Identification of critical steps in the hemp fibre textile production chain

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Abstract
Hemp textile quality depends on many decisions and processing steps throughout the production chain, and starts with the primary agricultural production. In order to develop a competitive, innovative and sustainable hemp fibre textile industry in the EU, all players in the whole production chain have to aim at the wanted final textile quality. Within the Hemp-Sys project, the critical steps that have an effect on final hemp textile quality have been identified in order to facilitate the decision making throughout production chain.
This presentation shows the highlights of the parameters that affect hemp textile products. The core quality for textiles, fibre fineness, is in particular determined by crop variety, the growing period and weather conditions, whereas seed density and stem section show limited influence. Regarding processing, de-gumming and fibre 'loss' strongly influence fibre fineness.
The results form the basis for the design of an integrated quality system (IQS) that will help farmers and fibre processors to optimise the value addition of their product and secure hemp textile industries of supplies of quality fibre feedstock.

Keywords: hemp, textile, fibre quality development

Introduction
Since the re-introduction of hemp as a fibre crop in the EU, growing of hemp was optimised for fibre yield. For textile applications, however, fibre fineness, strength and cleanness are critical economic parameters as well. These quality parameters depend on primary agricultural production, fibre extraction procedure and end-product manufacturing. In fact the quality has to be directed by selecting proper growing and processing conditions for hemp fibres.

To develop a competitive, innovative and sustainable hemp fibre textile industry in the EU, the whole production chain has to be integrated, since final yarn quality starts at the decisions made at the farm. The parameters that can be of influence for fibre quality are:
- Primary agricultural production: variety, seed density, growing period, soil, climate/weather, irrigation
- Fibre extraction: decortication, de-gumming, softening, hackling
- Textile processing: refining & homogenisation, cleaning & bleaching, spinning, dyeing, finishing, weaving

Next to these parameters, the section of the stem, related to the harvesting method, will play a role in fibre quality.

This paper identifies (non)critical parameters and steps in the hemp textile production chain. The effects are presented as trends, based on data from partners within the Hemp-Sys project:

DiSTA (I), UCSC (I), Wageningen University (NL), MTT (FI), TSF-MVKK (H), Agro-Hemp (H), Hungarohemp (H), Valdiserchio (I), Fibranova (I), Linificio (I), FIBRE (D) and A&F (NL). The first paragraph of results refers to fibre characteristics in the plant, the other paragraphs mainly refer to pilot-industrially processed fibres, unless otherwise stated. This evaluation provides a fingerprint of the integrated quality system IQS) that has to facilitate the management of the entire production and processing chain in the future.

Results and Discussion

The ultimate fibre fineness is established during agricultural production. The average diameter of the primary fibre cells varies with variety and growing conditions and decreases with higher seed density and higher internode number (Figure 1). The weather conditions have a similar effect on fibre fineness as difference of variety and seed density. The dry and hot year 2003 gave finer primary fibres compared to 2004. The most pronounced effect was found within the stem: yielding finest fibres going to the top. The variation in fibre diameter at one cross section of a single plant (Figure 2) is larger than the effect of variety, seed density, weather conditions or location in the stem.

The fineness of fibres at the end of the industrial processing is strongly influenced by the fibre extraction procedure, especially of de-gumming. De-gumming aims at partial removing the bonding substances between the fibres: lignin and pectin, thus facilitating refining of the fibres during further processing. The Shirley fineness –which increases with decreased fibre diameter– largely depends on effects of de-gumming/retting (Figure 3). The Shirley fineness method is described in Müssig (2001). Chemical composition analysis of hemp fibres before and after retting confirms the effect of retting on lignin and pectin content (Figure 4). The high lignin content after retting in the top section corresponds with the difficulty in separation of woody core tissue. For green decortication tests it was observed that adhering hurds content increased at smaller stem diameter. This reduced effect of green decortication can be attributed to the more flexible character of the woody core in the thin (top section) stem parts. Green decortication makes use of the difference between the flexible fibres and the stiff and brittle hurds. The higher content of both lignin and pectin in the unretted top section will contribute to this result. Furthermore, the average fibre fineness in the end depends on which fibres are 'lost' along the processing chain: the thin and/or thick fraction of the fibre spectrum (see Figure 2). During green decortication and hackling, 20-50% and 40-85% of fibres were removed, respectively. This indicates that at least 50% –but more likely a higher amount– of primary hemp fibres are 'lost' during processing.

