STRATEGY FOR A SUSTAINABLE FUTURE OF FIBRE CROPS

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ABSTRACT

During the last decade, there have been great efforts in the EEC to establish flax and hemp as a sustainable source for fibres. Although almost every German car manufacturer uses now natural fibre reinforced parts, most of the raw material for the low level application comes still from Eastern Europe and Asia at cheap prices. Thus, the strategy to establish a sustainable use of fibre plants in high cost countries must be revised.

The basic idea for a cost competitive future of flax and hemp in Western Europe is to provide tailor made high quality fibres for textile and non textile markets. A lot of work has been done to develop high performance composites on the laboratory scale. Very little progress can be noticed in marketing and high level processing. A solution will therefore be the following strategies:

- co-operative structures from raw material production to end users
- adaptive processing to balance variations in the raw material
- on line quality management for a feed back and a feed forward control
- production of fine fibres by chemical and biochemical processing

Some typical examples will be given and high end uses of fibres will also be presented.

INTRODUCTION

Renewable resources, which were important for the wealth of the people before the Industrial Revolution, are gaining more interest in our modern society due to their positive effects on agriculture, environment and economy. A significant advantage of renewable resources exist in their contribution to the conservation of finite fossil resources and their importance regarding the green house effect.

On the part of agriculture, the hope for an easing in the food markets, the creation of alternative production in the non food area as well as income opportunities are paramount. From the industrial standpoint, renewable resources present an opportunity for the development and marketing of innovative and ecologically compatible technologies and products.

Since the beginning of the 1980s, different institutions have intensively promoted the development of "renewable resources" in Germany. In the field of the bastfibres, esp. Flax and Hemp, the attention focussed on harvesting, decortication, mechanical and physical disintegration techniques and with great emphasis on non-traditional applications (1,2).

However, in relation to the extraordinary financial efforts made by the government, the high expectations of politicians and farmers to increase cultivation could not be satisfied so far. The actual cultivation area for bastfibres represent app. 1% of the total area of cultivated renewable resources in Germany only. On the other hand, almost any German car manufacturer uses nowadays Bastfibres for interior parts, but hardly from resources produced and processed in Western Europe. The reason is the mismatch between cost and performance. The solution of this dilemma can not be a further increase in subsidies nor will it be possible to reduce costs. The solution must be to put into the product more "intelligence" thus providing the industry with tailor made raw materials.

The paper will start with a short review of the limitations and successively will try to show some possible solutions of the dilemma.

LIMITATIONS – THE DILEMMA OF THE AGROINDUSTRY

Profits versus Mass Production

The basic dilemma of agricultural production is the low value of their products. Competition in the world on raw materials is mainly on price rather than on quality. Thus, production in high wage countries like Germany can only be a profitable when high added value products are sold. This is only possible in niche markets like the production of pharmaceuticals, but only in small areas. In turn, energy plants may be produced on large scales but at the expense of a profitable production. Bastfibers can be positioned as a compromise with the potential of a reasonable scale and a sufficient added value. In case of fibre plants, farmers need approximately at least 0.2 –0.5 DM per kg straw to balance their costs for farming without subsidies (Figure 1). Actual prices are at maximum 0.1 DM/kg straw. Figure 2 shows another important parameter which determines the overall costs of production.

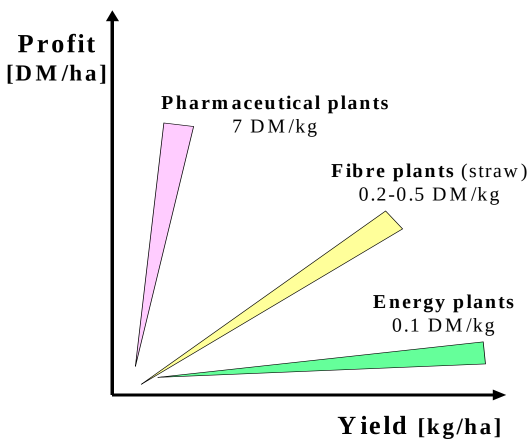


Figure 1: Profit versus yield for selected agricultural products (no subsidies)

