

Multi- and interdisciplinary nature of textile design research of linseed fibres

Tiina Härkäsalmi* and Ilpo Koskinen**

Aalto-University, School of Art and Design, Department of Design
Hämeentie 135 C, 00560 Helsinki, Finland

*e-mail: tiina.harkasalmi@aalto.fi

**e-mail: ilpo.koskinen@aalto.fi

Abstract:

In the future there will be an increasing need for renewable, recyclable and environmentally safety fibres, which are compatible with existing, cotton-based textile manufacturing technologies and are competitive on price and quality. In this study as a raw material the linseed fibres are used, which is almost an unexploited resource for high value end uses. This paper describes a multidisciplinary design study that consisted of three parts, a microbiological study that developed a Fusart®-method for cottonizing linseed fibres, a production model study aimed at showing how the fibres could be processed in an industrial scale, and a fibre quality evaluation study. In practise it means that lustrous and soft fibres, light coloured can be produced cost-efficiently and environmentally-consciously for textiles and potential for producing high-quality bio-based material with tailored properties.

Keywords: *design research, material research, fungus, textile design*

1. Introduction

The objective of this study is to explore the suitability of linseed elementary fibres in new textile and technical applications and creating prerequisites for product design and productization. The study is based on a multidisciplinary approach to the use of flax elementary fibres where, rather than traditional long-linen textile processing technology, short-fibre methods are employed. Special attention was paid to the quality requirements of rotor spinning. This means that the fibre characteristics such as fineness, length, elongation at break and extension at break should be modified to be similar to cotton. One important task is to remove noncellulosic substances such as pectins and lignin without damaging the fibre cellulose.

In this study product-development-oriented design research was combined with several product design perspectives including creativity, wide-ranging investigations and design using tangible models. The study was a holistic approach, which had a typical characteristic in the interaction between science, design practices and technology. The main aims were to create a method for producing high

quality linseed fibres in industrial scale; to evaluate this method for design purposes; and to suggest a few application areas, like using knitted and weaved textiles for composites.

2. Linseed Fibre: From Environmental Problem to Design Resource

There is a long tradition in producing flax fibres for textiles. People could twist fibres and make coloured textiles of wild flax already more than 30 thousand years (Kvavadze *et al.* 2009). Generally, only fibre varieties have been cultivated for textile applications. Traditional long-line linen processing technologies are based on long fibre bundles. With these methods, fibres are suitable in a rather small number of different end uses: mainly, they are suitable for use in conventional woven fabrics with plain or damask weaves and dyed as a yarn or fabric. The flax industry is focused on high value linen textiles. The problem is that the market is very dependent on fashion trends and its cyclical periods (Dam *et al.* 1994).

Flax has high utilitarian and ecological values, because it's absorbent, hygroscopic, and protective against UV radiation. The thermal and electrostatic properties are good for apparels because of cool handling and comfort of linen textiles. Also flax is being considered as an environmentally oriented alternative to synthetic fibres in fibre-reinforced polymer composites. The disadvantages are the stiffness and the bending rigidity of the fibres, low extensibility of flax yarns and the high creasability and relative poor abrasion resistance of linen fabrics (Akin *et al.* 2000; Salmon-Minotte & Franck 2005).

A cultivation area of fibre flax has decreased dramatically and instead cultivation of linseed has been growing. Linseed flax is grown only for seeds that are used as functional aids in foods, in paints, feed etc. Large amounts of linseed flax straw occur as a by-product of the linseed cultivation. The straw from linseed is nowadays mainly unexploited and it constitutes a major environmental problem for disposal. After harvesting the straw must be disposed of before the field can be ploughed. This is done either by burning or by removing the straw from the field and handling it as waste. Comparing the amount of fibre per hectare is rather low comparing with fibre flax yields, but in the world cultivation area of linseed in the year 2005 was 3.1 million hectares and has a potential raw fibre of more than 500 million tons¹. Cultivation of linseed requires less fertiliser and weed control than cotton. It's a good rotation crop. It grows also in temperate climates (Akin *et al.* 2000; Härkäsalmi 2008; Salmon-Minotte & Franck 2005).