The following series of results refer to fibre samples that have been green decorticated, de-gummed, softened and hackled and that have been refined on the Linimpianti Minisystem. So the samples analysed already have 'lost' a considerable amount of primary fibre as discussed above. The Minisystem is a simulation of the industrial stretching and doubling sequence performed just before yarn production. Fibres treated on the Minisystem allow prediction of achievable yarn quality.

There is an effect of variety on Shirley fibre fineness as measured after Minisystem treatment (Figure 5). Seed density only shows a very small effect on fibre fineness (Figures 6,7&8). Growth period has an effect for Tiborszallasi (TIB), but not for Futura 75 (FUT) it seems (Figures 6,7&8). The difference between TIB and the two FUT samples is their growth degree days value (0°C base temperature) at 1st harvest, 1313, 1595 and 1659, respectively. Another difference is that the TIB fibres were mechanically refined in a lab scale Coarse Separator instead of being hackled and treated in the Minisystem, however, for FUT no significant difference between Coarse Separator and Minisystem treatment was found (Figure 6&8). Fibres in the top 1 meter section of the stems were expected to be finer than fibres in the bottom section (see Figure 1), however, this did not hold for the FUT fibres investigated (Figure 8&9). Also TIB fibres did not show significant effect of stem section (see Figure 7). Spinning of the best TIB sample into a yarn with count 20Nm was possible, although with more breaks than usual for regular spinning.

Fibre Stelometer strength values of TIB and FUT variety are indicated in Figure 10. The Stelometer strength method is described in Van den Oever et al. (2003). From the data, no influence of different seed density can be concluded. Also harvest time had no effect on strength, except for two exceptional high values. Also for many lab refined samples no significant effects of density, harvest time and stem section were observed. An exception was the lower fibre strength in the foot sections of Beniko, Dioica and Fibranova.
Maturity of fibres increases with harvest time, especially at higher seed densities. If maturity has a positive effect on strength, there must be a negative effect as well after fibre de-gumming and refining, e.g. mechanical damage of fibres or kink band formation might be more severe in thick fibres. Brittleness can be excluded since no effect of harvest time on strain at fracture was observed.
For good processing, fibre strength after 6 passages on the Minisystem should be preferably higher than 40 cN/tex. Figure 10 indicates that this is not automatically obtained. Processing of hemp fibre needs special attention in order to maintain enough fibre strength to avoid breaks during spinning and weaving.

Analysing these data, the fingerprint of the IQS becomes visible. With future developments in hemp fibre breeding, growing and processing, improvements of quality can be directed and based on empirical quality data obtained.

Conclusions

- The fibre diameter range after agricultural production sets a limit to the maximum achievable yarn count, however, it is not automatically related to the fineness after processing into yarn.
- During agricultural production, final fibre fineness (i.e. after industrial processing) is in particular determined by crop variety and growing period, whereas seed density and stem section show limited influence.
- Within the processing chain, fibre fineness is mainly determined by de-gumming, although actual refining takes place during hackling and stretching and doubling. The ‘loss’ of stem sections and fibres strongly influence average fibre fineness as well.
- No significant influence of agronomy on fibre strength could be concluded. Processing needs special attention in order to avoid mechanical damage and maintain enough fibre strength.
- The results form the basis for the design of an integrated quality system (IQS) that will help farmers and fibre processors to optimise the value addition of their product and secure hemp textile industries of supplies of quality fibre feedstock.

Acknowledgements

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References

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Van den Oever M.J.A., Bas N., Van Soest L.J.M., Melis C., Van Dam J.E.G., 2003. Improved method for fibre content and quality analysis and their application to flax genetic diversity investigations. Industrial Crops and Products 18: 231-243.

