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Tube Ensiling of Hemp – Initial Practical Experience

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Abstract – Kurzfassung

The conventional production of natural fibres from e.g. hemp or flax is based on field drying and retting of fibre straw. Since at the usual harvest time in September, weather conditions are often problematical for harvesting and retting hemp, a weather-independent post-harvest technique was studied. The harvesting of hemp by means of a chopper followed by anaerobic storage is favourable for the farmer because the weather risk can be avoided. Additional steps are the same as those for ensiling of fodder. As a further advantage of this novel processing technology, the whole plant material will be processed to form final products such as insulation materials and fibre boards, or semi-finished products for injection moulding. At present, a pilot plant with a processing capacity of 1 t per hour hemp silage is being built up and tested. The investigations regarding storage costs and appropriate storage technology have shown that both stack silos and film silos are capable of preserving the raw material for more than one year. Initial results of the preservation of hemp in film tubes are presented.

Keywords: Hemp, wet preservation, tube ensiling, film tube, fibre board

Schlauchsilierung von Hanf - Erste Praxiserfahrungen

Die konventionelle Gewinnung von Naturfasern basiert auf der Feldtrocknung und der damit verbundenen Röste des Faserstrohs. Zum traditionellen Erntezeitpunkt im September sind die Witterungsbedingungen in Deutschland für die Hanfernte häufig ungünstig, so dass das Hanfstroh nicht rechtzeitig abtrocknet. Um dadurch entstehende Ernte- und Qualitätsverluste zu vermeiden, wurde ein neues Verfahren zur Hanfverwertung konzipiert, mit dem das Witterungsrisiko weitgehend ausgeschlossen werden kann. Hierbei wird der Hanf zur Ernte mit üblichen Feldhäckslern geerntet und anschließend ähnlich wie bei der Herstellung von Maissilage feucht konserviert. Unter Verwertung der gesamten Pflanzenmasse können aus dem gewonnenen Faserrohstoff beispielsweise Dämmstoffe, Faserplatten sowie Verstärkungs- und Füllstoffe für den Spritzguss hergestellt werden. Zur praxisnahen Erprobung und Weiterentwicklung dieses Verfahrens wird eine Pilotanlage mit einer Verarbeitungskapazität von 1 t Hanfsilage pro Stunde aufgebaut. Die Untersuchungen zur kostengünstigen ganzjährigen Rohstoffbereitstellung haben gezeigt, dass sich für die Konservierung sowohl Flachsilos als auch Siloschläuche eignen. Es werden erste Ergebnisse zur Bereitstellung des Hanfkonservats durch die Schlauchsilierung vorgestellt.

Schlüsselwörter: Hanf, Feuchtkonservierung, Schlauchsilierung, Silageschlauch, Faserplatte

1 Introduction

During the last 15 years, research and practice in natural fibre technology have shown that alongside their use as textiles, natural fibres can also be used successfully as reinforcing fibres in composite materials, in building materials, as insulation material, and in many other applications. For example, if they are used to replace glass fibres in composite materials, they achieve virtually the same material properties. Further advantages are that natural fibres are cheaper than glass fibres as a raw material, and the composite materials produced with them are up to 30% lighter (Schlößler et al. 2000). The reduction of the weight of products is of major significance, especially in the automotive industry. For farmers, cultivating natural fibre plants represents an alternative crop and alternative source of income. This is particularly true against the background that ever more restrictions in cultivating the other, traditional crops are being considered at present. Furthermore, there are ecological advantages, for example because cropping hemp does not require the use of any plant protection agents (Desanlis 2006). It is advantageous to include hemp in crop rotation because following crops produce up to 30 % higher yields (FNR 1997). Core issues of fibre plant cultivation (Drescher & Brodersen 1997, Mastel et al. 1998,

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Bócsa et al. 2000, Eerens 2003) and suitable harvesting methods (FNR 1997, Basetti & Mediavilla 1998, Gusovius 2002, Mastel & Götz 2002) have been solved satisfactorily during the past few years.

Ongoing research focuses over all on improvements in fibre retting and decortication to produce high quality fibres for the automotive and textile industry (Keller et al. 2001, Munder et al. 2004, Booth et al. 2004, Tofani 2006, Toonen 2006).

Disadvantages at present are above all the higher prices of natural fibre products for the final consumer by comparison with traditional construction and insulation materials. These prices result from the costs of processing the fibre. For farmers, in turn, the proceeds gained from natural fibre straw hardly cover costs, now that the EU subsidy has been reduced.

This results in the following conflict at present:

- There are increasingly fewer farmers who are willing to cultivate natural fibres.
- The excessively high final consumer prices for building and insulating materials lead to only insufficient demand, even taking into account ecological aspects and market launch programmes.
- Although it processes increasing quantities every year, the automotive industry prefers to procure cheaper fibres from abroad.

