Organic-PLUS - grant agreement No [774340]

Pathways to phase-out contentious inputs from organic agriculture in Europe

Deliverable 5.3: Version 2

Technical paper on

Twin screw extruder processing technology for fibres as raw material for peat substitution (WP SOIL)

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1. Introduction

1.1 Objective of fibre processing

One important aim of the Organic-PLUS project is to develop resource and energy efficient technologies to produce fibres from lignocellulosic plant materials as a raw material to substitute peat. For this purpose, Leibniz Institute für Agrartechnik und Bioekonomie (ATB), Germany leads the work in the task 5.3, "Processing of agroforestry and other plant material for improved characteristics". This report (D5.3) describes one technology available at pilot scale at ATB which changes the characteristics of plant fibres to make them better suited for peat replacement. The process is called extrusion, and will be described in some detail below. The purpose of this report is to inform stakeholders interested in peat replacement, including scientists involved in the Organic-PLUS project, to collect relevant materials for extrusion and to test further utilisations of extruded fibres.

In the extrusion process, a range of different sources of lignocellulosic material can be processed:

- Chipped wood from agroforestry such as poplar or willow (most common).
- Chopped forest residues e.g. prunings, sticks and branches.
- Material from landscape management.
- Grape vine and olive prunings.
- Other plant remains (e.g. perennial herbs).

These various raw materials have different properties which effect the processed fibres and their quality. As it is our intention to provide an alternative to growers who are used to using peat, we are interested in producing a material that behaves in a similar way. In particular, the water holding capacity of the fibres produced should resemble that of peat. Furthermore, the C:N ratio of the fibre mix after processing is supposed to be approximately the same as peat. This may require various additives to be used together with various types of fibres. The conditions during storage or other further treatment of the fibres or mixtures will also significantly affect the final product (Figure 1).

Even successful peat replacement media for organic nursery plants (Tolhurst, 2019 personal communication) based on woodchip compost may require up to 33% "light" material (e.g. vermiculite) to improve airflow, structure and density of the growing media. Processed fibres which could replace the vermiculite additive and present a more "peat like" property would make a total phase-out of peat even in the most challenging growing conditions, such as for nursery crops, plug plants and mushrooms casings a possibility. The required additional wood processing and energy input would make vermiculite (a clay based phyllosilicate product mined and usually imported into the EU[1]) not necessary and replace it with a locally produced bio-economy alternative.

A twin-screw extruder has proven to be an energy and resource efficient way to produce natural fibres from woodchips. Here, two screws operate side by side reaching into each other, crushing and ripping the material and causing heat up to 100 °C and pressure up to about 500 kPa. Due to the repeated

[1] Vermiculate, although allowed in organic production, has be in the discussion regarding health risks and Vermiculite mines throughout the world are now regularly tested for it and are supposed to sell products that contain no asbestos, which at least for the largest mine in Montana, US was not always the case.

sudden expansion of pressurized heated steam which is created within the extrusion process caused by the moisture inside the woodchips, and the high friction forces, the woodchips burst apart into fibres and exit the aperture. A twin screw extruder results in high homogeneity of the end product (Kuschel, 2004).

1.2 Requirements on fibre quality /materials for peat replacement

Physical properties such as bulk density, total pore volume, pore size distribution, as well as water-retentiveness and air capacity are of interest. Chemical properties like C:N ratio, ash content, nutrient content) and pH are of interest as well.