Figures

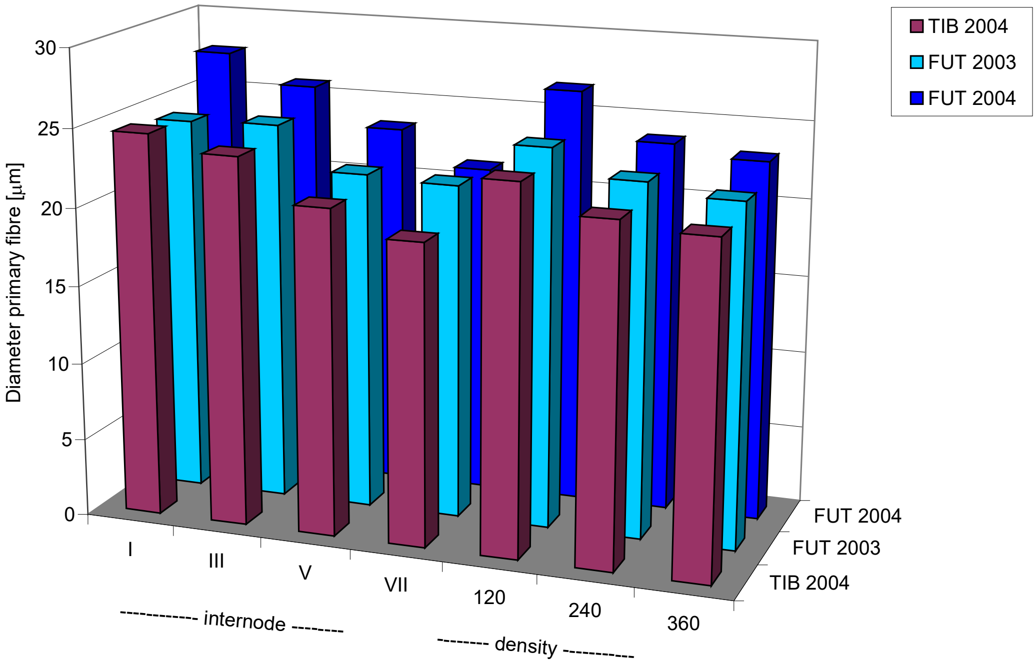

Figure 1. ***Effect of internode number, seed density (plants/m²), variety and year of growing on average primary hemp fibre diameter, determined by microscopic analysis. Futura and Tiborszallasi samples grown in Bologna (Italy).***

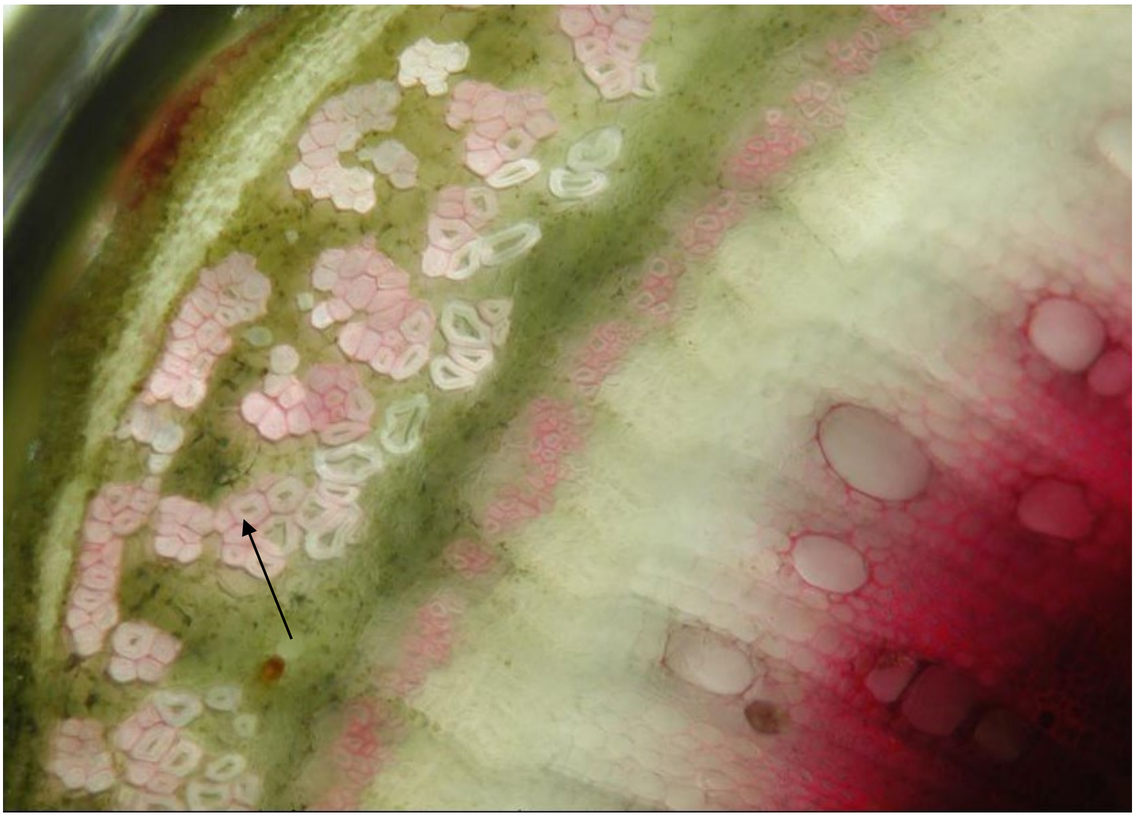

Figure 2. ***Cross section of hemp stem, the arrow pointing to primary hemp fibres. Futura variety grown in Wageningen (Netherlands) in 2004.***