Hence, cost reductions are imperative throughout the entire production chain of bast fibres in order to improve chances for cultivating natural fibre plants in future (Munder et al. 2003). Therefore, a new process for processing of wet-preserved hemp has been developed at the Leibniz-Institute for Agricultural Engineering Potsdam-Bornim (ATB). The implementation in a pilot plant is described below. Because the logistics of raw material supply, raw material price and quality are of major importance for the whole process line the focus of this work was on investigation the ensiling of hemp in film tubes. According to Matthiesen et al. (2006), this technology has the potential to ensure the supply of the pilot plant with high quality raw material at reasonable prices over the whole year.

1.1 *Process for treating wet-preserved hemp*

The global objective consists in developing an alternative process line for processing wet-preserved hemp, characterised by:

- a reduction in process costs,
- reduced investment in plant for fibre pulping and processing the preserved matter,
- simplicity of the plant, coupled with reliable operation,
- integrated quality assurance.

While in the traditional process hemp is mowed at harvesting time, dried on the field and possibly also retted, the preserved material line consists of chopping the hemp from the stand. The chopped material is then preserved in horizontal silos, for example like maize. A new process produces the desired final product from the wet-preserved material directly, using the whole plant mass. In principle two process lines are conceivable (Fig. 1). The right process line has already been realised in a pilot plant.

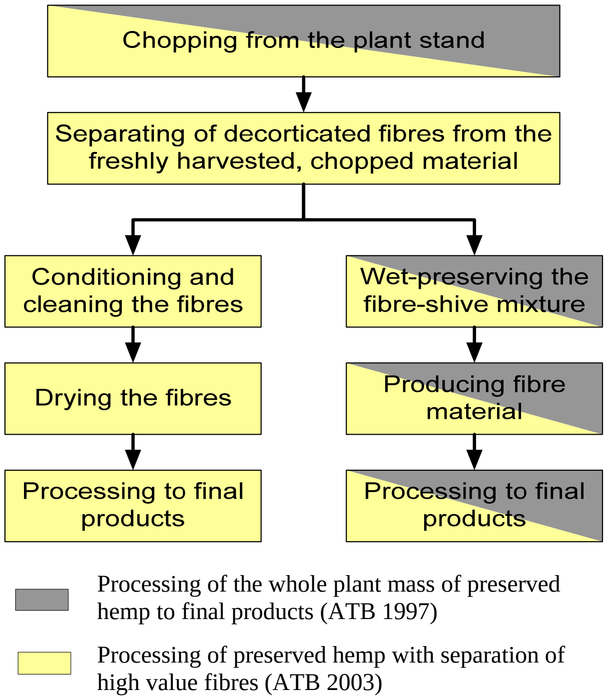

Fig. 1: Technologies for harvesting, preserving and processing of fibre plants

In the first process chain (right branch) the final product is made from the whole, wet-preserved, chopped material. In the second chain (left branch) long fibres are separated by a comb shaker (Pecenka 2004) from the fresh chopped plant material and processed further separately. Only the short fibres and shives are processed using the right process line. The advantages of both process lines consist in reducing the weather risk at harvesting time in September and in processing the whole plant mass to a final product without losses. Applications for products from these process lines are seen in the fields of insulation and construction panels, packing materials, linings, as well as in the use of fibres to reinforce lean concretes.

The processing of the wet-preserved plant material to e.g. fibre boards is carried out using the dry/half-dry method (Kühne 2004) as shown in Fig. 2.

The research work comprises the sub-projects: cultivation, harvesting and preservation, conditioning and processing technology, material and product quality,