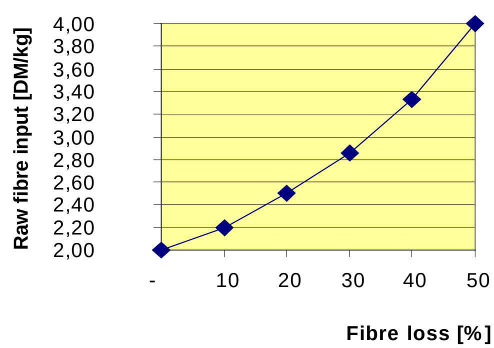


Figure 2: Additional costs through losses in good fibre yield

The example in figure 2 shows the costs added through the loss of good fibres during processing for a fictive material price at 2 DM/kg. It is important to emphasise, that the good fibre yield (after processing) per ha is a more important figure than the tons biomass/ha. This implies that the raw material must be adapted to specific processing e.g. decortication and refining.

Another parameter which is very important especially in the field of a technical application is the coefficient of variation CV. Unlike man made fibres, the CV-values for natural fibres are higher and therefore need more attention in processing. In general, narrowing the CV by selection means additional costs because of severe losses.

Mass Potential of Bastfiber Products in Relation to the Added Value

Figure 3 shows a selection of textile and non textile products and their added value. As can be seen from the graph, textile products usually show higher mass potential and higher added value in comparison to technical applications. In addition, consumer are much more related to variations in the homogeneity of the material. In case of linen, the inhomogeneity of the look is even a marketing aspect. However, traditional linen has its own market but this market has not shown any substantial increase during the last decades. Only newly developed fine short fibers from e.g. a chemical treatment may have a chance when spun on traditional cotton or wool spinning frames.

The demands in technical applications are much higher at lower costs. Man made fibres can be designed specifically to the individual application and the quality can be guarantied year by year. In addition, quality assessment is already standardised. Thus competition of bast fibers in this sector with man made fiber will be tough on high level applications. At low level applications bast fibers compete normally with other renewable resources like wood, the cost benefit for the farmers are only profitable at with high subsidies.

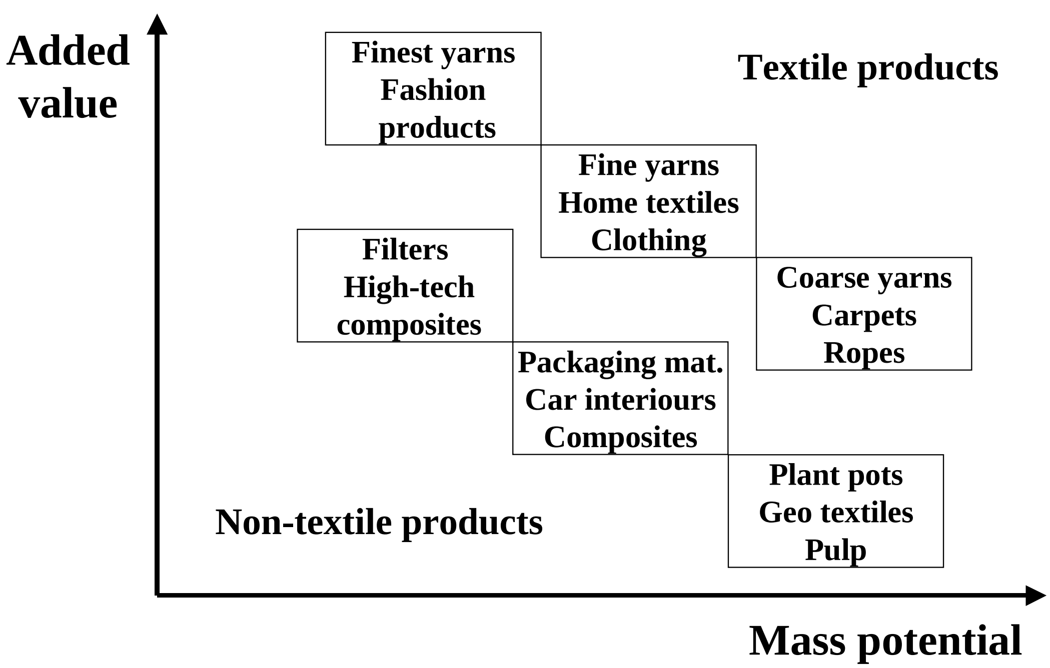


Figure 3: Added value versus mass potential of bastfibre products

LONG TERM SOLUTIONS

Cooperative Structures

An improvement of the economical situation for the farmers requires a long term solution. The future for novel applications of natural fibres is promising if we succeed in linking together farmers, fibre producers and product manufacturers thus creating cooperative and competitive structures to overcome the limitations associated with using natural fibres.