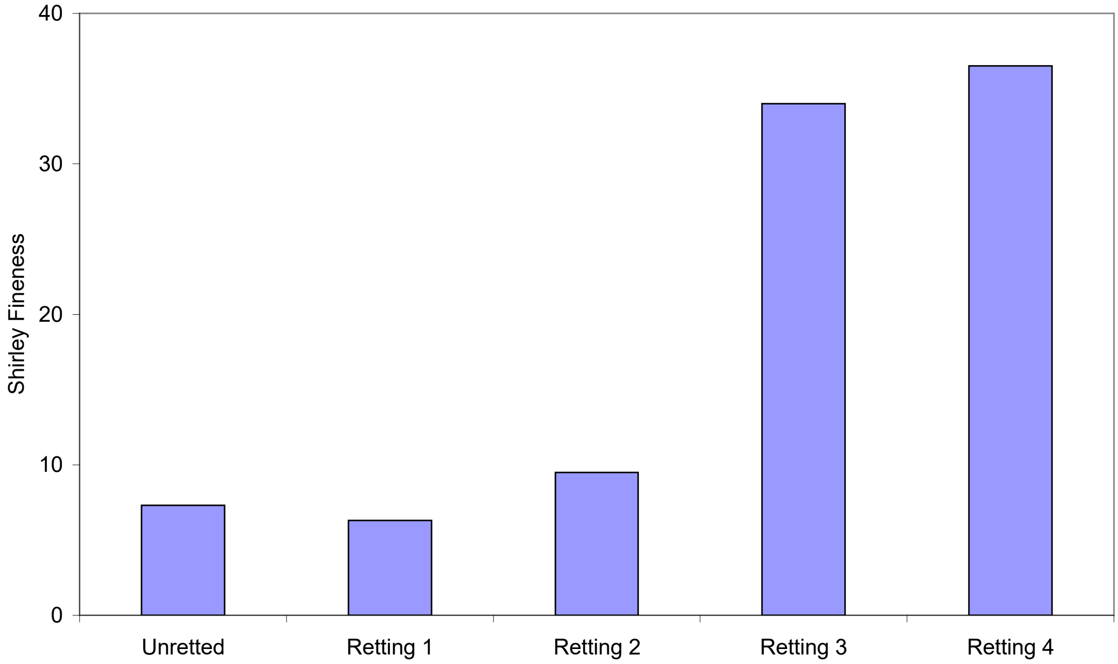

Figure 3. ***Effect of retting on hemp fibre fineness. Tiborszallasi variety grown in Mártélyi (Hungary) in 2003, emergence density 376 plants/m^2 and density at harvest 186 plants/m^2, green decorticated on a flax scutching line, pool retted and mechanically refined on a lab scale Coarse Separator.***