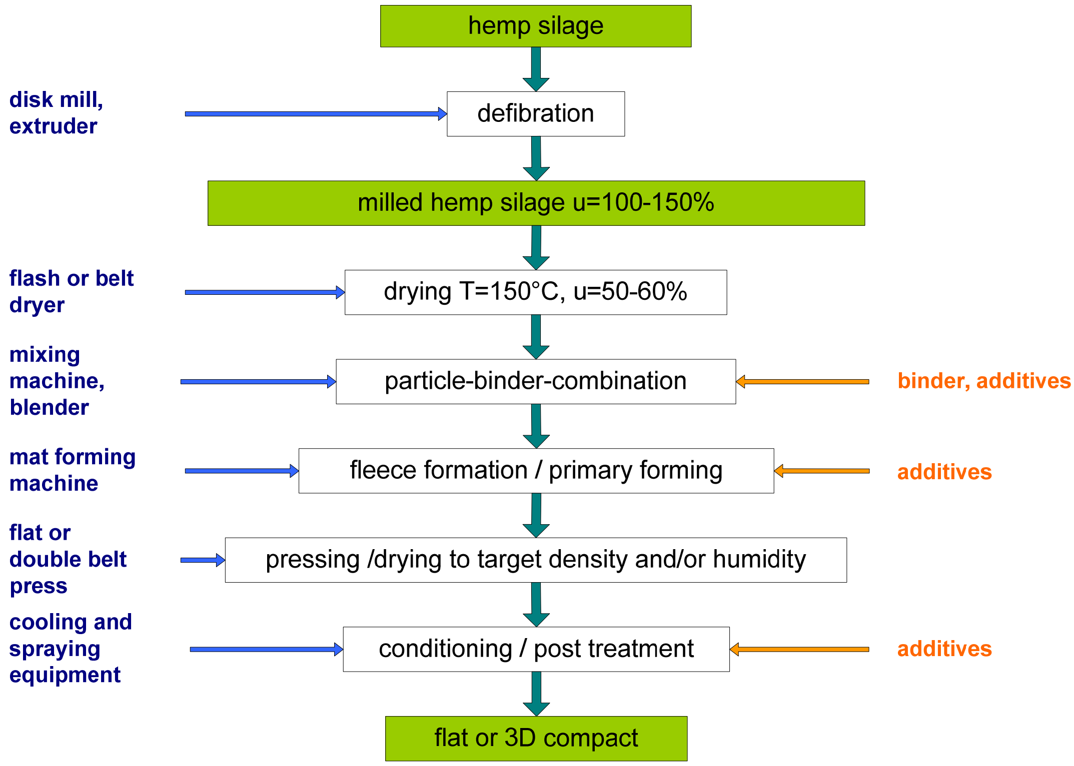

Fig. 2: Process line for processing wet-preserved hemp as realised in a pilot plant at the ATB

and economic assessment of the overall process (Idler & Ehlert 1999, Idler et al. 2002).

To meet the economic targets one main focus of the present research work lies in reducing the costs of harvesting and storing the fibre raw materials. To this end wet preservation of hemp in silo tubes was examined for the first time. The key areas of these examinations were:

- selection and testing of appropriate technologies for harvesting, transporting and storing raw materials under practical conditions,
- securing the quality of the raw material for providing hemp silage throughout the year,
- reducing the costs of raw materials.

1.2 *Cultivation, harvesting and wet preservation of hemp*

In the years 1998 to 2005 ensiling hemp as a raw material was studied for producing compression mouldings. These experiments ranged from laboratory scale (1-litre model silos) through storage in 120-litre drums, up to storage of 100 t hemp silage in a stack silo (Idler et al. 2000).

The objectives of this work were:

- to guarantee a high silage quality throughout the entire storage period,
- to examine the effects of differing ensiling agents on silage quality and raw material properties,
- to analyse the raw material properties, especially the fibre strength and fineness, over a storage period of up to 24 months depending on the ensiling conditions (Müssig 2005, Döring 2006),
- to examine the suitability of different raw materials in accordance with the process described in Fig. 2,
- to examine the properties of fibre panels made from hemp silage using different raw material mixtures and bonding agents.

Former studies by Idler et al. (2000) and Döring (2006) have shown that the quality and properties of hemp silage as a raw material are of crucial importance for the subsequent processability to produce fibre panels and for the product properties. There were some indications that the storage of raw materials in silage tubes is appropriate for ensuring low-cost, good preservation conditions and uniformly high silo compaction (Matthiesen et al. 2006). How far these observations may be applied to the process of wet preservation will be shown in this study.

2 Wet preservation of hemp

2.1 *Material and methods of wet preservation*

2.1.1 *Harvest and storage intake*

Hemp of two different varieties was drilled in May and harvested in August 2005. Three film tubes were taken to preserve the chopped material (Fig. 3).

Fig. 3: Film tubes protected with bird nets

In accordance with the experience gained by Fürll et al. (2006), an additive for accelerated promotion of fermenting quality for medium-difficult and easily ensilable grass and grass-clover in the dry substance range between 25 % and 40 % was selected as an ensiling agent (Table 1).

The tubes were filled as follows:

- tube 1 with the variety Felina 32 without any additive,
- tube 2 with a section of the variety Felina 32 and a section of the variety Fedora 17, both sections with additive,
- tube 3 with the variety Fedora 17 and with the same additive.

2.1.2 Determining the chopping length

The customary procedure for determining chopping lengths using screen analysis could not be applied for hemp chopping. The chopped material contained not only fibres, but also shives and bast components, as well as leaves. While the shives and leaf constituents were visually easily separable, the fibres were not individually separated. They were not severed by the chopper, but instead were in the form of jumbled balls. For initial information on the chopping length, the material was stored in quantities of one kilo at -20 °C until it was processed. The thawed material was sorted into three fractions by hand – fibres, shives and bast, and leaves (Fig. 4). The fresh mass (FM) and dry mass (DM) of all fractions were gravimetrically determined before and after drying at 105 °C for 3 h.