According to Reinhofer (2006) a good fibre for replacing peat should have the same or similar properties as peat:

low nutrient content
- high air volume (even at full water saturation) - substrate loosening
- high water storage capacity
- possibility for exact adjustment of the pH value
- low nutrient content, to facilitate controlled fertilization by addition of nutrients
- free of pathogens, pests and viable plant seeds
- low decomposability
- high homogeneity
- consistent quality (over years)
- be tolerated by crop plants
- low nitrogen immobilization
- low bacterial activity
- low salt content

Many of the peat properties listed by Reinhofer (2016) above can already be achieved with good woodchip compost, however, to replace vermiculite, the following specific properties are necessary:
1. adding high air volume (even at full water saturation) - substrate loosening to the woodchip compost
2. high homogeneity (good for special substrates and as mixture to other peat replacement material)
3. consistent quality
4. free of pathogens, pests, vegetation

Issues like ‘no nitrogen immobilisation’ and ‘low microbiological activity’ are not important as wood compost is nutrient rich and microbiologically active, which is desirable under organic conditions, even for mushroom casings, if not interacting adversely with mushroom growth.

1.3 Characteristics to measure

There are several different standards and methods to test the described properties of the produced fibre. Dependent on the purpose the fibre is intended for, various characteristics may be measured. For our purpose, EN13041 "Soil improvers and growing media. Determination of physical properties. Dry bulk density, air volume, water volume, shrinkage value and total pore space" will be used. Measuring all these characteristics in fibres is time and resource consuming. Hence, initial studies of some extruded plant materials and discussions about their suitability, are required before systematic measurements of these characteristics are conducted for a range of samples.

2. Processing of lignocellulosic materials from agriculture to fibres

2.1 Process chain

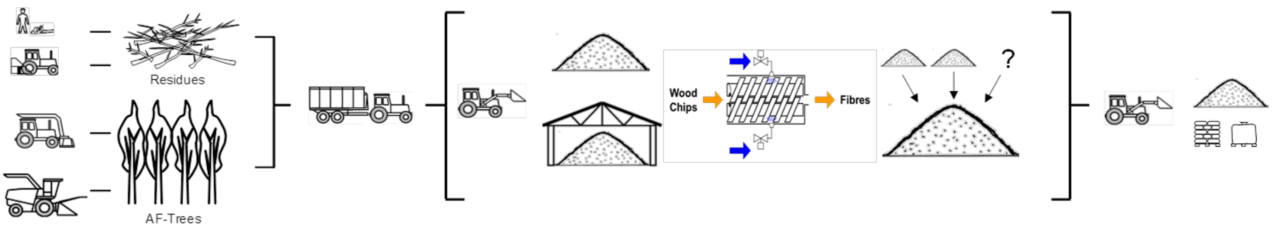

Figure 1 Process chain of lignocellulosic materials from agriculture/forest residues to fibres. (Source: ATB)

Figure 1 shows how the raw materials such as forest residues and agroforestry trees are processed into fibres. Trees from agroforestry are cut by a mower chipper or a modified forage harvester depending on the species and size. If the diameters are too wide, they are cut down manually with chainsaws and are processed with a mobile chipper (Pecenka and Hoffmann 2015). Forest residues and horticultural prunings undergo the same process.

After this process, the woodchips are transported to a storage location where it is possible to dry the woodchips to reduce biomass degradation and potential contamination with mould. Once the moisture content of the woodchips is below 20 % they are shelf stable.

Another possibility is to let the material decompose during storage for a period of approximately 6 months to decrease the C:N ratio, for example in poplar from 150 down to 50 (Hofmann, Mendel et al. 2017, Pecenka, Lenz et al. 2018). Microbiological processes within the woodchip pile may heat it up to about 60 °C. A combination of storing and decomposing the woodchips may have a positive effect on the end product. Woodchips are usually stored close to the extruder to minimise transportation costs and carbon emissions.

Shortly before extrusion, dry wood chips are usually conditioned to a certain moisture content to achieve specific properties in the fibres produced. The wood chips are conditioned in a barrel by adding a specific amount of water. The barrel will tumble for 48 to 72 hours to let the wood absorb the water. The amount of water added depends on the initial moisture content of the woodchips and the target moisture content.

Moisture content also has an effect on the energy consumption of the extruder. Adding additives is possible during extrusion or after, when the fibres are mixed. Ultimately the fibres are packaged and stored or shipped.

