). Male plants blossom before female plants and the species is wind pollinated. Until flowering is set off, the male and female plants can generally not be distinguished other than by differently exhibited growth patterns (Clarke, 1999). Male plants grow longer and thinner and branch out less than female plants do (Bócsa and Karus, 1998).

Origin

The natural habitat where hemp first evolved is Central Asia. There it was also the first fibre plant to be cultivated. Findings of hemp as a cultural plant in China date back to 12 000 years ago, long before it was known in Europe (Robinson, 1996). Its introduction in Europe may have been about 3500 years ago by nomads and later into Africa by Arab traders (figure 2) (Hillig, 2005). This Northern path of hemp distribution to Europe went from Siberia via the Middle East and into the Mediterranean area. From there it spread all the way to France. The Scythians (Indo-Iranians) who branched off from the Aryans, took it further north into the Baltic area. A later Southern introductory path was made by the Arabs, who brought in hemp from Africa to Spain (Robinson, 1996).

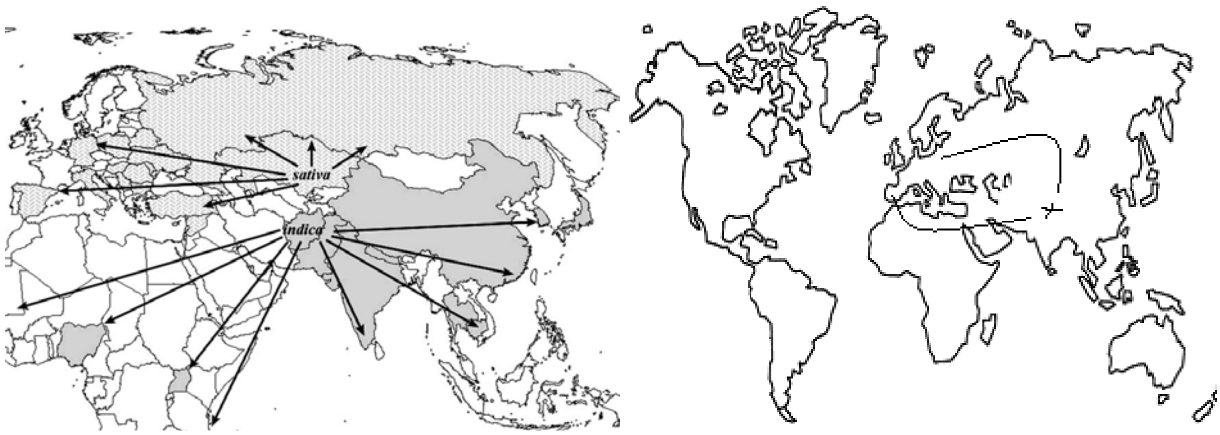

Figure 2. Left: Spreading of *Cannabis indica* and *Cannabis sativa* (Hillig, 2005). Right: Northern and Southern introductory pathways to Europe of *Cannabis sativa* (Robinson, 1996).

Classification

The hemp plant (*Cannabis sativa* L.) was originally classified by Carl von Linné in 1753 (Robinson, 1996) and belongs according to the latest classification to the family *Cannabaceae* consisting of the two genera *Cannabis* and *Humulus* (Bócsa and Karus, 1998). The popular view today as introduced by Serebriakova (1940) holds the opinion that the genus *Cannabis* is separated into the two species *Cannabis indica* (Indian hemp) and *Cannabis sativa* (common hemp) which is supported by genetic evidence from Hillig (2005). The subspecies of *Cannabis sativa* are *Cannabis sativa* ssp. *spontanea* (wild hemp) *Cannabis sativa* ssp. *culta* (cultivated hemp) (Bócsa and Karus, 1998). *Cannabis sativa* ssp. *culta* is then further divided into four geographical races; Northern hemp, Middle-Russian hemp, Southern hemp, and Far Eastern hemp (Hillig, 2005). The Northern type is short and yields a lot of seeds, while the Southern type is taller, more branched and yields more fibre (Osvald, 1959).

Why grow industrial hemp?

Industrial hemp is a versatile crop which can be grown for many purposes; seeds for food and oil, fibre for textiles and insulation, reinforcement in composite materials, and making paper (Robinson, 1996). The shives can also be used for lightweight particleboard in for example furniture and as building material (Svennerstedt, 2003). As a crop in general and fibre crop in particular, hemp has many advantages over other crops. This applies especially to cotton production where vast amounts of irrigation water and agrochemicals are needed. Cotton is also restricted to growing in a sub-tropical climate while hemp thrives in moderate climate and requires less input of water and agrochemicals for high yield which makes it a promising crop in organic farming (Ebskamp, 2002; van der Werf, 2004). Very few insects or diseases pose any major threats to hemp. The quick field establishment and canopy closure of the crop makes it extremely weed competitive, especially when sown at a high density for fibre production (Bennett *et al*., 2006). Provided with the right external conditions hemp does not require much labour from the time of sowing to harvest, according to several interviewed growers. Hemp can easily be introduced in a crop rotation having early and late flowering varieties which are convenient with respect to preceeding or following or other more demanding crops taking advantage of for example hemp’s deep root system which aerates and improves the soil structure. After harvest a lot of the plant and root material can be left and tilled in the field which also minimises loss of valuable nutrients (Barron *et al*., 2003).

Breeding

Genetic background and breeding objectives

Cannabis can be considered as one isolated gene pool. All populations within the genus can intercross, but the genus is reproductively isolated from other genera (de Meijer, 1999), however research by Hillig (2005) proves speciation between *Cannabis sativa* and *Cannabis indica*. While still uncertain, this is probably due to human selection for fibre and seed in the first case and for drug production in the latter case. Selection has mainly affected the fibre content and the presence of THC. The fibre and seed varieties are bred for both high seed and fibre yield, but also a low amount of THC, whereas the drug strains have been bred to contain a high level of THC (Clarke, 1999). During the 1960ies and 70ies the THC content in dried leaves varied between 1% and 3%, but intensive cultivation has given rise to cultivars with up to 6 – 20% THC (Ashton, 2001).

In light of the recent rediscovery of hemp as such a multifaceted and versatile crop there is economic incentive to, apart from breeding for fibre and seed yield, also breed for seed oil yield and resistance to pests and diseases. In order to widen the range of habitats in which hemp can be cultivated, it is also bred for tolerance to salt (Clarke, 1999).

Breeding and varieties

Hemp is mainly bred in Europe for the production of fibres. The objective is to maximise the fibre yield. This can be done in two ways; the stalk yield per area unit can be increased, and the percentage of fibre in the stalk can be increased (Clarke, 1999).

Being able to provide both fibre and seeds it is mainly the female plants which contribute to the products of hemp and this leads us to one of the primary obstacles with breeding – it is a dioecious species and breeding for fibre content must be based on individual plant selection (Clarke, 1999). With the Bredemann method where a male stem is cut lengthways and its fibre content can be determined, only the best plants are allowed to flower and pollinate females. With this method a threefold increase of the fibre content was obtained over a 30 year period (Ranalli, 2004). The other obstacle breeders have had to overcome is hemp being wind pollinated and intercrossing freely meaning that any potential female seed parent must be isolated in order to control pollination (Clarke, 1999).