As a screen analysis could not be carried out for these materials, and as manual evaluation of the samples is very time and cost consuming, for graphic evaluation a distinction was made only between the two material

Table 1: Overview of sowing, harvesting and preservation of hemp in 2005

Process/Technology	Parameters
Soil preparation	Plough, disc harrow, cultivator
Sowing	2.5.2005, *Canabis sativa* L.
Varieties	Felina 32 (undressed, Certificate 487754 YC, France, 70)
	Fedora 17 (undressed, Certificate 488781YC, France, 88)
Sowing intensity	40 kg ha^{-1}
Drilling machine	Rear-mounted drilling machine from Messrs. NODET with a working width of 2.2 metres.
Harvesting	17 August 2005 using a CLAAS Jaguar 850 with an RU 450 header chopping length set at 2 cm (tube 1) and 1 cm (tubes 2 and 3),
	125 t chopped material harvested from 5 ha (equivalent to approx. 60 dt DM ha^{-1})
Additive	Silostar Gras from Messrs. H. Wilhelm Schaumann GmbH
	Active agents: sodium benzoate and $2.5 \cdot 10^8$ CfU g^{-1} homo-fermentative lactic acid bacteria (*Lactobacillus plantarum*, *Pediococcus pentosaceus*)
Application rate	1 kg t^{-1} silage material
Doser	Silamat spezial, Messrs. H. Wilhelm Schaumann GmbH
Preservation method	Tube ensiling
Silage press	AG BAGGER G 6700 from BAG Budissa Agroservice GmbH
	Product taken up via a feed table with rubber belt
	Compaction: tractor operated press (130 hp) with rotor, steering via windscreen brake system, Tunnel diameter: 8 ft (2.40 m)
Film tube	AGRAR-bag, film thickness: 240 µm
Protection	Bird protection netting, Type: Agrifil, material thickness: 290 g m^{-2}

Fig. 4: Manually sorted, hand-chopped material: a) chopped material, b) fibres, c) leaves, d) shives

fractions of fibres and other plant components (shives, bast, leaves) relevant for further processing. This evaluation made on the basis of the dry matter content showed that about two thirds of the approx. 30 % by weight fibre component present in the hemp plant is already exposed completely by harvesting with the chopper. Fig. 5 provides an overview of the connection between theoretical chopping lengths and efficient chopping lengths. It turned out, that setting a shorter chopping length also leads to a more exact cut. The proportions by weight in size categories with lengths below 10 mm and above 20 mm are then much smaller.

2.1.3 *Chemical analysis*

The starting material and preserved samples were examined for dry matter content, pH value and crude fibre and total sugar content. In addition, the fermentation acid spectrum and the alcohol contents of the preserved samples were determined. During storage the cell juice pressed out was examined for selected in-

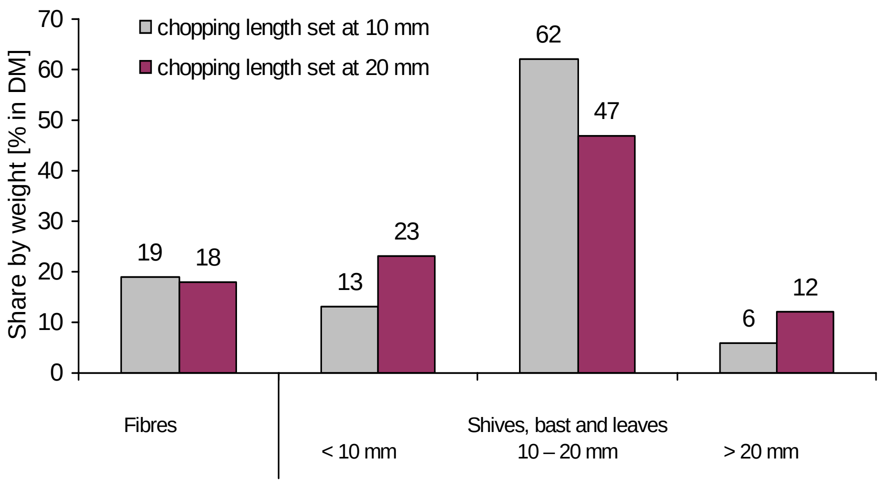

Fig. 5: Chopping lengths of hemp (n = 2)

gredients. In addition to the dry matter content and the pH value, the crude fibre and crude protein content, the content of organic acids, the nitrogen and phosphorus contents, and the contents of saccharose, fructose and glucose were determined (Table 2). Five samples distributed over the length and cross section from the core zone of the tube were drawn as samples of the preserved material. The samples were taken at the storage intake and after 36 weeks storage.

2.2 *Results and discussion of wet preservation*

2.2.1 *Storage intake*

Three tubes of roughly the same length were filled with the chopped material with a mean pressing density of 600 kg m^{-3} (Table 3). The tubes were filled as described in chapter 2.1.1. The hemp choppings had a DM content of between 22 and 25 % FM at the time of harvesting (Table 3). The material was thus at the lower limit for use of the ensiling additive. The sugar contents determined were altogether in the upper range of the other values determined. For the variety Felina 32, the values fluctuate between 1.8 and 6.6 % DM. Hemp of the Fedora variety shows a lower sugar content than that of the Felina variety, according to our investigations. The contents determined varied in the course of the years 1997 till 2004 between 0.9 and 3.9 % DM. The crude fibre contents were within the expected ranges.