Linseed fibres are generally considered too short, highly lignified and less uniform than fibres from fibre cultivars. Also it's counted coarser than required for high quality textiles, but is an option for production of technical-grade fibre for composites. Further it has been proposed that the fibre to be

¹ The estimated yield is based on 1800 kg straw per hectare with the fibre content of 10 % (Härkäsalmi 2008).

used for cottonization should be as fine as possible so that the technical quality and appearance of the yarn would be satisfactory (Akin, Himmelsbach & Morrison 2000; Dam *et al.* 1994; Salmon-Minotte & Franck 2005). But the fact is that there is not much scientific data of linseed fibres. After all linseed fibres consist of elementary fibres and their qualities are close to cotton, like fineness and length. The usability of linseed fibres should be increased with developing processing methods starting from harvesting.

How can one turn linseed fibres into a usable resource for textile design? This paper describes a multidisciplinary design study that consisted of three parts, a microbiological study that developed a method for cottonizing linseed fibres with a mould from the *Fusarium* family, a production model study aimed at showing how the fibres could be processed in an industrial scale, and a fibre quality evaluation study. Each step was done by a designer, who collaborated with various experts from other disciplines.

3. Cottonization with Fusart®-method

In textile applications flax fibres should be modified to elementary fibres with cottonization that is a multistage mechanical and chemical process where the pectinous glues between the bundles are removed. Last decades it has been many attempts, for example enzymatic treatments and steam explosion, but until now without commercialized application in industrial scale (Wang *et al.* 2003).

In this study a new Fusart®-method for cottonizing flax fibres was created (PCT/FI2009/050059). This method can be used in for retting, smoothening and cottonizing linseed fibres and for removal of lignin. Cleaned and carded fibre will be degraded to elementary fibres with the method and thus wash-



ing, cottonization, bleaching and dyeing of fibres can all be done in the same wet-process (Figure 1). It's based on the textile designer's aesthetical perception made in the winter-retted hemp field in the spring 2001. Here and there were stalks with reddish barks, but the fibres underneath were almost white and cottonized. They were contaminated by mould *Fusarium*. This microbiological finding led to a development process of cottonization method. Developing this method preceded many phases. First the designer isolated the fungus with the help of plant pathologist. The identification of fungal mono-

Figure 1. The principle of Fusart®-method

culture was done in CBS (Centralbureau voor Schimmelcultures, Utrecht, the Netherlands) In CBS the fungus was identified to be *Fusarium sambucinum* Fuckel var. *sambucinum*. The mechanism by which the fungus modifies flax fibres is so far non-explored. In the beginning the designer did all the cultivations and treatments at home. After first accepted patent application, it was easier to find co-operators, and the fungus was cultivated in the laboratory with standard methods. To find optimal treatment conditions hundreds of tests with different circumstances. Finally, on the basis of visual appearance and softness of the fibres two different treatment methods, mechanical stirring and static retting were studied more extensively. The effects of treatments to the elementary fibre characters were measured.

When this treatment is combined with dyeing of fibres novel ingrain yarns of flax will be obtained (usually bast fibres are dyed as yarn or fabric). This whole process can be performed with normal fibre dyeing techniques. These yarns are also suitable for knitting. 100 % flax yarns spun with traditional methods are relative rigid and therefore do not bend well enough around knitting needles. Physical and chemical treatments are needed to soften the yarns to facilitate knitting (Dam et. al. 1994; Salmon-Minotte & Franck 2005). Fibre that has been cottonized this way is raw material, whose composition and degree of purity can be defined, and is ready for yarn making with cotton spinning methods, non woven industry, or other technical applications. Recently, the use of bast fibres as an alternative material in composites has been considered, but the problem with it is the high cost of refining, fibre stiffness, and the high percentage of unnecessary particles (e.g. pectin and lignin), which restrict the adhesion of fibres to the plastic or other matrices.

4. The Production Model Study

Processing textile fibres is a linear process where the material processing technology determines the quality and the price of the end product. Changes in processing technology leads normally required changes in the whole production chain, because each step of fibre extraction and processing alters the properties of the material decisively. Thus, the technical quality management must include characterisation of the raw material, characterisation during fibre extraction and processing and characterisation of the final fibre respective product. In every production step has to be designed according to the quality of the incoming material and final quality which is specified by the application.

In this study a production concept based on "total fibre" lines was created, including the following phases: linseed harvesting, refining processes (like scutching, carding), cottonizing with Fusart®-method and rotor spinning. Various material experiments were designed and fabricated with different

processing techniques, such as knitting, weaving, needle-felting, moulding and wet-laying (Figure 2).