European breeding for increased fibre content began in the 1920s. During the 1930s the first monoecious plants were described, constituting a foundation for the development of monoecious varieties. The advantage with a monoecious hemp population stand over a dioecious one is the uniformity in growth. The male and female vegetative period difference aggravates harvest and affects fibre quality since the male plants wither and become retted after flowering while still in the field, whereas female plants continue to mature. In the 1950s the countries having a leading role in modern hemp breeding and genetics were the former Soviet Union, Germany, Italy and Hungary. A decade later France started to develop their own varieties. These are now dominating the fields of the EU. Russia has been the most successful country in breeding for a very low THC content (Bócsa, 1999). In 1996, two French cultivars nearly devoid of THC were registered; “Santhica 32” and “Epsilon 68” (de Meijer, 1999). Entirely THC-free cultivars are, however, impossible to obtain since the compound has an important but poorly understood role in plant development (Bócsa and

Karus, 1998). The following varieties are grown for fibre and are legally accepted in the EU for cultivation in 2008 (table 3).

Table 3. EU's list of approved cultivars for the year 2008 (Jordbruksverket, 2008).

Beniko	Epsilon 68	Lipko
Bialobrzeskie	Fasamo	Lovrin 110
Cannacomp	Fedora 17	Red Petiole
Carmagnola	Felina 32	Santhica 23
Chamaeleon	Felina 34	Santhica 27
CS	Ferimon	Silesia
Delta 405	Fibranova	Silvana
Denise	Fibrimon 24	UNIKO-B
Diana	Futura 75	Uso 31
Delta-Llosa	Kompolti hybrid TC	Zenit
Dioica 88	Kompolti	

At times when there has been a shortage of seeds, the direction of breeding has been towards unisexual varieties (solely female plants). By pollinating the female dioecious hemp plant with pollen from a monoecious plant it is possible to obtain a very high rate of female plants (Bócsa and Karus, 1998).

Breeding specifically for high quality fibre is no longer an objective as refined fibre processing techniques are available. However, comparative analyses have shown that male hemp has noticeably better fibre quality characters than female hemp, and dioecious forms are better than monoecious ones (Bócsa, 1999). As many products made of hemp fibre are subject to wear and tear, the emphasis in production is now put on quality traits such as fibre length, fineness, strength, flexibility and friction (Bócsa and Karus, 1998).

What are fibres?

Fibre function and definition

A hemp fibre yarn is shown in figure 4. In botanical terms, fibres are described as long, straight and thin, often occurring in bundles. Bast fibres (extraxylary fibres) are made up from sclerenchyma cells which have thick secondary cell walls that usually become lignified. They have a structure constitution made to support the plant (Mediavilla *et al.*, 2001; Roberts, 2006). Sclerenchyma cells are dead cells with thick lignified secondary cell walls simply blocking any transport of

Figure 4. Industrial hemp fibre yarn (Wikimedia Commons, 2007a).

water and solutes (Amaducci *et al.*, 2005). Figure 5 explains the relationships between different cell and fibre types.

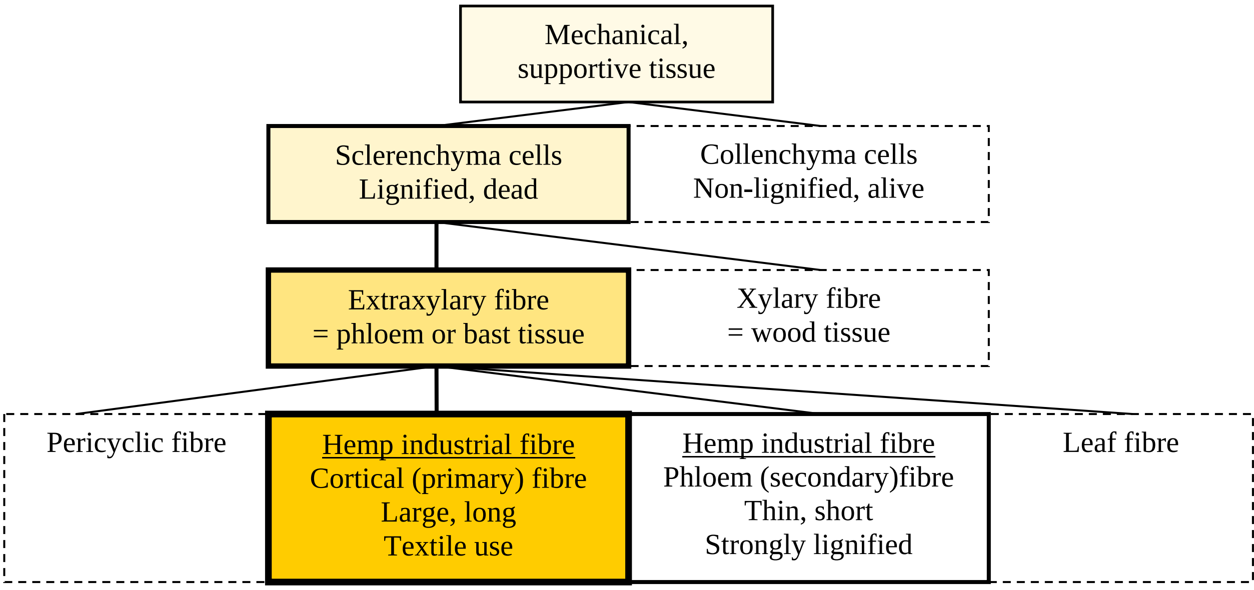

Figure 5. Schematic illustration of the hemp textile fibre origin. Modiefied from Amaducci *et al*., 2005.

The main constituent of plant fibres is cellulose. In primary and secondary cell walls of hemp, cellulose is present in the range of 10–20% and about 50%, respectively. Cotton fibres consist up to 98% of cellulose (Mediavilla *et al*., 2001).

Fibre quality and external growth factors

Textile fibre quality parameters

Historically hemp has mainly been used for coarser textiles. Now, thanks to technical advances in the fibre processing industry, hemp is also used for finer garments. The common opinion about hemp fibres is that they are both strong and long. From a raw material perspective low variation in properties, purity and cleanness are important for a high quality end product (Ranalli 1999). Ranalli (1999) also discusses other quality criteria for hemp fibre and clothing as being subject to wear and tear; brittleness, elasticity, wear resistance, durability, absorbing capacity, thermal and fire resistance. For simplicity however, the focus here is on fibre length, fineness, strength, friction and colour as these are the basic parameters easy to evaluate immediately after extraction. The others will largely be affected by processing and time.

Hemp fibres are relatively long, but the actual cells range from 5–55 mm in length, while the diameter varies between 16 and 50 µm (Ranalli, 1999). The fibres are not round and uniform in shape. Especially young plant fibres are oblong when seen in a transverse section, but they become rounder as they mature. Young plants also produce silk-like, fine-textured, very flexible and thin fibres. Unfortunately these fibres have proven to have poor and uneven quality (Amaducci *et al*., 2005).

There are many ways to define the fibre quality, but the most important parameters when discussing textile use are fibre length, fibre diameter and tensile strength. The length/diameter ratio indicates the fibre strength and thereby its suitability for textile application (Amaducci *et al*., 2005). Textile application requires a thin, fine fibre diameter and a high strength. The finer the fibre, the higher is its considered value. Textile fibres are long, thin and flexible and have a diameter of less than 100 µm while the length is at least 100 times that of the diameter (that is 10 mm). Clothes' fibres should not be thicker than 40 µm or they will feel itchy on the skin, but fibres less than 10 µm may be too weak and break (Östbom, 2007). To describe how the parameters length, strength, diameter and friction need to vary and relate to each other in order to build up a good quality fibre for spinning and textile use, Östbom (2007) used a circle diagram (modified in figure 6). When, for instance, the strength is small the other sections need to be larger and vice versa. For comparison purposes to find out what fibres are suitable for textile application, Östbom also calculated a ratio between strength and diameter (MPa/µm) which should be as high as possible. The standard ratio for flax fibre is 25. Compared to flax, hemp fibres are longer and more coarse (Ranalli, 2001). The ratio does not need to be more than 12.5 for hemp fibre in a blend with cotton (Östbom, 2007).