During storage in the film tubes an unexpected considerable flow of pressed cell juice could be observed in the material. The volume was not determined. The analytical parameters listed in Table 4 were determined for possible use of the juice, e.g. as an additive in fermentations as protein enrichment of the material.

Table 2: Methodology of the parameters examined (VDLUFA 1997, Idler et al. 2000)

Parameter	Method
Dry matter content	VDLUFA MB. Vol. 3, chapter 3.1
pH value	VDLUFA MB. Vol. 3, chapter 18.1
Crude fibre	VDLUFA MB. Vol. 3, chapter 6.1.2
Crude protein	Calculated in accordance with nitrogen determination
Total sugar	VDLUFA MB. Vol. 3, chapter 7.1.1
Saccharose	In-house methods, Idler et al., 2000
Fructose	In-house methods, Idler et al., 2000
Glucose	In-house methods, Idler et al., 2000
Fermentation acids/alcohols	In-house methods, Idler et al., 2000
Organic acids	In-house methods, Idler et al., 2000
Nitrogen	VDLUFA MB. Vol. 3, chapter 4.1.1
Phosphorus	VDLUFA MB. Vol. 3, chapter 2.2.2.6

2.2.2 *Quality of the preserved material*

After 36 weeks the quality of the preserved material was assessed for the first time. As the tubes were lying on a slight slope, a substantial amount of fermentation juice was to be expected when they were first opened. Approx. 150 l seepage juice per tube was caught and disposed of as waste. During the next sampling four weeks later (data not shown) no notable further quantity of seepage juice had developed.

Table 3: Characteristics of the film tubes and the parent material (n = 3)

Parameter	Dimension	Tube 1 Felina 32	Tube 2 Sect. Fedora 17	Tube 2 Sect. Felina 32	Tube 3 Fedora 17
Weight	t	42.5	17.5	25.0	40.1
Additives	kg t FM^{-1}	0	1 (Silostar G)		< 1 (Silostar G)
Tube length	m	13.5	14.5		16.5
Tube volume	m³	61	66		75
Pressing density	kg m^{-3}	695	585		540
$DM_{105\,°C}$	% FM	23.1	22.5		25.3
pH value	-	7.4	7.2		6.9
Total sugar	% DM	5.8	4.7		3.6
Crude fibre	% DM	45.5	40.3		38.4

Table 4: Selected ingredients of the cell juice pressed out of Felina 32 hemp choppings

DM $_{150\,°C}$	% FM	5.7
pH value	-	6.1
Phosphorus	mg l^{-1}	346.6
Nitrogen	% DM	4.0
Crude protein	% DM	24.8
Crude fibre	% DM	0.5
Saccharose	% DM	13.4
Glucose	% DM	25.3
Fructose	% DM	39.4
Organic acids	% DM	0.4

As expected, as a consequence of adding the ensiling agent the pH value dropped by comparison with the untreated control (Table 5). Compared to tube 2 the higher pH value in tube 3 can be explained by an insufficient application volume. The parameters set at the doser had changed without this being noticed during the harvest. It can be concluded from the retained amount of additive that only approx. one third of the intended quantity was applied.

The crude fibre component in tube 1 remained nearly unchanged by comparison with storage outtake after 36 weeks, and dropped slightly in tubes 2 and 3. The total acid quantities formed varied substantially, however. Whereas the lowest acid content was formed in tube 1 as expected, the figures were much higher in tubes 2 and 3 with approx. 80 g kg DM^{-1}. This is attributable to the effect of the ensiling agent ensuring a good preservation. Since the differences of the sum of organic acids between tubes 2 and 3 are not particularly distinct, it can be concluded that the additive application rate plays a minor role. By comparison with grass ensiling usually amended with 1 kg t FM^{-1}, we assume that hemp requires lower additive amendments to achieve the same preservation during ensiling. A sensory examination showed that the material in all tubes was well structured and had an aromatic odour that was a little more intensive in tubes 2 and 3. The silage was also free of visible mould infestation and spoil-causing agents.

2.2.3 *Mechanical properties of the preserved fibre material*

The mechanical properties of the fibres in the hemp silage have been investigated regarding the established test methods for hemp fibres. The fineness of the hemp fibres has been determined with the Airflow method and specified as FBAI value (FIBRE Bastfaser Airflow Index) according to the test standard of the Faserinstitut Bremen (Müssig 2001, FIBRE 2002). The tensile strength of the fibres has been tested according to DIN EN ISO 5079 for staple fibres.