Institutional cooperations, research into new processing methods and products and a reasonable market promotion are necessary to guaranty a constant industrial supply, high quality manufacturing and consumers‘ acceptance on a long term.

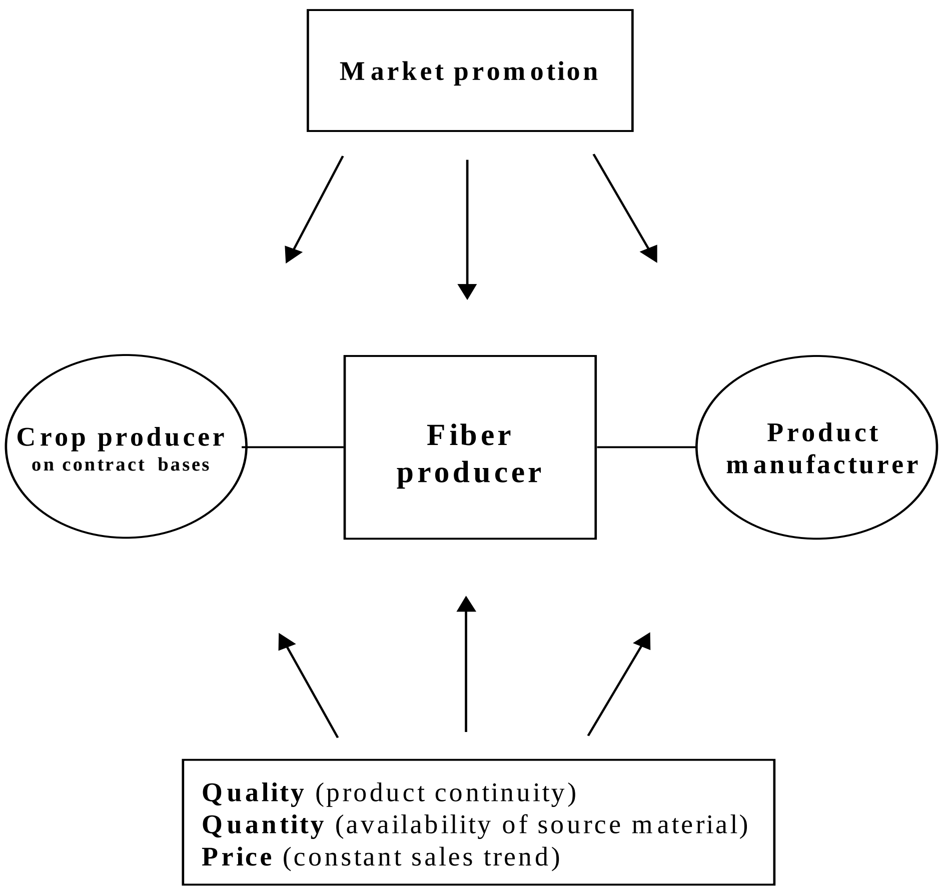


Figure 4: Cooperative structures between farmers, fibre producers and manufacturers

This strategy is opposed to the actual trend in the industry, where shareholder values override flexibility. Companies like this need a huge infrastructure to produce mass commodities at low cost. However, the trend in SME is more directed to supply complex systems rather than a single product. This demand can only be satisfied by closing the chain in high added value products, ranging from the farmers to the end users.

Adaptive Processing for Tailor Made Fibres

From raw material to the final product- integration of all steps in the processing chain create new opportunities for intelligent products at lower costs (3,4). Highly flexible structures are necessary to fulfil the future consumer demands individually.

The basic steps in hemp and flax processing are:

- Harvesting/Retting and Decortication
- Cleaning and Refining
- Final Preparation

The first steps in hemp and flax processing (e.g. cleaning, refining) are in most cases a mechanical treatment of the material which should lead to a coarser, but very clean fibre. For medium and lower added value products, the fibre can go then directly to the preparation step (aftertreatment) which is specific to the final application e.g. producing non wovens for composites.