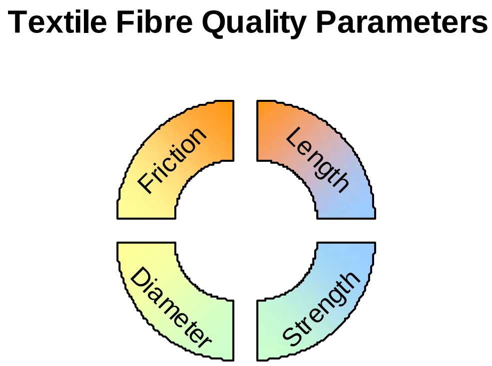

Figure 6. Should one of the textile fibre quality parameters length, strength, diameter or friction be small, the other ones need to be larger in order to constitute an overall good quality fibre. Modified from Östbom (2007).

The quality parameters diameter, shape (transverse section), maturation, and quantity of secondary fibre all vary with factors such as plant density, harvest time, internodes and even within the same plant portion (Amaducci *et al*., 2005). In crowded populations the plant will have limited branching, develop less foliage and the stem will be thin (Clarke, 1999).When looking at a hemp plant, the longer and thinner the stalks are, the higher the fibre content and the better the fibre quality (Bócsa and Karus, 1998).

Quality guidelines

There are no standardised measures for hemp as for flax, but in an EU project, IENICA, guidelines (table 7) have been developed for traders of hemp and flax. Colour, length and diameter are closely related to the retting process. Under-retting will result in too coarse fibres while over-retting makes the fibre weak which leads to fibre loss during the cleaning process. Hemp fibre quality is often judged visually by lustre and colour. High quality fibre is lustrous and "gives a decided snap when broken" (Ranalli, 1999). The IENICA primary class colour standards for retted hemp are steel grey, silver grey, and light grey, whereas for unretted hemp they are light yellow, dark yellow or green yellow. For lower classes of both retted and unretted hemp darker nuances are accepted.

Table 7. Fibre quality parameter guidelines developed within the IENICA project. The colour codes presented above are not true to nature but merely used to illustrate the concept and the differences in colours and nuances. Data obtained from IENICA (2004).

HEMP STRAW		**Retted straw**		**Raw straw**	
Colour	Class 1	Light grey		Light yellow	
		Silver grey		Dark yellow	
		Steel grey		Green yellow	
	Low classes	Dark grey		Light grey	Dark grey
		Green grey		Light green	Dark green
		Brown grey		**Light brown**	
Length	High classes	110-130 cm		110-130 cm	
	Minimum	80 cm		80 cm	
Stem width	Class 1	4-6 mm*	3-6 mm**	4-6 mm	
	2	4-8 mm*	3-8 mm**	4-8 mm	
	3	3-12 mm*	3-12 mm**	3-12 mm	
Retting degree	Class 1	90% of stems*		N/A	
	2	80% of stems*		N/A	
	3	<70% of stems**		N/A	
Health condition	Class 1	>90% of stems		>90% of stems	
	2	>80% of stems		>80% of stems	
	3	>70% of stems		>70% of stems	
Moisture content		<20%***		<20%***	
Impurities content		<15%		<15%	

*clothing textiles **cordage ***wet basis

The desired properties of the straw have been decided in order to provide uniform material for the processing industry. Hemp straw should be at least 80 cm long, but 110–130 cm is required for the higher classes. First class straw should contain no more than 10% unhealthy tissue. The corresponding values for second and third class straw are 20% and 30% respectively. The fibre strength, or tenacity, should be between 27 and 69 centiNewton/tex, which roughly equals 270–690 MPa. The fineness preferred is less than 1.5 tex (which equals 36.9 µm), that is 1.5 g/km of yarn. For blends with cotton and chemical fibres the fibre length should be 25–45 mm whereas in wool blends the length should be 60–120 mm, and the fineness needs to be below 2 tex (49.2 µm). The profitability and price of hemp as a fibre crop can vary by 100% depending on the quality of the fibre (IENICA, 2004).

Climate

Hemp is well adapted to growing in temperate regions with a mild and cool climate but will thrive in a wide range of environmental conditions. Hemp grown to produce fibre is favoured by a humid atmosphere (Ranalli, 1999). Even though originating from Central Asia it has been cultivated all the way from the Equator to the Polar Circle (Haverkort *et al.*, 1999). No cultivars for fibre or seed exist for the tropical or subtropical regions (Clarke, 1999).

Temperature

The base temperature for leaf appearance of hemp is 1^{o}C and 2.5^{o}C for canopy establishment. During spring and the initial stage after germination the seedlings can survive short periods of frost down to -8–-10^{o}C, but older plants only tolerate -5–-6^{o}C (Haverkort *et al*., 1999). Its rapid vegetative growth phase will start after the fifth set of leaves has appeared if the average daily temperature reaches 16^{o}C, approximately 35 days after germination. Under these conditions its height can increase up to 6–10 cm/day (Bócsa and Karus, 1998). Optimal growth is reached on sunny days with temperatures between 19 and 25^{o}C (Bócsa and Karus, 1998), but hemp grows well also within a range of 14–27^{o}C (Barron *et al*., 2003). From germination to technical maturity, that is the full flowering of male plants, fibre hemp requires 1900–2000 growth degree days, GDD. GDD represents the accumulated average day temperature (Bócsa and Karus, 1998).

Water

Being a highly productive crop, hemp requires 300–500 l of water per produced kg of dry matter. A total of 500–700 mm of precipitation is needed for the whole season and 250–300 mm of water during the vegetative growth phase. The precipitation in June and July is of particular importance as it strongly influences the yield (Bócsa and Karus, 1998). During the first six weeks there is need for ample supply of water as the roots are still near the surface of the soil. As they grow deeper the hemp plant will tolerate drought better (Barron *et al*., 2003).

It is important to prepare the soil well in order to satisfy the water requirement but as little as one or two days of flooding can be detrimental to a population (Bócsa and Karus, 1998). Heavy rain, hail or wind will however not cause much damage to a hemp crop if it is sown at a high density (Ranalli, 1999).

Light

As reported by Ranalli (1999) the stem yield of hemp can be limited by an early flowering date, and as hemp is a short day plant its flowering date is the first criterion to consider when choosing an appropriate cultivar for optimal fibre production, the ideal being that no flowering occurs before harvest. Long days, as in Northern Europe, will delay flowering but even in tests where the day length was set to 24 h flowering was not totally prevented.

Hemp needs good light conditions and the total amount of light will affect the fibre quality to a larger extent than it will affect the yield (Bócsa and Karus, 1998). Many other spring crops will suffer from lack of light due to slow growth of their canopy, but this is a minor problem for hemp as it is able to grow and establish fairly well even at low temperatures (2.5 ^{o}C for canopy establishment) (Haverkort *et al.*, 1999).