The strengths of the hemp fibres determined for fibres directly after chopping with a forage harvester nor-

Table 5: Characteristics of chopped hemp after 36 weeks of anaerobic storage (n = 5)

Parameter	Dimension	Tube 1 Felina 32 Without additive -	Tube 2 Section Fedora 17 Additive Silostar G 1 kg t FM^{-1}	Tube 3 Fedora 17 Additive Silostar G < 1 kg t FM^{-1}
DM $_{105\,°C}$	% FM	22.9	24.8	25.7
pH value	-	5.4	4.8	5.2
Sugar	% DM	0.5	1.7	1.3
Crude fibre	% DM	44.4	37.1	35.7
Ethanol	% DM	n.d.	0.3	0.9
Propanol	% DM	n.d.	0.1	0.1
Lactic acid	% DM	1.7	6.5	4.0
Acetic acid	% DM	0.1	1.3	2.2
Propionic acid	% DM	0.1	0.1	1.0
i-butyric acid	% DM	n.d.	0.2	n.d.
n-butyric acid	% DM	n.d.	0.1	0.1
i-valerian acid	% DM	n.d.	n.d.	0.1
n-valerian acid	% DM	n.d.	n.d.	n.d.
Caproic acid	% DM	n.d.	n.d.	0.2
Sum of organic acids	% DM	1.9	8.2	7.6

n.d. = not detectable

mally fluctuate between 20 and 30 cN/tex, and between 40 and 45 FBAI for the fibre fineness, depending on the variety and the harvest date. The fibre strengths are reduced by up to 50 % as the duration of the preservation increases over 12 months. The fibre fineness normally only increases slightly with the preservation time up to 30-35 FBAI (Müssig 2005, Döring 2006). The investigation of test samples from tube 3 showed values of approx. 13 cN/tex for the tensile strength and of approx. 39 FBAI for the fibre fineness after 36 weeks of preservation.

Initial tests of processing the hemp silage to particle boards in the pilot plant have shown that the raw material provided by means of tube ensiling is suitable for meeting the process and material-specific requirements made in production of high-grade moulded bodies (Döring 2006).

3 Technical - Economic Assessment

Besides the possibility of reducing weather-related risk at harvest time and processing the whole plant mass, it is essential for farmers to obtain a profit from the production of hemp silage. Moreover, farmers will only engage in hemp silage production if the expected profits are higher than profits achieved with competing crops. The objective of the following technical-economic assessment is to compare the cost-competitiveness of hemp silage production with the production of hemp straw and conventional crops. A further aim is to identify ways of reducing production costs and to assess the impact of process optimisations. The assumption made is that farmers are more likely to adopt hemp cultivation if cultivation costs are reduced and higher profits gained. The focus of the analysis is on the process steps of cultivation, harvest and storage. The assessment of further hemp processing steps is subject of ongoing research.

3.1 Methodology and database

The analysis is based on costs and revenues calculated according to the guidelines of the German Agricultural Society (DLG 2004). The decision support tool SunReg was used for cost and profit calculations (Grundmann et al. 2004).

The underlying process steps and respective machines are described in Table 1. Data for standard machines were adopted from KTBL (2004) and Hanff et al. (2005). Since no optimised technology is available for hemp harvesting, a sensitivity analysis is applied to show the impact of the harvest performance on the profit margin of hemp cultivation. The production of hemp straw and rye are used as benchmarks in the following analyses. Economic parameters for rye production are presented to draw some conclusions on the competitiveness of hemp compared with a low-profitability food crop.

Yields correspond to levels achieved under normal climatic conditions and medium fertility soils (Table 6). The yield of hemp silage is higher than the yield of hemp straw, because the total plant is harvested in hemp silage production. Prices were surveyed from expert interviews (Steeger 2004) and literature (Graf et al. 2005). A much lower price is expected for hemp silage by comparison with hemp straw. Transfer payments are considered on the basis of the premiums paid to farmers in the State of Brandenburg in Germany.

3.2 Gross profit margin calculation

Costs for inputs (i.e. seeds and fertilisers) as well as cost for land are the same in both hemp cultivation lines (Table 7). The average cost of leased land in the State of Brandenburg (Germany) is 150.72 € * ha^{-1}. Higher costs for inputs in rye production show that intensities in hemp cultivation are much lower compared with conventional crops. The difference in intensities is particularly evident in the application of fertilisers, herbicides and fungicides. On the other hand, hemp seed costs are notably higher than those for rye.

Total operating costs are disaggregated to identify major cost drivers (Table 7). The operating costs of soil preparation, seeding and fertilisation do not differ between the hemp cultivation lines. The main costs in hemp straw production are related to harvesting, seeding and storage operations. In the remaining operations (i.e. harvest, transport and storage), harvesting is the dominant cost driver in both hemp cultivation lines.