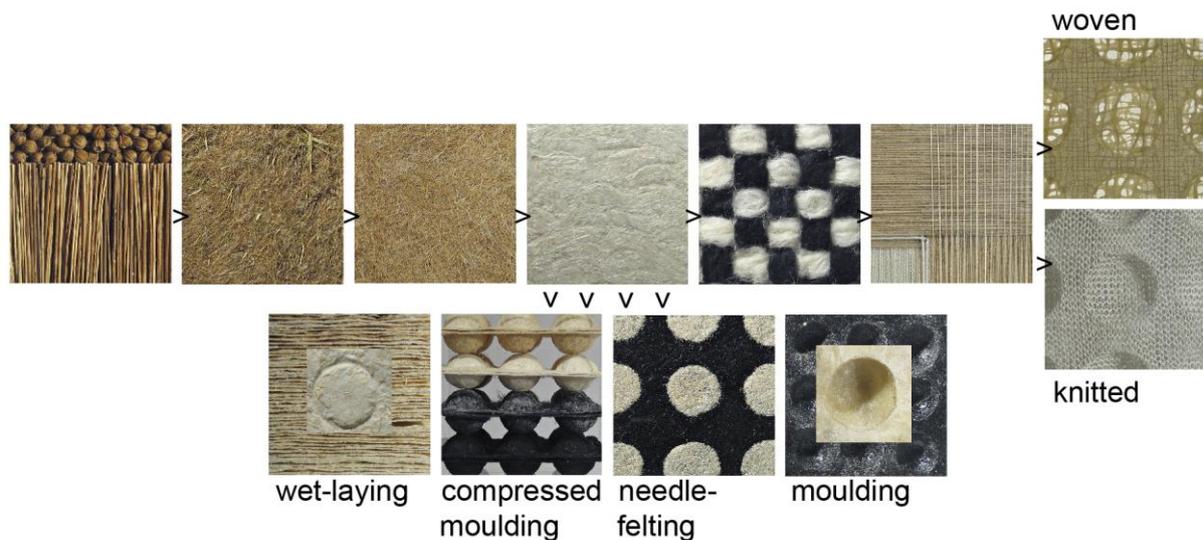


Figure 2. The production model of linseed fibres

In production model the stability of the production chain minimizing process-stages and negative environmental effects were increased compared to the traditional long-line flax processing technology.

This study showed that short-fibre methods give an impetus of linseed fibres in new application fields. Also the negative impacts on the environment can be reduced through the reduction of energy use and increase in material efficiency (Härkäsalmi 2008).

4.1. Primary Production

The field trials were carried out in the research farm of the University of Helsinki in Siuntio in southern Finland in the years 2003 and 2005. The cultivar Laser was used, because in previous trials the yields and quality of seeds had been advantageous. Because the processing methods are based on short fibre, thus the harvesting can be done with normal farm machinery and by baling all the straw together randomly orientated. According to a study done in the University of Helsinki, Department of Agrotechnology, the baling and removal of straw from the field increases the required work time two hours per hectare.

The unretted crop was harvested when the capsules were ripe and the straw was mature, thus the fibres are easily mechanically separated from wooden parts of the plant. In harvesting seeds the straw was reaped and cut up to the field. The straw was round baled on the next day of harvesting when the retting process hasn't started.

Because the fibre content of bales is only 20 %, in trashing the linseeds the straw was reaped and cut up to the field with chopper as a pre-decorticating. If the straw is decorticate during the harvest part of the shives are left on the field to loosen the ground. At the same time the fraction of fibre in the bale increases and the cubic weight of the bale grow since the cut up straw can be baled more tightly. Thus, the volume of the cut straw material to be transported is markedly less than the volume of the

uncut straw material. The volume of the decorticated straw material was 7.3 m³ per hectare while the volume of uncut straw material was 18 m³ per hectare. In the year 2003 the fibre yield of cultivar Laser was 390 kg per hectare (Härkäsalmi 2008).

4.2. Pre-treatments

With traditional methods the entire crop has to be retted and dried for storage although the amount of useful fibre in it is relatively low. Energy consumption of drying flax is 0.91-2.7 kWh/kg evaporated water. In this study the wood like material was cost efficiently mechanically removed from the straw beforehand with a mechanical braking and scutching –machine for short-fibre. This way the expenses of drying will be directed only to the fibre fraction. After that fibres were carded to remove most of the shives with needle-felt carding engine for flax fibres. Carded raw material was in form of bundles in length of 40–300 mm each of bundles consisted of 8–50 elementary fibres. (Härkäsalmi 2008.)