Soil

As expressed by Bócsa and Karus (1998), suitable fibre hemp soils are those that can give a potential yield of 10 000 kg dry matter/ha, that is the soil needs to have good water permeability, be well-drained, and aerated. It also needs to have high potential for accumulating nutrients. Such soils should be rich in organic matter as for example degraded black soils, brown redzina soils and brown steppe soils. These soils potentially yield 6 000–9 500 kg/ha. Marshy soils that retain too much water will influence the tensile strength of the fibre negatively (Bócsa and Karus, 1998). Being a fibrous plant, hemp is better than many other agricultural crops at extracting heavy metals from the soil, which is why it is known for its soil remediating properties (Ranalli, 1999). The pH level of the soil should be between 5.8 and 6.0 (Bócsa and Karus, 1998), but a pH above 6 is also acceptable (Barron *et al.*, 2003).

Nutrients

Hemp has relatively low fertiliser demands apart from a high nitrogen, N, requirement, especially during its rapid vegetative growth phase. If the soil is not in good condition, the crop will benefit from added N. According to Ranalli (1999), European experiments showed that optimal growth and a yield of 15 000 kg dry matter/ha was obtained after application of

175 kg mineral N/ha. Excess N may however lead to a large stalk, thin bark and reduced fibre quality and content (Bócsa and Karus, 1998), lodging (Barron *et al*., 2003), leafy succulent growth and a stem diameter too wide (Ranalli, 1999). It is important to adjust the amount of fertilisation to the soil type and its condition. In organic cropping it is also pivotal to calculate the amount of added N from an applied total amount of manure, since mineral fertilisers are not allowed. Per m^2, 3–5 kg of organic matter can, according to Barron *et al*. (2003), cope with hemp's high N supply requirements. Recommendations in Hungary are that half the needed amount is applied in the field after harvest of the previous crop and before the sowing of the hemp, and the other half is applied in the spring (Bócsa and Karus, 1998). For compost and natural minerals the amount of the different nutrients are highly variable depending on the components, but the percentage by weight in swine manure for example are N: 6.48 %, P_2O_5: 9 %, K_2O: 9 %, Mg: 8 %, and Ca: 2 % (Zublena *et al*., 1997).

Phosphorous, (P), and potassium, (K), are also well-needed macronutrients. The P requirement is not high, around 50–70 kg/ha, but is important with regards to some fibre quality traits – elasticity and strength – which is why the nutrient soil availability is of high significance (Bócsa and Karus, 1998; Barron *et al*., 2003). The requirement of P increases continually throughout the vegetative phase to reach a maximum in June and July during fibre development. It is important that P is applied such that it remains in the layers of soil where the most roots are present. K affects the fibre quality more than P does. It is normally recommended that K is applied in the form of KSO_4, potassium sulphate, because the chloride, Cl^-, ions in potassium chloride, KCl_2, are detrimental to fibre development. Calcium, Ca, and magnesium, Mg, are normally applied to a crop rotation as a whole and to keep the soil in good condition (Bócsa and Karus, 1998). Thanks to a lot of the hemp foliage and some part of the stem being left in the field after harvest and retting, a considerable amount of the nutrients can be returned and reincorporated into the soil. According to Barron *et al.* (2003) this amounts to two thirds of the N, Mg and Ca applied, half the amount of K, and one third of the P.

Growth cycle

Germination

A complete life cycle from germination via leaf and fibre formation, vegetative growth, leaf transformation, and flowering, to mature seeds normally takes 4–6 months but may be as short as 2 months or as long as 10 months. Approximate growth phases are shown below in figure 8. The seeds are sown outdoors in the springtime and germinate after three to seven days (Clarke, 1999). Computer models made to fit north-western Europe show that at a density of 64 plants per m^2, plant emergence occurs after 16 days when sown in mid March, after 11 days when sown in mid April and after 7 days when sown in mid May. To maximise the perception of photosynthetically active radiation (PAR) hemp is favoured by an early sowing date as it grows well even at low temperatures, but the risk of frost damage must also be taken into account (Haverkort *et al*., 1999).

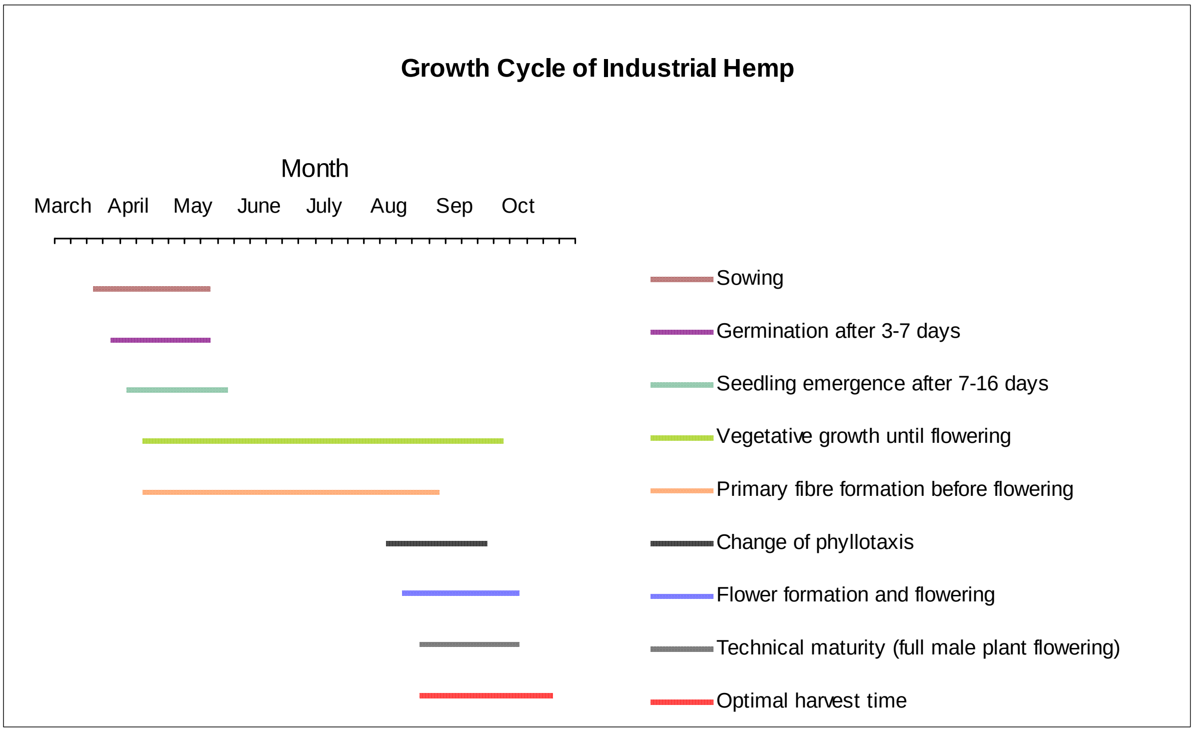

Figure 8. The different phases and events in the growth cycle of industrial hemp. Germination and emergence occur 3–7 days and 7–16 days after sowing, respectively, depending on time of sowing. Vegetative growth is vigorous during the first 2–3 months, and primary fibres for textile use are formed. Technical maturity and optimal harvest time occurs around the peak of flowering before too stem lignification begins and too much of secondary fibres are formed. Adapted from Keller *et al*. (2001) and Mediavilla *et al*. (2001).