Table 6: Yields and premiums for two cultivation lines of hemp and of rye

Position	Dimension	Hemp Straw	Hemp Silage	Rye
Yield	t DM * ha^{-1}	7.0	8.0	6.4
Price	€ * t DM^{-1}	110.0	75.0	75.0
Premiums	€ * ha^{-1}	285.0	285.0	285.0
Revenues	€ * ha^{-1}	1,055.0	885.0	765.0

Table 7: Calculation of costs for the production and post harvest operations of two cultivation lines of hemp and of rye

Item	Dimension	Hemp Straw[1]	Hemp Silage[2]	Rye
Input costs				
Costs of seeding	€ * ha^{-1}	132.0	132.00	22.19
Costs of fertilisers	€ * ha^{-1}	47.5	47.5	112.9
Costs of herbicides, fungicides, ..	€ * ha^{-1}	0.0	0.0	105.6
Costs of interest	€ * ha^{-1}	4.5	4.5	6.0
Total costs of inputs	€ * ha^{-1}	184.0	184.0	246.7
Operating costs				
Soil preparation	€ * ha^{-1}	117.9	117.9	171.0
Seeding	€ * ha^{-1}	151.7	151.7	22.2
Fertilisation	€ * ha^{-1}	52.8	52.8	15.2
Plant protection	€ * ha^{-1}	0.0	0.0	6.3
Harvest	€ * ha^{-1}	376.4 – 556.4	261.6 – 566.2	120.1
Transport	€ * ha^{-1}	11.8	12.2	64.5
Storage	€ * ha^{-1}	154.1	63.0	92.2

[1] CLAAS Jaguar 850 + RU 450 (cuttings length of 1.5 - 2 cm); rotary windrower (8.5 m) and rotary turner (8.5 m); Round bales (Ø = 1.5 m)
[2] CLAAS Jaguar 850 + RU 450 (cutting length of 1.5 - 2 cm)

The data on harvest performance show a great variance for hemp silage and hemp straw, since harvest technologies for hemp have not been optimised so far. Hemp cutting performances range from 0.4 to 2.9 ha * h^{-1} according to on-field trials, literature (Graf et al. 2005), and expert interviews (Gusovius 2002). Table 8 presents the data used in the following impact analysis.

The ranges of machine and labour demand for hemp cutting are similar in both hemp lines (Table 8). The main difference between the hemp lines results from the fact, that additional machines and labour are needed for the hemp straw harvest to turn, dry, bale and load the straw bales.

Total labour costs are up to three times higher for hemp straw harvest compared with silage harvest (Table 10). Total labour costs make up 10 % of harvesting costs for hemp straw and 5 % for hemp silage. Harvesting costs due also result from high variable and fixed machine costs, which make up 87 % of harvesting costs for hemp straw and 92-95 % for hemp silage. Hemp cutting and baling are the main cost drivers in hemp straw and hemp silage harvest (Table 9). Because of this, improvements in harvest perform-

Table 8: Time need for different hemp harvesting operations

Item	Dimension	Hemp Straw[1]	Hemp Silage[2]
Machine time for cutting hemp	h * ha^{-1}	0.8 – 2.2	0.8 – 2.2
Labour demand for cutting hemp	h * ha^{-1}	1.0 – 2.6	1.0 - 2.6
Machine time for turning and drying hemp	h * ha^{-1}	0.2	-
Labour demand for turning and drying hemp	h * ha^{-1}	0.3	-
Machine time for baling	h * ha^{-1}	0.4	-
Labour demand for baling	h * ha^{-1}	0.5	-
Machine time for loading bales	h * ha^{-1}	0.2	-
Labour demand for loading bales	h * ha^{-1}	0.3	-

[1] CLAAS Jaguar 850 + RU 450 (cuttings length of 1.5 - 2 cm); rotary windrower (8.5 m) and rotary turner (8.5 m); Round bales (Ø = 1.5 m)
[2] CLAAS Jaguar 850 + RU 450 (cutting length of 1.5 - 2 cm)

Table 9: Costs per hemp harvesting operation

Item	Dimension	Hemp Straw[1]	Hemp Silage[2]
Cutting hemp	€ * ha^{-1}	203.5 – 383.5	261.6 – 566.2
Turning hemp	€ * ha^{-1}	17.2	-
Baling	€ * ha^{-1}	146.3	-
Loading	€ * ha^{-1}	9.5	-
Total harvesting costs	€ * ha^{-1}	376.4 – 556.4	261.6 – 566.2

Table 10: Hemp harvesting costs

Item	Dimension	Hemp Straw[1]	Hemp Silage[2]
Total labour costs	€ * ha^{-1}	41.5 – 63.3	12.5 – 34.3
Total variable machine costs	€ * ha^{-1}	152.9 – 194.9	103.5 – 267.1
Fixed machine costs	€ * ha^{-1}	177.1 – 291.7	142.7 – 257.3
Interests	€ * ha^{-1}	4.5 – 6.1	2.9 – 7.5
Total harvesting costs	€ * ha^{-1}	376.0 – 556.0	261.6 – 566.2

[1] CLAAS Jaguar 850 + RU 450 (cuttings length of 1.5 - 2 cm); rotary windrower (8.5 m) and rotary turner (8.5 m); Round bales (Ø = 1.5 m)
[2] CLAAS Jaguar 850 + RU 450 (cutting length of 1.5 - 2 cm)

ance will result in major cost reductions in both hemp lines. Especially measures that reduce the hemp cutting time and the required amount of fuels and lubricants per unit of product should be prioritised.