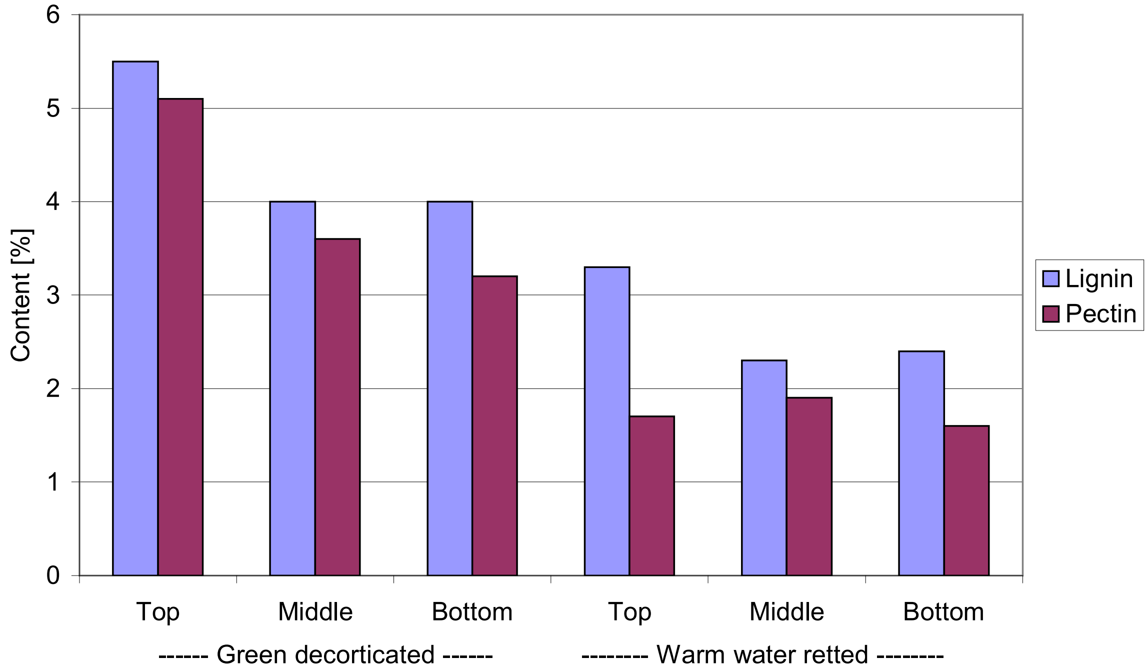

Figure 4. ***Chemical composition vs. location in the stem of green decorticated and retted fibres. Futura variety grown in Wageningen (NL) in 2003, emergence density 225 plants/m^2 and density at harvest 54 plants/m^2.***

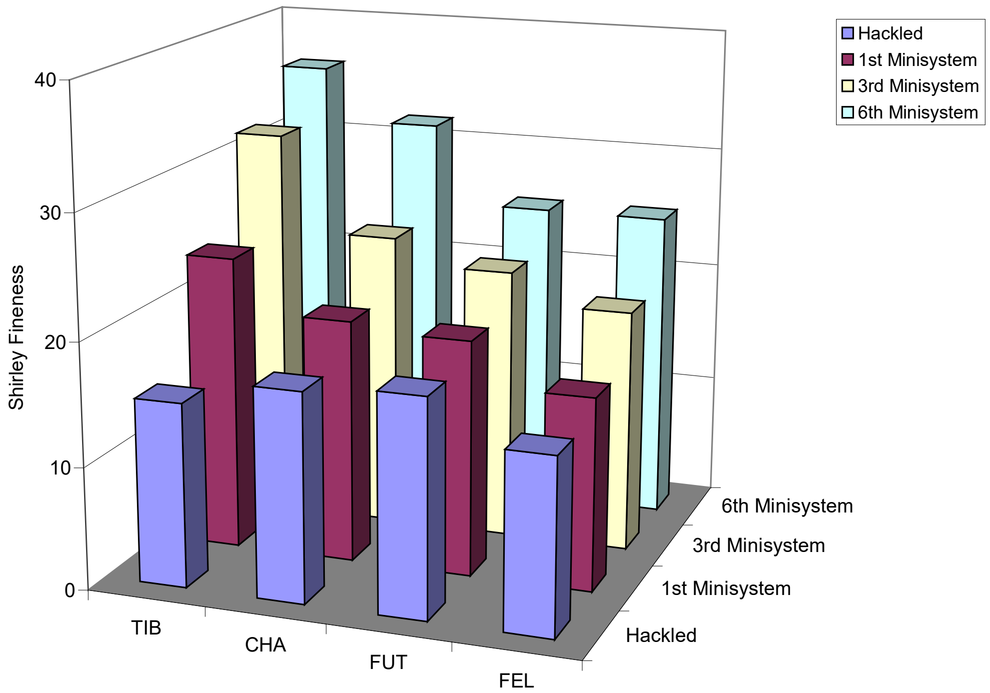

Figure 5. ***Effect of variety and refining on hemp fibre fineness. Tiborszallasi grown in Mártélyi (H) in 2003, fibres from top+bottom section, pool retted, hackled at Linificio. Chamaleon, Futura and Felina, grown in Valdiserchio (I) in 2004, fibres from bottom section, pool retted, hackled in Eastern Europe.***