4.3. Cottonization with the Fusart®-method

The samples were treated with above mentioned supernatant of fungus *Fusarium* which was grown 28 days in constant light. Mycelia were grown in flasks into which sterilized culture liquid has been added. After this the fungal culture was filtrated e.g. through Miracloth in order to separate the mycelium from the culture liquid. Ammonium sulphate was added to the culture liquid gradually until the percentage of ammonium sulphate is 70. Ammonium sulphate lowers the pH of the liquid by 1.5 units. The solution was mixed for one hour in +4 °C after which it will be centrifuged for 30 minutes in +5 °C with 10 000 rpm. The precipitate formed contains the proteins of the culture liquid. Supernatant is collected and used for fibre treatments (Härkäsalmi *et al.*2008). For further studies mechanical stirring with Linitest-testdying apparatus and static retting was compared. The basic variants were amount of fungus, time and temperature of the liquid. The liquid to fibre ratio was 1/20 and 10 g of salt per litre was added. In stirred tests 14 ml culture liquid per gram fibre was used and the treatment time was two or four hours. In static retting 0.5 ml/g fibre culture liquid was added gradually every six or eight hours. The total treatment time varied from 12 to 24 hours. Three parallel samples of treatments were done and they were repeated at least three times. The linear density, breaking tenacity and elongation at break was measured from controls and from three Fusart®-treated samples. The linear density of the elementary fibres varied 3.47–4.31 dtex, breaking tenacity 21.2–42.3 cN/tex and elongation at break 2.1–2.9 % (Table 1).

Table 1. Effects of Fusart®-treatments to the linear density, breaking tenacity and elongation at break of the fibres

Sample		Temperature [C°]	Treatment time and the intervals of adding fungus [h/h]	Total amount of fungus [ml/g]	Linear density [dtex]	Breaking tenacity [cN/tex]	Elongation at break [%]
1	Mechanical	57	2	14	3.74	42.3	2.6

	stirring						
2	Static retting	20	18/6	1.5	3.69	40.2	2.6
3	Static retting	20	24/8	1.5	4.31	41.1	2.9
4	Control 1: washed raw fibre	57	2	0	4.35	40.9	2.1
5	Control 2: carded raw fibre			0	4.57	52.9	2.5
	Cotton*				1–4	15–50	4.8–9.3

*Franck 2005

4.4. Spinning

The appearance, strength and texture of the fabrics depend on the nature of the fibres and the way in which they have been spun to the yarns. Instead of traditional wet or dry spinning cotton system and rotor spinning was used. The reason for that was to reduce the costs by increased productivity and to increase the versatility of yarns. Rotor spinning is widespread and is a major spinning method for short staple yarns (Lord 2003, 185–186). Cottonized (affined) fibre flax fibres have been used blended together with e.g. cotton or polyester. The percentage of flax in ring spun yarn (50 Tex) is 40 % and in 22-66 tex rotor spun yarns 25-50 % (Cierpucha et al. 2006; Salmon-Minotte & Franck 2005).

The yarn manufacture experiments were carried out with rotor spinning at the Tampere University of Technology. The treatment included carding the lap and sliver and rotor spinning. The carding machines were not set especially for flax instead settings for cotton was used. In the spinning experiments were tested samples that have been treated with fungus *Fusarium* by static retting in the room temperature (20 °C) 18 or 24 for hours. 0.5 ml/g supernatant of fungus was added three times so that the total amount of fungus was 1.5 ml per fibre gram. Spinning with 100 % flax there was a problem with sliver formation. To help fibres twist easier together pre-treated cotton fibre was added to batches, so that the portion of cottonized flax was 80–90 %. With these propositions yarn formations succeeded. The average tex-value of the slivers was measured of five parallel samples (1 m), (Table 2).

Table 2. The results of spinning experiments using static retting

Total time [h] – intervals of adding fungus [h]	Total amount of supernatant [ml/g]	Amount of flax [%]	Sliver [tex]	Spinning
18 - 6	1.5	90	3560	+++
		100	2220*	-
24 – 8	1.5	80	2740	+++
		90	-	-
		100	-	-
* the average is measured of 4 m sliver - not succeeded				

5. Handle and Visual Appearance

Because industry relies on fibres on guaranteed and specified raw materials, attention was next paid to the visual appearance and softness of fibres. The production model described above shows that lustrous and soft fibres can be produced with lower costs and environmentally-friendly for textiles, and linseed fibres have a potential for producing high-quality bio-based material with tailored properties. The next question is the aesthetic and physiological look and feel of the fibres thus produced.