The possibility of treating relatively moist materials in an extruder, avoiding energy and work required for drying the materials, is a characteristic which adds on to the possibilities of this technology.

2.2 Technical solutions for fibre extrusion

2.2.1 Twin screw extruder

Figure 2. Open twin screw extruder with material inside (left), whole extruder opened (right). (Source ATB.)

As shown in Figure 2, in a twin screw extruder, opposing screws apply mechanical energy to the woodchips. The raw material is crushed, sheared and squeezed. The moist wood chips are split mainly parallel to the fibre bundle structure. During this process the pressure is up to 500 kPa and the temperature reaches approximately 100 °C. A sudden relaxation (steam explosion) results in tearing of the cell structure. The last part of the screw in front of the aperture is designed to force a partial reverse flow. This favours a plug formation (a formation of material being compressed into a plug) and the build-up of an internal overpressure in the 'comminuting' space (space inside the extruder where the material is sheared, crushed and mixed) and leads to a particularly intense pressure and shear stress. The high temperature in the extruder also causes the lignin to reach its "glass transition temperature". This transition is manifested as an abrupt softening of the lignin either at a single temperature (the glass transition "point") or over a relatively narrow temperature range.
(Irvine 1985, Kuschel, 2004)

2.2.2 Single screw extruder

A single screw extruder also operates by mechanical energy input. In the process, material is pressed against the profiled inner casing of the extruder, causing shearing, tearing, crushing and squeezing. A twin screw extruder, however, is more efficient at defibreing than a single screw extruder.

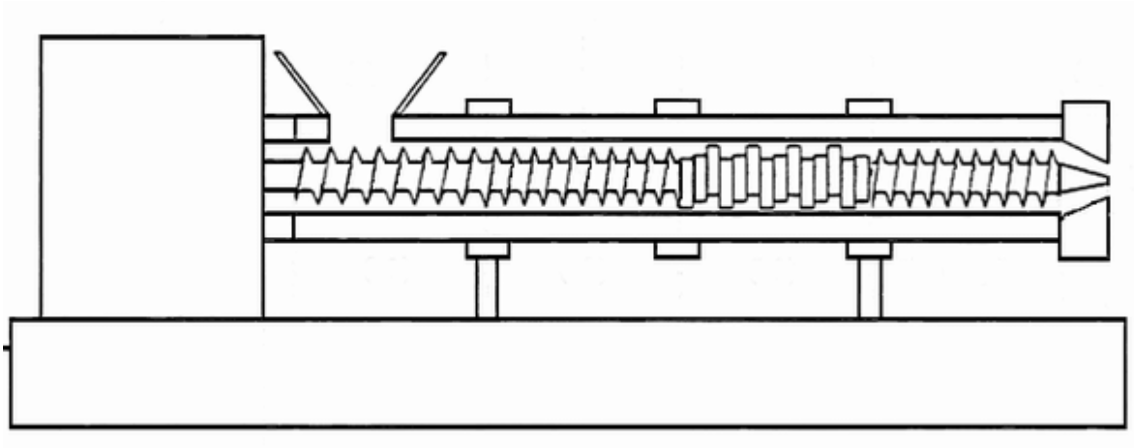

Figure 3 Single screw extruder. (Mehuys 2004)

2.2.3 *Refiner/disc mill (high energy)*

A refiner is a large disc mill operating at high speed, which produces a very good quality fibre. However, the energy consumption is high (1,2 - 2 MWh/t). It operates at very high pressures of about 4,000 kPa and temperatures between 110 °C and 200 °C (Kuschel 2004). These fibres are very clean and mainly used for paper or board (MDF (Medium density fibre board) and HDF (High density fibre board) production.