The next step can be either a mechanical refining of the fibres or a chemical treatment depending on the final application. Mechanical refining is well established and leads to fibres which can be used in a spinning mill to produce coarser yarns (Nm10-12). Alternatively, fine fibres with a high elementarization can be produced chemically esp. by steam explosion (Stex) (5). In this technique, saturated steam at about 160 °C degrades the middle lamella of the fibre bundles and due to the sudden release of the pressure, the material is mechanically separated into single fibres. This technique provides fine fibres which can be spun on a traditional cotton line to finer yarns in the Nm range 20-25. Finer fibres also perform a lot better in Natural Fibre Reinforced Composites, as each individual fibre contributes to the overall strength (6).

A further disintegration at higher severity's of the treatments yields into a total disintegration of the supramolecular structure and produces pulp.

Enzymatic treatments esp. after the chemical refining step, allows to create highly specific materials on demand.

For each application there are highly specific targets which have to be matched individually. However, there are also some "overall" general targets which should be achieved.

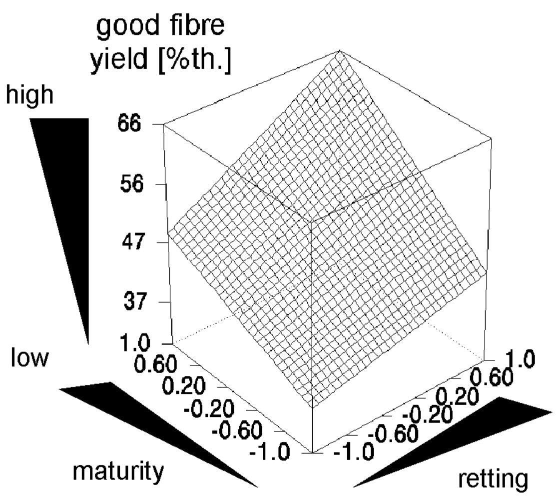
- Decortication ability resp. Decortication Resistance
- Coefficient of Variation of all parameters
- Processability

Besides fibre yield per hectare, decortication ability plays a major role in the economy of the processing line. Clean fibres with high yields are the target for every application with high added values. Any residual shive need further refining in the successive steps of the processing line, thus increasing efforts and costs and decreasing yield.

A major aspect in the state of the art technical and textile application of flax and hemp is the inhomogeneity of the material. All technological and morphological variations as well as the chemical composition shows a broad distribution within the plant and within hectare. This leads to difficulties in assessing fibre quality and successively the raw material cannot be processed optimally. The result is a mixture of over- and underprocessed materials with a lower proportion of best fibre quality. As industry relies (through the tailor made man made fibres) on guarantied and specified raw materials, the CV-value should be small or tailor made by specification.

Processability describes the overall performance during mechanical and chemical processing. For mechanical processing, maturity of the fibre must be high in order to survive the strong impact of the mechanical energy. Chemical composition plays a major role for chemical treatment. Here, pectin, hemicelluloses and especially lignin influences the splitability of the fibre bundles. Fine yarns can only be spun, if all bundles are separated into their ultimate fibre. Best technical performance in composites is only possible with fine fibres, as each individual fibre must contribute to the technological performance.

An example of a process design is shown in figures 5 and 6. The main quality parameter for a mechanical processing is maturity and retting. There seems to be a limit at approximately 60-70% good fibre yield in mechanical production even when a fully mature and well retted raw material is used to produce reasonable fine fibres. Wet chemical processes on the other hand offer the advantage to specifically design the fibre in its morphological variation and chemical composition. As figure 6 shows, there are several solutions possible to produce fine or very fine fibres with high or low admixture (pectin) content.



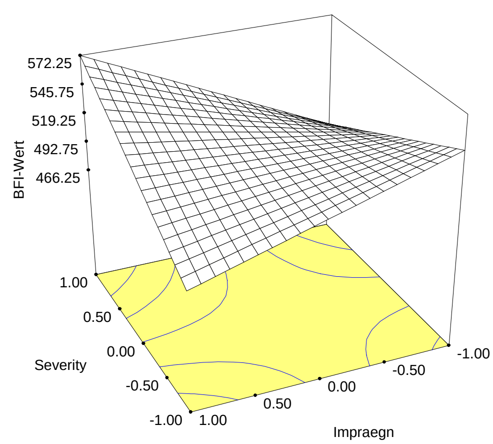


Figure 5 (left): Fibre yield depending on retting and maturity by mechanical refining
Figure 6 (right): Fibre design (fineness BFI) by steam explosion (low values are fine fibres)
(coded values: -1=lower limit, 1=upper limit)

The material can either be designed by the processing parameter Temperature/Time of treatment (severity of treatment) and/or by the addition of chemicals (severity of chemistry).