Vegetative growth

Approximately 10 cm above the cotyledons the first true leaves appear. Initially there will only be one leaflet per leaf. As the plant grows, the number of leaflets will increase to eventually reach a number of up to 13 leaflets (Bócsa and Karus, 1998). The environmental influences on the growth habit are strong. During the first 2–3 months the vegetative growth will be vigorous as a response to increasing day length (Clarke, 1999). On long summer days the growth is rapid, up to 6–10 cm/day. Under optimal conditions – that is good light availability, a well-drained soil and plenty of nutrients and water – the hemp plant grows tall and branches extensively. In a normal growth cycle of 4–6 months it can grow 5 m tall (Bócsa and Karus, 1998). However, when given poor amounts of nutrition and little water the foliage will be minimal and a plant can flower and give seeds when it is only 20 cm tall. The sowing density of plants also has a profound effect on the morphology. In crowded populations (figure 9), such as when cultivated for fibre, the plant will branch less, develop less foliage and the stem will be thinner than the stem of a plant given more space (Clarke, 1999).

Figure 9. Left: Densely planted stand of industrial hemp. Middle: Young hemp plant (Wikimedia commons, 2007b). Right: Field after harvest. Left and right photos: Elin Bengtsson.

Fibre formation

The fibre (figure 10) for textile use is the primary fibre originating from the pericycle between the phloem and the cortex (Amaducci *et al*., 2005). Primary fibres are formed and filled during vegetative growth before flowering (Mediavilla *et al*., 2001). They are formed by the apical meristem and the number of elementary fibres remains constant throughout one internode and its vegetative phase. Along with internode elongation these sclerenchyma cells and fibres will elongate. Immediately after elongation has ceased, formation of secondary fibre (Amaducci *et al*., 2005) and cell wall lignin polymerisation take place which both harden the stem (Mediavilla *et al*., 2001). During flower formation, when sowing ‘Kompolti’ at a density of 60 kg/ha and 170 plants per m^2 after some thinning (a typical density for fibre production in central Europe), Mediavilla *et al.* (2001) found the increase in fibre yield to be most pronounced on the lower third of the stem, where 54 % of the fibre was located. It was discovered in Hungary in the 1960s that there was a strong negative correlation between the fibre content and the fibre quality. A 1 % increase in fibre content led to a reduction of the fibre fineness that is the fibres were thinner because the increase in total fibre content was due to an increase of the secondary fibres (Bócsa, 1999). At the end of flowering, when technical maturity (full flowering of male plants) was reached, both maximum stem yield and bark yield was obtained by due to an increase in the production of secondary fibre Mediavilla *et al*. (2001). Amaducci *et al*. (2005) found this to be coupled with the lignification of the secondary fibres. At this point the bark quality may decrease as secondary fibre is not wanted.

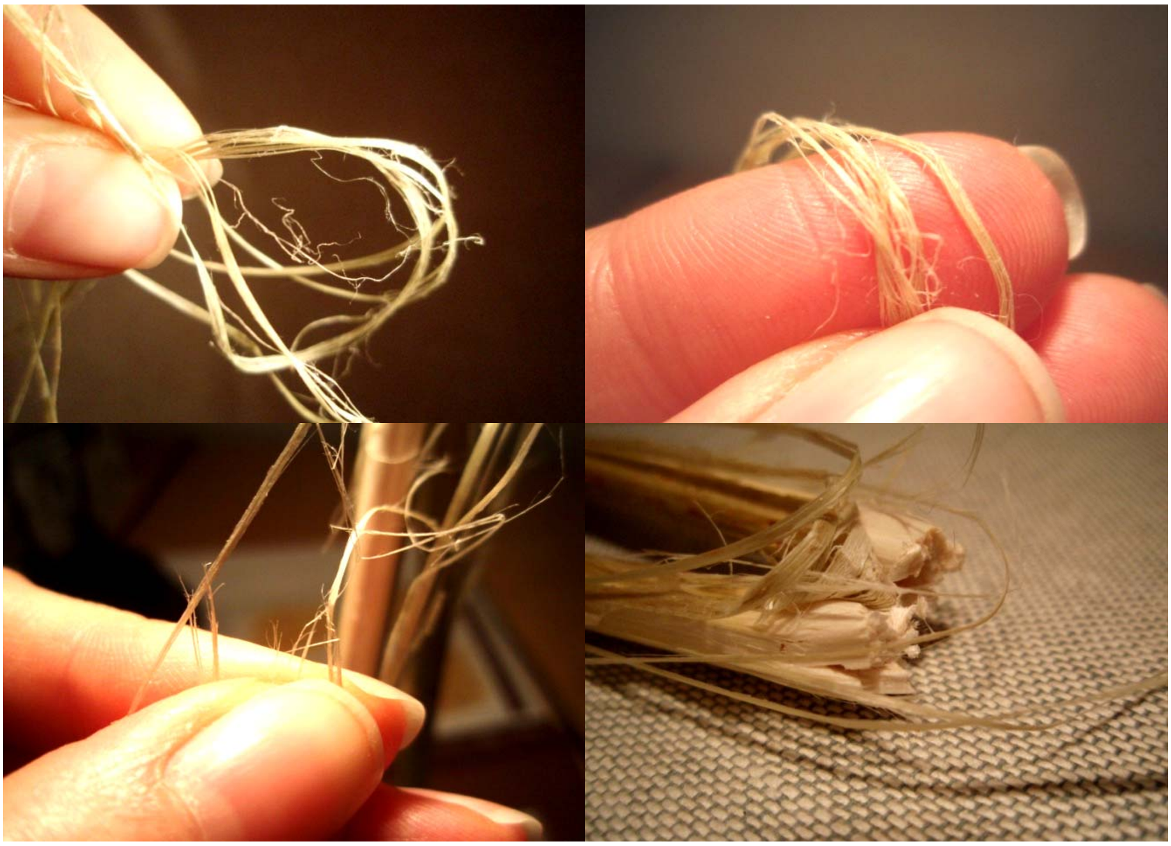

Figure 10. Upper right and upper left: Unretted and partly separated raw industrial hemp fibres directly off the stem. Lower left: Thin fibre ends. Lower right: Broken off stem with epidermis and fibres. Photo: Elin Bengtsson.

Flowering

For flowering, hemp requires short days of 12–14 hours depending on strain, cultivar, and its latitudinal origin. Just before flowering the leaf arrangement changes from opposite decussate to alternate and remains so throughout the growth cycle. Also the size and number of leaflets per leaf decreases until there is only one small leaflet under each pair of flowers. Male plants have a more rapid leaf transformation than female plants, and they also increase faster in height during vegetative growth than female plants. Apart from that, it is difficult to distinguish between the sexes before flowering (Clarke, 1999).

Male flowers hang in long branched clusters while the female flowers and situated two by two in the axils of the leaves on the central stem. Hemp is anemophilous, wind pollinated, and after the pollen is shed the male plant dies. The female plant may continue to mature up to 5 months if pollination is sparse (Clarke, 1999). Early flowering cultivars such as the French and Hungarian ones flower in August. During the following weeks in September stem growth is slowed down and eventually stops, making this the optimal time for harvest of these cultivars. Later flowering cultivars will also continue to have stem growth for a longer period of time (Haverkort *et al.*, 1999). Seeds are mature 3–6 weeks after pollination and drop to the ground if not collected. Fresh seed viability is nearly 100 % but it quickly decreases with age. After 3–5 years of storage at room temperature seed viability will have declined to 50 % (Clarke, 1999).