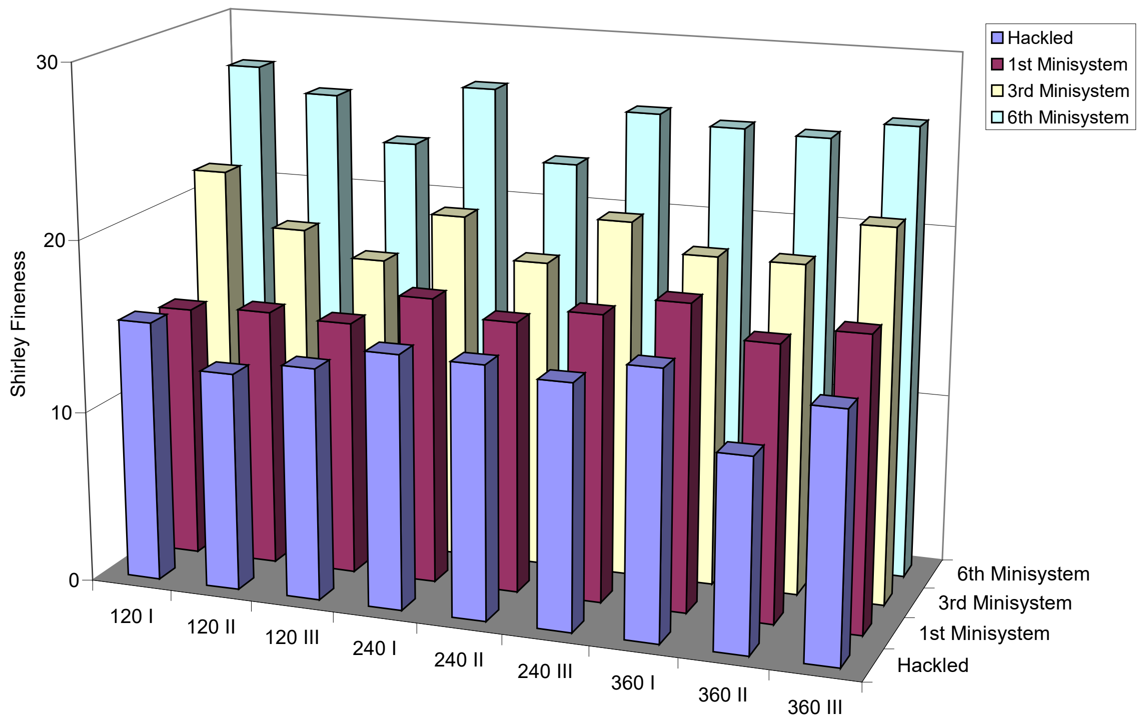

Figure 6. ***Effect of seed density (plants/m^2) and growing time (GDD = 1595, 2001 & 2373) on hemp fibre fineness after refining. Futura density trial in Bologna (I) in 2004, fibres from bottom stem section, pool retted, hackled in Eastern Europe.***