On line Quality Analysis and Certification

Quality assessment is an essential part of the commercialisation of flax and hemp and plays a key role for optimised processing and high end uses of products. The lack of general valid quality parameters and objective measurements up to now is a restricting factor which inhibits larger consumption. The properties of the raw material defines the adequate processing and the quality of the final product. In the case of man made fibres or even with cotton, the raw material can be used almost as it is. This is not possible in the case of flax and hemp. Each step of fibre extraction and processing alters the properties of the material decisively. Thus, the quality management must include the following steps (7):

- characterisation of the raw material
- characterisation during fibre extraction and processing
- characterisation of the final fibre resp. product

Flax and Hemp processing is a multistep production. Each step can be designed specifically to the quality of the incoming material and the final quality which is specified by the application. Thus each step can be used to balance variations of the raw material and intermediates as well as to optimize according to the specific target values. As demonstrated before, when the process models are known, the options for tailor made products are open. This strategy is called product property design and allows a feed back control but also a feed forward design.

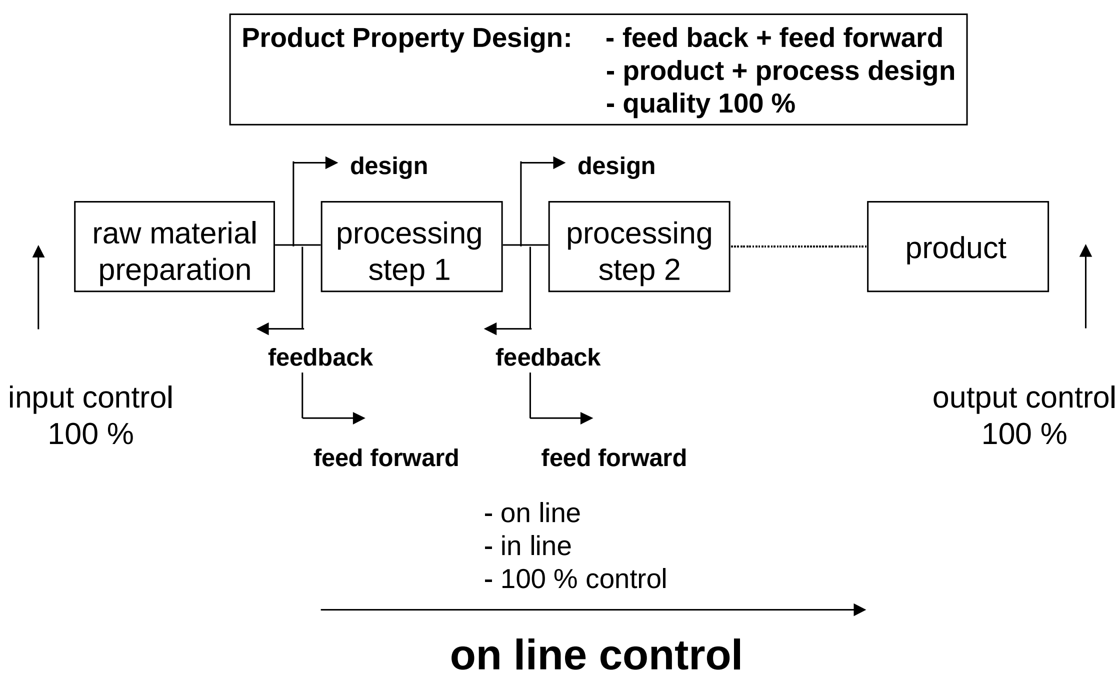


Figure 7: High level control and Product Property Design

Only non-invasive methods allow a direct and full (100%) control of the processing. IR-Spectroscopy is ideally suited to detect and attribute chemical composition on a molecular level. NIR-spectroscopy, but also UV/VIS spectroscopy provides information on the supramolecular as well as morphological (due to stray light measurements) and global chemical structure (due to the specific absorption at certain wavelengths). Detection of the diffuse reflected light gives more insight into the chemical components, the proportion between diffuse and specular reflected light puts an emphasis on morphological structures. Thus UV/VIS and NIR spectroscopy is ideally suited for a fast and non penetrating on line control, resp. quick quality control.