The impact of optimising the performance of hemp cutting is presented in Fig. 6. Higher prices paid for hemp straw do not compensate the higher costs in hemp straw production when hemp cutting performances are high. In the case studied, a profit is made at performances of 0.9 ha * h^{-1} hemp silage and 0.8 ha * h^{-1} hemp straw harvest. Profit levels are equal to those for rye production at harvesting performances of 1.5 ha * h^{-1} for hemp silage. Hemp straw production and hemp silage production are about as profitable as rye production under the assumed conditions.

At present, it is not possible to draw a final conclusion on the profitability of hemp cultivation, mainly because of the high variance existing in harvesting performance parameters. Therefore, there is an urgent need to assess hemp harvesting parameters and optimise hemp harvest technology, since the impact of harvesting performance is decisive for the profitability and competitiveness of hemp cultivation.

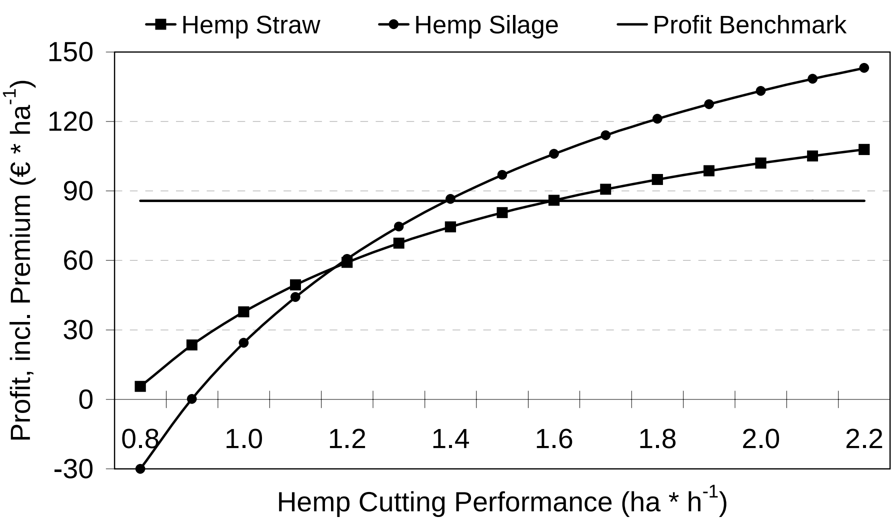

Fig. 6: Impact of harvesting performance on the profit margin of hemp cultivation

4 Conclusions

The first results show that it is possible to produce stable preserved material from chopped hemp by tube ensiling that meets the requirements of subsequent processing in a pilot plant.

The addition of an ensiling agent does not appear to be necessary merely for preservation in the film tube. However, earlier examinations had shown that this additive makes it possible to achieve selected changes of fibre properties, such as for example fineness and strength. That is why further chemical ensiling agents and application techniques will be tested in the coming experiments. As the preliminary experiments showed a positive correlation between the application of formic acid and the targeted property changes of the hemp fibres, this additive will be verified in practical tests. The cell juice pressed out during ensiling is to be recorded quantitatively and qualitatively and new potential uses are to be derived from the results.

Sub-sections of hemp silage processing have already been tested successfully in the pilot plant. These processing tests have shown that the crude fibre materials produced by tube ensiling are sufficient to meet the process and material-specific demands for production of high-grade moulded bodies. Further research projects will be focused on optimising the processing procedures with different raw material mixtures, binding agents and machine settings.

The economic studies on tube ensiling have shown that optimised harvesting technology is of central importance for viable hemp cropping, as over 40 % and more of the total costs of producing raw materials are incurred during harvesting. The main cost factors here are mowing / chopping of the hemp. If an area harvesting rate similar to that for maize could be achieved when harvesting hemp with a field chopper, harvesting costs could be reduced by 20 to 30 %. The comparison of hemp cropping for straw and silage production with rye, a widespread crop in the German State of Brandenburg, has shown that comparable revenues can be achieved at a working rate for chopping the hemp of approx. 1.5 ha per hour. In this case a price of € 75 per ton DM hemp silage and of € 110 for hemp straw was assumed. Thus hemp silage as a raw material is approx. 30 % cheaper for the further processor, but brings the same revenue for the farmer. It is concluded from these results that analysing and optimising harvesting technologies and techniques for producing silage will be a key area of further research work.

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