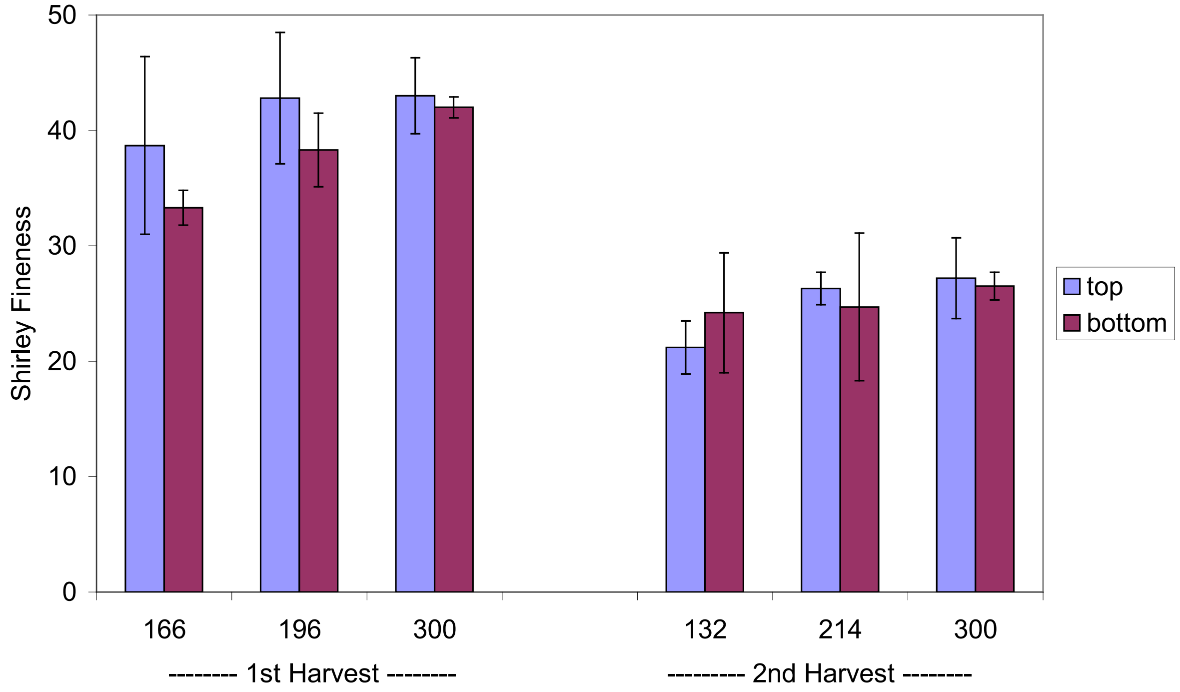

Figure 7. ***Effect of seed density (numbers on the X-axis indicate plants/m^2 at harvest) and growing time (GDD = 1313 & 2032) on hemp fibre fineness. Tiborszallasi grown in Bologna in 2003, warm water retted and scutched, mechanically refined on a lab scale Coarse Separator.***

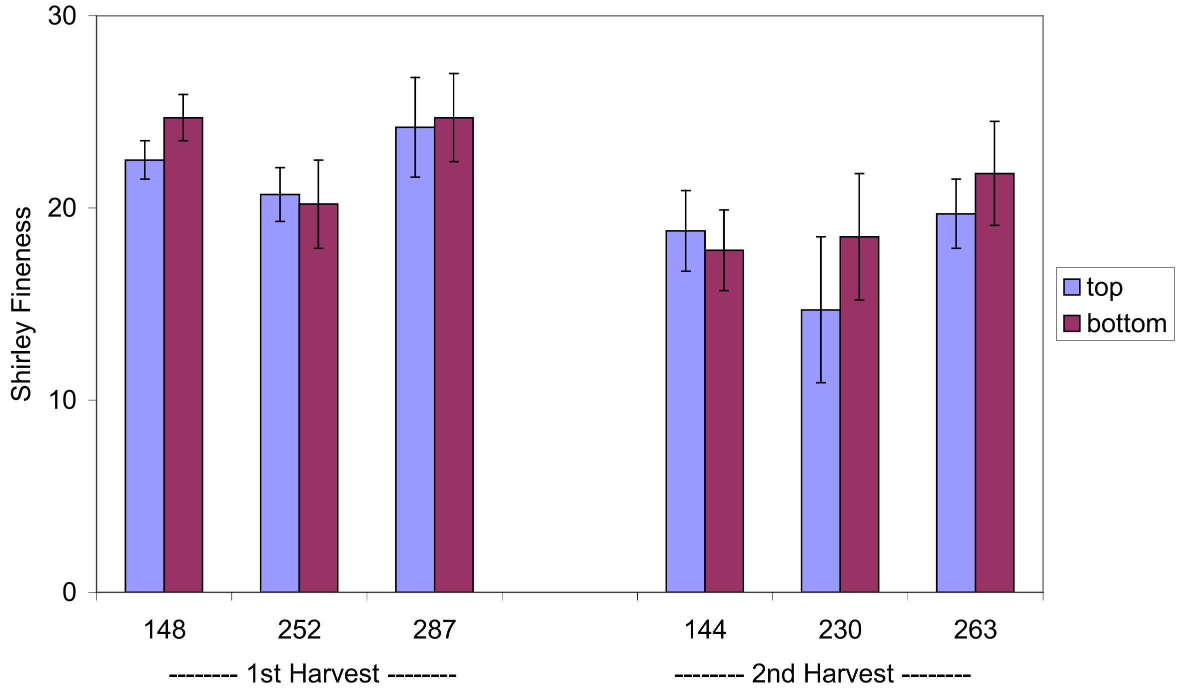

Figure 8. ***Effect of seed density (numbers on the X-axis indicate plants/m^2 at harvest) and growing time (GDD = 1659 & 2227) on hemp fibre fineness. Futura grown in Bologna in 2003, warm water retted and scutched, mechanically refined on a lab scale Coarse Separator.***