Pectin, lignin and cellulose can easily be identified and also quantified due to their specific absorption in the IR-region. In addition, the specific morphology of the cellulose can also be analysed. Retting degree can be quantified by NIR-spectroscopy and fineness can be determined due to stray light measurements.

Data analysis is a key point in the exploitation of the multidimensional information arrays. A major aspect of the data analysis will be the separation of superposed information, the exclusion of redundant information and especially the reduction of the dimension of the information.

In the first approach, all data can be analysed by means of a factor- or. principle component analysis. Technological data can be correlated to the spectroscopic data by PLS methods. Specific know how of experts can be integrated in the a second approach by the so called "target factor analysis". Moreover, new developments in multiway data mining can analyse intercorrelated data. All these types of data analysis reduce dimensions decisively and also provides true loading plots for the interpretation of the data. A third aspect is the integration of Neural Nets. In modern data modelling methods, the more robust principal component analysis will be combined with the better handling of neural nets of non linear distortions

Nevertheless, the assessment of the final fibre will still be oriented to the standard fibre classification used in cotton and wool industry. Table 1 gives a review of specific targets for a certification which was suggested by industry.

Unlike in the established fibre industry dealing with cotton, wool or man made fibres, there exist no standards for flax and hemp (8).

Technical yarns	Mechanical bonded non-wovens	Various fields of application as reinforcing fibre	Friction linings	Paper production
Fibre length • **mean fibre length** 50-100 mm • **CV_H** < 70%	**Fibre length** • **mean fibre length** 20-70 mm • **CV_H** 50 %	**Fibre tenacity** • **tensile strength** 700 -1100 N/mm^2 or 47-73 cN/tex • **elongation** $\geq$ 2 % • **E-modulus** 40-70 kN/mm^2	**Fibre length** • **mean fibre length** 0,1-10 mm • **CV_H** 50%	**Fibre length** • **mean fibre length** 4 mm • **Long fibre length** 8 mm • **long fibre length** 1 mm
Fineness • **mean fineness** 5-20 dtex or 20-86 µm	**Fineness** • **mean fineness** $\leq$ 5 dtex or $\leq$ 20 µm **Fibre-Fibre-adhesion** high	**Fibre length** • **mean fibre length** 3-25 mm/ $\geq$ 25 mm • **short fibre length** $\leq$ 10 % **Fineness** • mean fineness 3-17 dtex or 10-74 µm **Fibre-Fibre-adhesion** zero **Trash** almost free of dust and wood	**Fineness** • **mean fineness** 10-20 µm **Density** 1,4-1,5 g/cm^3 **Surface area** 1500-10000 cm^2/g **Moisture** 8-10% **Flash point** 300-600° C	**Impurities** • **trash contents** $\leq$ 10% • **fibre fragments** $\leq$ 10%

Table 1: Material and fibre properties for technical applications

SELECTED EXAMPLES

It is beyond the scope of this review to show all possible applications of fibres. The use of fibres in industry may be divided into three fundamental categories:

- Textile Applications (clothing)
- Non Wovens
- Technical Textiles

Textile Applications (clothing):

Germany is still the world's fourth largest textile exporter (1. China, 2.Honkong, 3. Italy) (second after USA on import) with an absolute volume of approximately 20 Billion Euro (1995). There was almost a constant use of cotton throughout the years (50-60 000 tons/a), but a sharp decay in numbers of companies and labour force. Thus productivity has increased dramatically. Although the textile industry shows a bad image, but in terms of volume and added value this is the most suitable industry for bastfibers. As mentioned before, promising new developments must be verified on an industrial level to prove, that fine short fibers from chemically treated flax and hemp can be spun profitable on standard equipment. In any case, only fine fibres from flax and hemp, spun to fine yarns will have a market on a long run. A global figure describes the high added value of textile products (excluding raw material) of approximately 10 Euro/kg on average for yarn and fabrics.