In textile applications garment has to be comfortable in aesthetic and physiological sense. From the users point of view the important product properties are comfort, appearance retention, safety, strength, biological resistance, environmental resistance and care (Lindfors 2002). The comfort of textile is composed mainly of the handle, thermal insulation and moisture absorbance of the raw material. In order to find a method for the comfort evaluation of textiles, the concept “fabric hand/handle” is commonly used method for assessing fabric/material quality and prospective performance in end use in particular: this notion refers to the total sensations experienced when fabric/material is touched in the fingers and it is often the fundamental aspect that determines the success or failure of a textile product.

By sensory evaluation, one gets to know properties of the material, such as flexibility, compressibility, elasticity, resilience, density, surface contour (roughness, smoothness), surface friction and thermal characters. The comfort sensation of a raw material has multidimensional attributes and is impossible to quantify through a single physical property. Fabric handle is a generic term for tactile sensations associated with fabrics that influence consumer preferences (Bishop, D.P. 1996; Hui, C.L. et al. 2004; Mäkinen et al. 2005). The consumers made the decisions by touching, through their own experience.

Subjective handle evaluation of fibres was made by five textile design expert judges. The assessment was done by sensory evaluation with touch and sight together. Seven samples were to be put in order according to opposite characteristics: soft-hard; smooth-coarse; glossy-dull; light-dark and general impression of the best sample was given in words. Six of the samples were treated with the fungus *Fusarium* and one sample was washed raw fibre. The evaluators were almost unanimous in their evaluation and they found it difficult to order the three softest samples. According to evaluators the softest sample was the static retted sample which was treated 18 hours in room temperature. The supernatant of fungus was added three times (0.5 ml/g) every six hours. The total amount of supernatant was 1.5 g per fibre gram. All the best samples were characterized as being silky, warm, glossy, and because of their pleasing touch suitable for clothing. The washed raw fibre was distinguished from the other samples for being the coarsest, hardest, darkest and dullest. The softest samples had the best spinning capabilities. The linkage between softness and the spinability is obvious.

Because this study had practical goals in change in handle and visuality of raw material there was also a phase, in which designer made material experiments to explore the tactility of the materials and their usefulness for textile design. As raw materials were used flax and hemp plants to compare the

fibre characters of these materials. The artefacts were made in ball-form (\emptyset some 16 cm in diameter) to disrupt the current conventions of two dimensional surface of textiles and open new ways of seeing the material (Figure 3). The subjective material experiments were essential to find new solutions for fibre processing and enlarged the understanding of raw materials, the differences between materials and nuances of the fibres. These artefacts worked as a playground for testing ideas and the experiments were free from predominated methods. The artefacts were also a tool for concretise the ideas that have their basic in intuition and in tacit knowledge. And after all they work as note pad for further studies. For example, under-retted needle-felt can also be cottonized or this fungus can be also used for dyeing the fibres.



Figure 3. The material experiments of linseed, winter-retted fibre flax, oil hemp and winter-retted fibre hemp

6. Conclusions

There is still strong supposition that the textile designers task is to decorate the fabric, or in other words to wrap nicely the existing yarns to the fabric. The textiles are a combination of the complicated technological processes in making fibres for textile products. The processes effect to the material and end-use properties will be evaluated from the consumers' point of view. In companies textile designer's task is to combine the demands of the used technology and marketing sector. So, in practice the designer is a user of yarn that has been developed by fibre technologists. But after all, textiles have

to satisfy the user. The designer researcher has to have knowledge of every phase of the production chain to development novel raw materials. After all, fibres are the fundament of textiles. Somewhat tongue-in-cheek, I suggest that we call textile design research of fibres for fibralogy (lat. *fibra* + *logos*). There is an analogy with the fibre art as synonym for textile art.

Design research often has a very multidisciplinary nature and it is combined more or less with user studies, design-driven practices and art history. This study differs from that, because natural sciences and especially microbiology and agro-technology played a big role. It shows that textile designers can conduct multidisciplinary research even with material scientists and microbiologists, and can even take the lead in such research processes after learning some facts about science. Such cooperation gives designers new types of tools for creating innovations like the Fusart®- method developed in this study. The method is still under development and deeper knowledge for fibre modification is needed. The result of this preliminary study of fungus *Fusarium* indicate that the Fusart®- method can upgrade the application areas of linseed fibres.