Optimal harvest time

There are various methods used in helping to determine harvest time. Some growers go by calendar date, some by stem colour, and others by drop of internode leaves or crop growing stage. Deciding when to harvest is crucial in obtaining both high fibre yield and optimal quality (Bócsa and Karus, 1998). Lignin plays an important role in the plant defence mechanism against pathogens, but with respect to retting it is difficult to digest both chemically and enzymatically. In order to obtain high quality fibre it is important to find a harvest date where the amount of lignin is as small as possible. Mediavilla *et al*. (2001) found the optimal harvest time with respect to lignin to be during the vegetative phase just before flowering. The dilemma is that a harvest at this time is prohibited by law. At least 10 days need to pass after flowering or alternatively the seeds must be mature (Jordbruksverket, 2008). This is to prevent the grower from collecting pollen for breeding purposes. However, investigating optimal harvest time of unretted hemp, Keller *et al*. (2001) concluded that harvest in the beginning of seed maturity was optimal for easy separation of fibres from shives and bark.

Organic hemp cultivation

Organic practices and applications

During the last few decades when hemp has been grown in Eastern European countries, it has been cultivated just like any other crop, in a conventional manner (Bócsa and Karus, 1998). There, custom practice has been to use chemical defoliation before harvest as the foliage takes up too much space when baling and also provides excellent breeding ground for bacteria during the customary water retting process which was never really adopted by Western Europe where instead field retting was employed. Due to cutting the stems in 50-60 cm long pieces without chemical defoliation, field retting is made quicker and easier (McPartland, 1999). The interest for organic cultivation practices arose in Eastern Europe only after the demand for organic hemp increased in Western Europe. In France, England, Germany, and the Netherlands hemp plantations are rarely chemically treated. The costs are normally higher than what the return is for the increase in yield after treatment, making it unnecessary. Also, a higher market value is obtained from uncontaminated material (Bócsa and Karus, 1998).

In conventional growing systems where synthetic fertilisers and agrochemicals are used many of the threats of soil nutrient depletion, weeds, pests, and diseases are easily overcome. But on an organic farm where synthetic substances are not allowed, these threats are very much the reality and other forms of control need to be employed (Barron *et al*., 2003).

When deciding to grow organically the first aspect normally considered is the crop rotation. Sustainable crop rotations as seen from an organic viewpoint take things such as location and climate into consideration. Fibre hemp has been unanimously recommended to follow a grass or legume based ley and to precede cereals (Barron *et al*., 2003; Bócsa and Karus, 1998). The medium to high N levels required by hemp is partly provided by the ley which normally is clover or some other leguminous crop (Barron *et al*., 2003). An additional 80–120 kg of N/ha in the form of liquid manure and dung from stables, make up for the rest. In fact, this is perfect for hemp which prefers the nutrients being released gradually (Bócsa and Karus, 1998). Since good crop rotations alter between nutrient demanding and nutrient replenishing crops, hemp's relatively high demand with respect to giving and taking might be considered as less advantageous. An outbalancing factor though, is that hemp also provides a high biomass return from roots, leaves and stubble residues after harvesting. From the leaves and stem left in the field after harvest, 20–25 % of the removed nutrient amount can be returned for nitrogen, phosphorous, potassium, magnesium and calcium (Barron *et al*., 2003). In addition, the up to 2 m long and deep-penetrating roots have a beneficial impact on the soil structure, improving both the aeration and water balance. Hemp also contributes to a reduced risk of nitrogen leakage and eutrophication, as this is prevented when residual nitrogen is taken up by the roots from the deeper soil layers. Apart from building soil structural stability and fertility, the crop rotation also includes the improvement of biological activity with a thriving soil fauna (Barron *et al*., 2003; Bócsa and Karus 1998). There have been many reports on increased yields in winter wheat preceded by hemp (Bócsa and Karus, 1998).

Weeds are seldom a problem in fibre hemp plantations. This is primarily due to two factors. The first one is that hemp for fibre use is sown densely, leaving little space for weeds to establish. The second is that hemp itself establishes and grows very quickly, and those few weeds that have emerged are soon shaded by hemp as its canopy closes. Most weeds will never mature under these conditions, which is why hemp serves as a truly remarkable weed break and no herbicides are required. This is highly favourable in organic as well as conventional cropping systems. Noteworthy is also that hemp is extremely sensitive to herbicides and herbicidal residues – something the conventional grower needs to consider when sketching the crop rotational scheme (Bócsa and Karus, 1998).

In Germany, tests on hemp textiles are regularly carried out by control agencies to make sure there are no harmful substance residues. Standards are normally set to match cotton, flax and wool. Hemp plantations are however commonly treated with pesticides for cotton, thus easily detected. Although testing negative, the lack of detection does not prove pesticide-free cultivation. The hemp fibres are far from as exposed as cotton fibres. Firstly, the fibres are well hidden within the bark and never directly subjected to anything sprayed onto the plant. Secondly, hemp fibres have a supportive rather than transportive function in the plant and therefore they do not absorb pesticides (Bócsa and Karus, 1998).

The hemp qualitative traits as an organically grown crop are even more extensive than previously mentioned. It has low susceptibility to diseases and pests and is fairly tolerant to the most common ones when attacked or infested (Barron *et al*., 2003), or as McPartland (1999) puts it "Hemp is pest tolerant, not pest-free" as many seem to believe. The low frequency of fields nearby with closely related crops where pest and disease could linger and spread is one of the reasons behind hemp's low susceptibility to these. During all growth stages hemp is a low-maintenance crop. What do require some effort are the harvesting and retting processes. Coming from a family previously unintroduced in the crop rotation, hemp also favours biodiversity on the larger scale. Barron *et al*. (2003) point out that in organic farming systems profit is not always the self-evident and primary objective. Measuring all the advantages with this cropping system in economical terms is not feasible, nor desirable. However, considering hemp being a short cycle crop it provides good return.

Keeping a holistic view, McPartland (1999) sheds light over the outlook and interchangeability of hemp as a crop grown for textile purposes. "The substitution of cotton with hemp in the textile industry would lead to considerable ecological advantages during the cultivation and harvesting stages. The reduction in primary energy consumption and emissions would be about three times per each ton of fibre."

As noted earlier, hemp is not pest free. In fact, many diseases and pests find hemp an attractive crop, but the damage is often limited and does only rarely cause severe yield losses. Since fibre hemp grows in dense plantations and canopy closure occurs early, insects are attracted to the protective environment. High humidity also predisposes stalks and leaves to fungal diseases. So far, more than 300 insect species attacking hemp are described in the literature (McPartland, 1999).

Plant threats and protection

There is a plethora of leaf damaging insects infesting hemp; caterpillars, leaf miners, aphids, whiteflies, leafhoppers, mealy bugs, scales and thrips (McPartland, 1999). The insects attacking hemp may be many, but few are a serious threat. The hemp flea beetle (*Psylliodes attenuata* Koch) occurs primarily in Eastern Europe. The larvae feed on the cotyledons and the hypocotyl, and later on on developed leaves so that the plant growth rate is slowed down. The hemp borer (*Grapholita delineana*) feeds as a larva on top leaves. After pupation the larvae feed from the cavity of the stem and the more tender parts. The fibres from infested plants do not meet industry standards and the fibre yield is also lower. The European corn borer (*Ostrinia nubilalis*) affects primarily eastern and south-eastern Europe. Its caterpillars make holes in the stem causing them to break in the wind (Bócsa and Karus, 1998).