Non Wovens:

More than 700 000 tons of non wovens were produced in Europe in 1995, more than 1 Mio tons are predicted for the year 2005. There was an annual increase in production during the last years, the annual increase in sales was on average between 5 and 7%. The global average selling price of non wovens (end product) on average is only half of the price in clothing textiles, approx. 5 Euro/kg. The use of flax and hemp as insulating material may be promising. Again, only fine fibers may be used as they show a competitive technical behaviour to glass fibers.

Technical textiles/ Composites with high end use

In 1995, more than 2.6 million tons of fabrics and almost 1.5 million tons of composites as technical textiles were produced. The global selling price for those materials was on average 5-6 Euro/kg. Flax and hemp can compete with their strength with glass fibers. Figure 8 shows a graph of gals fiber or natural fiber reinforced epoxy resin. As can be seen, fine fibers show a much higher performance than coarse fibers. Fibers from the Stex-process are as good as glass fiber reinforced materials on absolute values and better in relation to their density. Stex processed fibers with an additional enzymatic aftertreatment are superior to glass fibers (6,8).

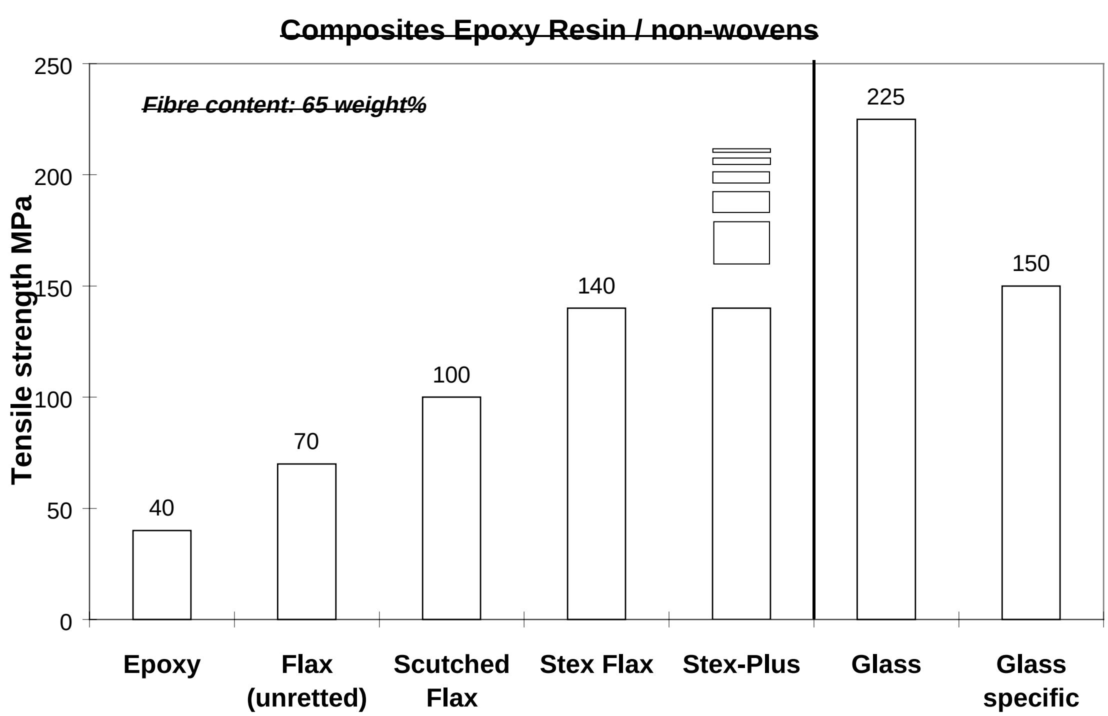


Figure 8: Tensile strength of different composites

CONCLUSION

Although there a numerous new applications for flax and hemp in Europe, there is up to now no benefit for the European farmers obvious. This is mainly due to the high costs in material production and processing relative to the low level applications. Thus, new strategies must overcome this problem. On one hand, cooperation between the different industries is necessary. New processing technologies for fine fibers together with a proper on line qualification and certification must be installed to improve the cost/performance ratio of the fibers. Tailor made high level applications in niche markets may substitute the low level use in industry. In order to increase production on the farmers level a great variety of different, but highly specific use of the inherent fiber properties is much more favourable than a competition between other renewable resources. In all cases, fine fibres show a much better performance than coarse fibers.

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