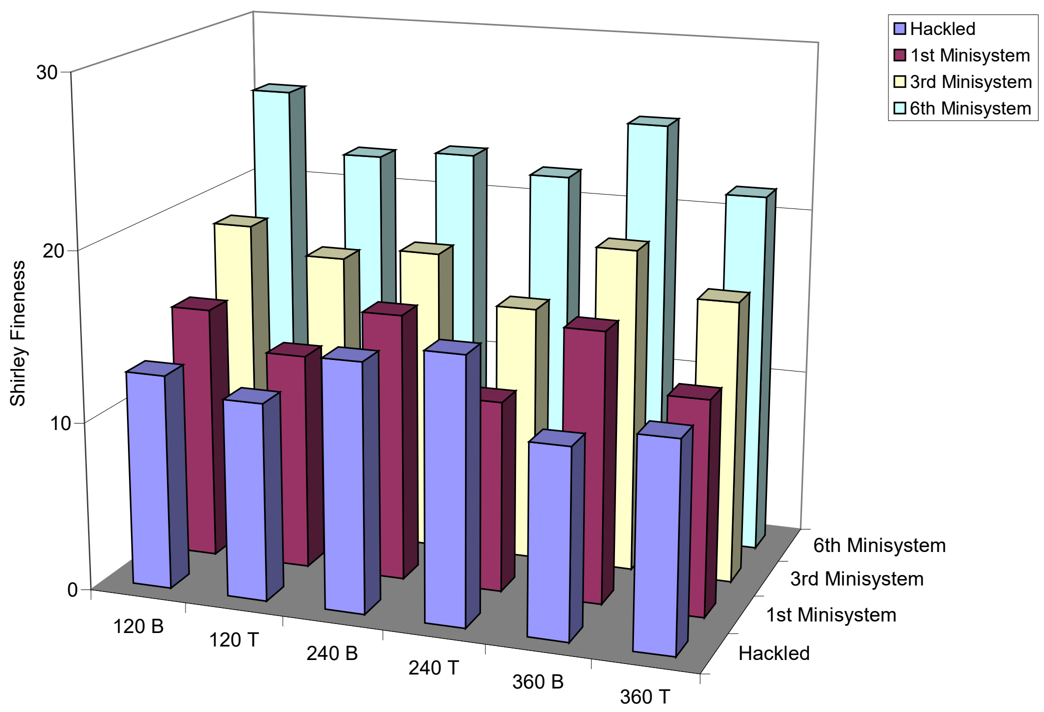

Figure 9. ***Effect of stem section (B=bottom, T=top) on hemp fibre fineness after refining, at three seed densities. Futura density trial in Bologna (I) in 2004, GDD = 2001, pool retted and hackled in Eastern Europe.***

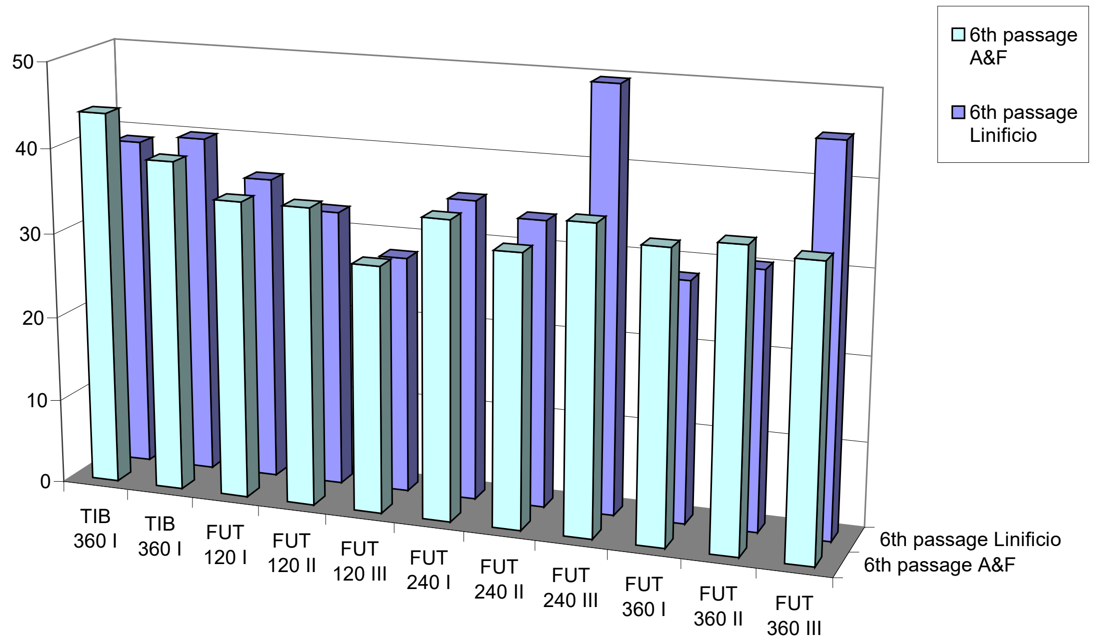

Figure 10. ***Effect of density (plants/m^2) and harvest time on fibre strength, determined using a Stelometer. Tiborszallasi grown in Mártélyi (H) in 2003, fibres from top+bottom section, hackled at Linificio. Futura grown in Bologna (I) in 2004, fibres from bottom stem section, hackled in Eastern Europe.***