The biocontrol methods for insect pests are mainly other predatory insects or parasitoids. *Trichogramma* wasps are parasitoids which have been used successfully against the European hemp borer. To the grower's discontent they are not limited to stay within the boundaries of the field. Fortunately there are alternative options, for instance microbial pesticides with bacteria, viruses, protozoans, or nematodes. *Bacillus thuringiensis* is a favourite against caterpillars, beetle larvae and maggots. The Nuclear polyhedrosis virus is sometimes used towards caterpillars and borers. These microbial pesticides are easily mixed with water and sprayed onto the foliage. They are also specific and the only drawback is they need to be ingested by the pest to work which means they do not affect insects with sucking mouthparts. Those insects will instead be combated by the application of fungi. Other measures of control are soap and oil which suffocate small insects. Organically approved plant derived pesticides are also on the market (McPartland, 1999).

In addition a number of colourful leaf spots occur on hemp; white, black, brown, yellow and olive leaf spots. Mildews occur in the forms downy, powdery, and black mildew (McPartland, 1999). Hemp rust (*Melampsora cannabina*) attacks the fibre in the plant. A thiocarbamate solution can be applied in conventional cultivation, but its high aqueous toxicity renders it unsuitable for sites with erosion or runoff (Bócsa and Karus, 1998). Fungal attacks easily occur after pest infestations but are rare as epidemics. Grey mould (*Botrytis cinerea*) particularly occurs on hemp in Western Europe where humidity and temperatures are high (McPartland, 1999). The plants break and fall over. During field retting stalks can be attacked if subjected to recurrent rainfall. A good crop rotation and resistance breeding serve as the two best control methods since the cost of fungicides does far from compensating for the relatively higher price of organic hemp. *Pythium debaryanum* thrives in wet and poorly aerated soils. It will attack seeds and sprouting plants and cause plantlets to topple over, but is easily prevented if the field water balance is improved. Hemp canker (*Sclerotinia sclerotiorum*) grows under the same preconditions as *Pythium* but attacks the roots, causing the plant to dry out and die (Bócsa and Karus, 1998).

Many types of nematodes occur on hemp. Although there is no successful treatment, resistant plant varieties are available (Bócsa and Karus, 1998).

The only weed of importance is a root parasitic plant, broomrape (*Orobanche ramosa*), but it only appears in hemp seed plantations with Chinese varieties, and there are resistant varieties available (Bócsa and Karus, 1998). Hemp can also be infected with bacteria or viruses, but biocontrol is less efficient against these disease organisms and fungi.

Preventative measures

Preventative cultural and mechanical control usually has good effect, making the environment unfavourable for pathogen and pest survival. This includes tillage, destruction of infested crop residues, and maintaining a good water and nutritional balance throughout the growing season. The use of resistant varieties and keeping a good crop rotation are key factors to keeping the plantation devoid of pest organisms. Curative methods such as steam sterilisation of the soil can be used against nematodes. The approach with sex pheromone insect traps has been successful against both European hemp borer and hemp borer moths (McPartland, 1999).

Postharvest

Retting

Release of the hemp bast fibres from the stem is done by separation of them from the woody core, to which they are attached by pectin, a glue-like substance made up from galacturonic acid units. The chain of postharvest processes to attain high quality hemp fibre normally begins with retting, but fibre separation can also be done mechanically with unretted stalks (Östbom, 2007).

Retting is a natural degrading process where the pectic substances holding the fibres in place are subjected to and broken down by fungi, bacteria or enzymes (Ranalli, 1999). Without retting, there can be significant fibre loss during the subsequent refinement processes (Bócsa and Karus, 1998).

Water retting is a method where stalk bundles are submerged in water. Normally the bundles are placed in streams, tanks or ponds and left for about 10 days (Ranalli, 1999). Warm water of 30–34^{o}C shortens the process to 4 days (Osvald, 1959). The water becomes highly rich in bacteria degrading the pectin. From an ecological point of view this type of retting is not a sustainable method as it uses vast amounts of water and also leaves the water deficit of oxygen and with a high concentration of bacteria that risk polluting the environment (Ranalli, 1999). However, when comparing this retting process with other types, Östbom (2007) found that water retting gave the best fibre quality when visually determining the quality parameters length, colour and smoothness. But water retting also seemed to have a more pronounced thinning effect on the diameter of the fibres, than did field retting.

Dew- or field retting usually takes about 2–3 weeks and is completed when the hemp fibres are easily separated from the bark when the stem is bent. The hemp stalks are simply left in thin piles in the field after harvest for exposure to rain and dew (Bócsa and Karus, 1998). For uniform retting they are turned over once or twice. Preferably the crop should be homogenous with regard to height and stem thickness too (Ranalli, 1999). Both field and water retting traditionally require a lot of manual work (Keller *et al.*, 2001). Winter retting is taking advantage of the natural fluctuations of temperature and humidity over the course of the entire winter. The harvest is not done until springtime and the result is easy-to-handle already dried and separated stalks (Östbom, 2007). In some cases herbicides are applied to the crop which is left to dry standing. This method called stand retting takes longer than dew retting since there is no contact with the soil to provide any moisture (Barron *et al.*, 2003). Enzymatic retting is also commonly performed in tanks with the addition of pectin degrading enzymes into the water (Östbom, 2007). According to Barron *et al.* (2003) it is an environmentally friendly method which gives good quality fibre which is strong yet fine. Ultrasonic retting and steam explosion are physical methods used to minimise the fibre damage. These however, together with chemical retting processes, have high chemical and energy input and are costly (Keller *et al.,* 2001).

Drying is important to halt the retting process (Ranalli, 1999). Over-retting adversely affects fibre thickness and leads to discolouration of the fibres which turn dark grey or brown (Östbom, 2007). Under-retting where the humidity is not sufficient can also lead to reduced fibre quality (Barron *et al.*, 2003).

Unretted dry green hemp stalks can be decorticated mechanically without any profound effect on the tensile fibre strength if harvested at the right time. An optimal harvest time at the beginning of seed maturity was determined for the variety ‘Kompolti’ by Keller *et al.* (2001). Fibres from unretted hemp stalks become cheaper since the handling time is shorter. They also contain a lower degree of microorganisms and do not require bleaching, which is more environmentally safe (Östbom, 2007).

Fibre separation

Once retting is completed and the stalks are properly dried, the fibres need to be separated. The process is mechanised and the stalks are passed between rollers which break the stems. Thereafter the fibres are separated from the woody core. This procedure is called scutching and can be done either by beating the stalks, or by passing the stems trough blades rotating parallel to the fibres. The blades cut close to the fibres and the shives and short fibres are discarded. The final element before the fibre can be spun, is combing or “hanckling” it to further parallelise the fibres. After this treatment the fibres are soft and shiny and ready for spinning (Ranalli, 2001).

Cottonisation

Cottonisation of coarse and very long hemp fibres can be done to make them attain quality characteristics similar to that of cotton. Shorter hemp fibres are obtained from splitting up the long tow gained in the regular fibre separating process. This is for the most part necessary when the fibre is intended for garment textile use. The process makes the fibres soft and adaptable to be combined with other short fibres and spun on cotton spinning machines (Östbom, 2007).

Legislation and related authorities

Legislation regarding organic cultivation

The Nordic definition of organic farming was passed by the Nordic department of the International Federation of Organic Agriculture Movements (IFOAM) in 1989. IFOAM is an international umbrella organisation with around 700 member organisations and institutes. One of its main tasks is to facilitate for producers consumers and intermediaries by setting up uniform regulations regarding production, processing and trade (Sandskär, 2005). IFOAM's definition of organic farming is described here. Organic farming regards a self supporting, sustainable agro-ecosystem in balance. The system is based, as far as possible, on local and renewable resources. A key difference between organic and conventional farming is the view on purchased means for production. For the conventional grower the only aspects of importance are the business administrative and economical aspects, whereas the organic grower has the limitation to base his cultivation on the prerequisites of the location. This limitation means there is strong incentive for the organic grower to minimise nutrient losses where they can be influenced (Jordbruksverket, 2007b).