This paper was written in chronological order starting from cultivation. In fact there were many iterative circles to achieve the final product model. In this case was it very important to understand the whole production chain. Starting from the discovery of the fungus, which enabled new direction of linseed fibre applications. Literally it meant fieldwork. How does the bast fibres grow, what the quality of the material when harvested, restoring, pre-treatment, conventional manufacturing methods and machines. The fieldwork was not only perception but also participation in every phase of fibre processing. In this study many professionals from different fields were consulted: among others agrotechnician, microbiologist, plant pathologist, textile engineer and economist. One is missing: the sociologist. He had a role as a responsible professor to spar and spur the designer researcher into getting outcomes and after all as a co-writer.

References

- Akin, D.E., Himmelsbach, D.S. & Morrison III, W. H. (2000) Biobased Fiber Production: Enzyme retting for Flax/Linen Fibers. *Journal of Polymers and the Environment* 8(3), pp. 103–109.
- Akin, D.E., Dodd, R.B., Perkins, W., Henriksson, G. & Eriksson, K-E (2002) Spray Enzymatic Retting: A New Method for Processing Flax Fibers. *Textile Research Journal* 70(6), pp. 486–494.
- Bishop, D.P. (1996) Fabrics: Sensory and Mechanical Properties. *Textile Progress* 26(3), pp. 1–62.
- Cierpucha, W., Czaplicki, Z., Mańkowski, J., Kołodziej, J., Zaręba, S. & Szporek, J. (2006) Blended Rotor-Spun Yarns with a High Proportion of Flax. *FIBRES & TEXTILES in Eastern Europe* January/December Vol. 14, No 5(59), pp. 80–83.
- Dam, J.E.G. van, Vilsteren, G.E.T. van, Zomers, F.H.A., Hamilton, I.T. & Shannon, B. (1994) *Industrial Fibre Crops*. Study on increased application of domestically produced plant fibres in textiles, pulp and paper production and composite materials. European Commission: (EC DGXII - EUR 16101 EN).

Franck, Robert, R. (2005) Overview. In *Bast and other plant fibres*. (Ed. Robert R. Franck), Woodhead, Cambridge, pp. 1–23.

Hui, C.L., Lau, T.W.,- Ng, S.F. & Chan, K.C.C. 2004. Neural Network Prediction of Human Psychological Perceptions of Fabric Hand. *Textile Research Journal* 74(5), pp. 375–383.

Härkäsalmi, T. (2008) *Runkokuituja lyhytkuitumenetelmin - kohti pellavan ja hampun ympäristömyötäistä tuotteistamista* [Bast fibres by short-fibre methods – towards an environmentally-conscious productization of flax and hemp]. Taideteollisen korkeakoulun julkaisusarja A 90, Helsinki. Academic dissertation. (in Finnish)

Härkäsalmi, T., Maijala, P., Galkin, S. Hatakka, A. & Nykter, M. (2008) *Method for retting, smoothening and cottonizing bast fibers, and for removal of lignin of plant origin*. International patent application no PCT/FI/2009/050059, published 20.07.2009 under No. WO2009/092865.

ISO/TR 14062:fi (2002) Environmental management. Integrating environmental aspects into product design and development. Technical report. Helsinki: Finnish standards Association SFS.

Kvavadze, E., Bar-yosef, O., Belfer-Cohen, A., Boaretto, E., Jakeli, N., Matskevich, Z. & Meshveliani, T. (2009) 30.000-Year-Old Wild Flax Fibers. *Science* vol. 325, pp. 1359.

Lindfors, E. (2002). Tekstiilituotteen teknologiset ominaisuudet. Tekstiilituotteen käyttö- ja hoito-ominaisuuksien tarkastelu kuluttajan näkökulmasta. Joensuun yliopisto. Kasvatustieteellisiä julkaisuja n:o 77. Academic dissertation.

Mäkinen, M., Meinander, H., Luible, C. & Magnenat-Thalmann, N. (2005) Influence of Physical Parameters on Fabric Hand. HAP05, Workshop on Haptic and Tactile Perception of Deformable Objects 1.12.2005, 8–16. Available at <<ftp://ftp.gdv.uni-hannover.de/papers/haptex05/12.pdf>> [Accessed 25 June 2007]

Salmon-Minotte, J. & Franck, R.R. (2005) Flax. In *Bast and other plant fibres*. (Ed. Robert R. Franck), Woodhead, Cambridge, pp. 94–175.

Wang, H.M., Postle, R., Kessler, R.W. & Kessler, W. (2003) Removing Pectin and Lignin During Chemical Processing of Hemp for Textile Applications. *Textile Research Journal* 73(8), pp. 664–669.