For member countries of the EU, the council's regulations serve as the basis for organic production, but countries and organisations are allowed to have further restricted arrangements (Sandskär, 2005). The EU regulations comprise production, processing, storage and import of organically manufactured agricultural products and foodstuffs. There are also regulations about the control, labelling, and marketing of organic products (Jordbruksverket, 2007a).

The EU has a set of requirements which must be met by any organic grower. Firstly, the cultivation must be carried out within a varied and balanced crop rotation. The soil fertility and biological activity also need to be sustained or improved by one or several measures comprising cultivation of leguminous leys, green manure or plants with a deep root system. Tillage of the soil with the addition of organic material derived from an organic farm, or addition of manure and other by-products from organic husbandry will also enhance the soil quality (Jordbruksverket, 2007a).

In Sweden, the Swedish Board of Agriculture, Jordbruksverket, is the authority with the overall responsibility for organic production and handling. There are also two control organs, KRAV and SMAK performing the actual control on the farms and certifying the produce as organic. These are both authorised by IFOAM as control organs, and KRAV's regulations are based on those set by IFOAM (Sandskär, 2005).

There are a number of regulations to follow as an organic grower. To begin with, there must pass a certain amount of time between growing as a conventional farmer and growing as an organic farmer. When it concerns annual plants, such as hemp in this case, this period is 2 years. Until 2 years have passed the produce can be neither labelled nor marketed as organic. Genetically modified organisms (GMOs) are totally prohibited, as well as any products derived from GMOs. Even seeds need to come from plants which have been grown organically for at least one generation (Jordbruksverket, 2007a).

For plant protection purposes one or several steps have to be taken into action to prevent the crop from being damaged by pests, diseases or weeds. Again the crop rotation and the order of the crops are central issues as well as choosing appropriate species and varieties. Mechanical processing, flaming of the soil surface, and use of traps and capture bars serve as good preventative measures. It is also essential to favour or sometimes even plant out the natural enemies of the pests. Occasionally, these methods will not suffice and the need for curative methods may arise. In the "EU regulations for organic cultivation" booklet there is a list of products with their active substance given. These may be used in exceptional cases (Jordbruksverket, 2007a).

Another list which may become of use is their list of manure and soil improving products in case the basic measures do not make the soil fertile enough. Each product is accompanied by preconditions. For example; the need has to be confirmed by the organ controlling the organic cultivation. Potassium salt (KSO_4) and raw phosphates are two examples of additive nutrients on the list (Jordbruksverket, 2007a).

Legislation regarding hemp cultivation

A decision is taken annually as to which varieties of industrial hemp are allowed within the EU. The criterion for being on the list is that the level of THC must never exceed 0.2 % of the weight in any test, or else the variety will be discarded from the list of approved ones.

When it comes to growing industrial hemp in Sweden it is mandatory to apply for a financial support, “gårdsstöd”. If this is not done, the cultivation will be considered illegal for narcotic purposes. However, in order to actually receive the financial support, several criteria must be fulfilled.

- The variety has to be on the list of approved varieties, and the cultivation field needs to be within the borders of Sweden.
- Hemp seeds need to be certified and sown solely.
- The label from the seed package needs to be sent in to the Swedish Board of Agriculture before a specific date.
- Harvest must be carried out at earliest after seed maturation or 10 days after flowering has ended.
- Also, some special preconditions need to be fulfilled, “tvärvillkoren”.
    - All agricultural land must be managed in an environmentally friendly way to preserve the land in good condition.
    - Swedish legislation aiming at achieving positive effects on environment, human health, and plant and animal protection must be followed (Jordbruksverket, 2008).

The time of harvest regulated at the EU level (earliest 10 days after the end of flowering) sometimes poses a problem to the farmer. To ensure pollen is not collected at harvest for illegal breeding purposes, there need to be more mature than immature seeds. But stem growth is completed already at the time of seed production. Later harvest will cause stems to be more lignified than what is optimal for the decortication and following fibre separation processes. It may also hinder the farmer from sowing the subsequent crop at an adequate time (Barron *et al.*, 2003).

Conclusion

Obtaining a good quality hemp fibre for the textile industry by organic means requires good planning all the way from choosing the right cultivar to the postharvest processing of the fibre. This includes deciding on location, practices throughout the cultivation period, being up to date with the plant stand development, harvesting at the very right moment and finally choosing an appropriate retting method, all in order to produce a fibre with the desired characteristics.

Despite all advice given, hemp is a low maintenance crop easily cultivated for textile fibre production in an organic way. The major problem is being unable to harvest at a time when the primary fibre quality is at its best and the decortication processes does not negatively influence the fibre quality. However, thanks to postharvest retting techniques and processing a lot can be done to make the fibre soft and applicable for use in garments.

Although no official standards are set by the textile industry for hemp fibres as those for flax, there are guidelines provided by the IENICA project. When looking at the textile fibre quality parameters length and diameter, the desired values are >10 mm and <100 µm. Fine fibres are highly valued. The hemp natural fibre diameter varies between 16 and 50 µm, but since fibre suitable for garments should have a diameter of <40 µm, I suggest this as the higher limit in a standard for hemp fibres used for garments. The IENICA guidelines also recommend a fibre strength of between 270 and 690 MPa. The strength largely depends on the fibre diameter, at least up to a certain diameter after which the increase in strength levels off. The higher the strength/diameter ratio of the fibre is, the more likely it is that it will constitute a textile fibre of high quality. It seems clear that a hemp standard ratio very well could be set higher than 12.5 (as suggested for a blend with cotton) since such a low ratio often is the result of a fibre coarser than 40 µm. Considering the Östbom trials where fibres appear coarser and weaker as compared to other hemp fibre studies, a hypothetical minimum ratio which I set to 15 gave a diameter range of ~22–37 µm. Peak ratios of 18,19 and 20 were obtained at diameters of ~23–26 µm and fiber strengths from ~440–490 MPa, so possibly for high class thin fibre and high strength, the ratio could be even higher than 15. My personal suggestion for a strength minimum is 300 MPa to allow for thin fibres of ~20 µm and a ratio of at least 15.

Unfortunately, peak values in strength above 520 MPa invariably seems to result from a fibre that is coarser than 35 μm, i.e. close to the suggested upper limit for the fibre diameter.

Recovering the quality guidelines developed within the IENICA project were as far as I could reach in trying to find quality *standards* from the industry point of view, for hemp fibre intended for textiles. However, it was satisfying to find that the IENICA guidelines for uniform material were easily attainable by either cultivation method, organic or conventional. Hemp showed to be not only suitable but excellent as a crop in organic cultivation. I was able to look at the different growth stages and specific organic practices that are crucial in obtaining a fibre of optimal quality for processing. Even though several quality parameters of hemp fibre can be influenced by cultivation practices, the fine fibre quality required by the industry for the fabrication of garment textiles turned out to be largely a matter of postharvest processing techniques. My view today is that despite hemp fibre being slightly tricky to process, hemp has great potential in meeting future demands of crops and growing practices adapted to be more environmentally friendly. If there had been more time for this study I would have liked to also look at quality comparisons with other types of plant fibre that are used in garments as well as their growing techniques and implementations from an environmental point of view.

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