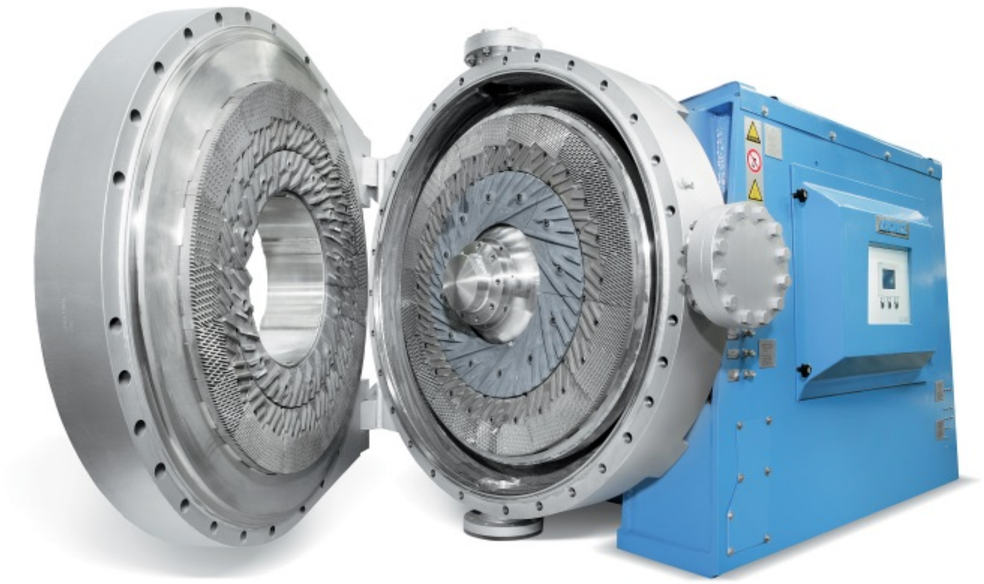

Figure 4. Refiner of the company Andritz (Source: Croce & Wir, Mantscha 160, 8052 Graz - Austria)

2.3 Raw materials and required raw material properties

Many different lignocellulosic materials can be used to be processed to fibres. Most commonly wood from short rotation coppice or agroforestry like poplar (*Populus*), willow (*Salix*) or black locust (*Robinia*) is used because of its high quality. It is important for high fibre quality that no leaves remain on the trees before harvesting. Leaves cause a high proportion of fines and therefore low quality woodchips that tend to mould quickly. However, in a process for producing peat replacing fibres, this may be beneficial. Pruning residues from vineyards and fruit trees are usually cut during wintertime and for that reason have no leaves attached. Harvesting with heavy machinery on frozen soil could also be desirable to minimise soil compaction in agroforestry. Other woody residues from landscape maintenance such as trimming grass and herbal plants usually have a high proportion of fines and are not suitable for fibre, however municipal wood from gardens, parks and graveyards can be interesting if the conifer content is below 25% or the material mixed with other sources.

In order to be able to store raw materials over a long period of time, the moisture content should be below 20 %. Short storage at higher moisture content is possible.

Figure 5 Vine prunings after extrusion and blow drying. Left side (coarser end product) was extruded at 50 % moisture content right side (finer end product) at 40 %. (Source: ATB)

As figure 5 shows, a high moisture content around 50 % during extrusion results in coarser/longer fibres. Low moisture content result in short fibres. At very low moisture content, the produced fibres are very short and appear as dust. If used as a component of compost at a rate of 1/3, even longer fibres might be desirable, which mean less drying is needed and 60-70% moisture could produce an ideal product.

It is useful to condition the raw material before processing to have an even moisture distribution. Higher moisture contents result in lower energy consumption because the friction in the extruder is reduced.

Table 1 Overview of promising material for fibre production (SRC =Short Rotation Coppice, AFS =Agro Forestry Systems)

SRC/AFS	Forestry/ Municipal wood	Pruning	Processing residues
Poplar, Willow, Black Locust	Residues from forest operations, municipal woodlands	Grape vine, Olive, Fruit trees	Spice/Herb production Timber milling residues?

3. Pilot plant at ATB

3.1 Twin screw extruder for biomass processing

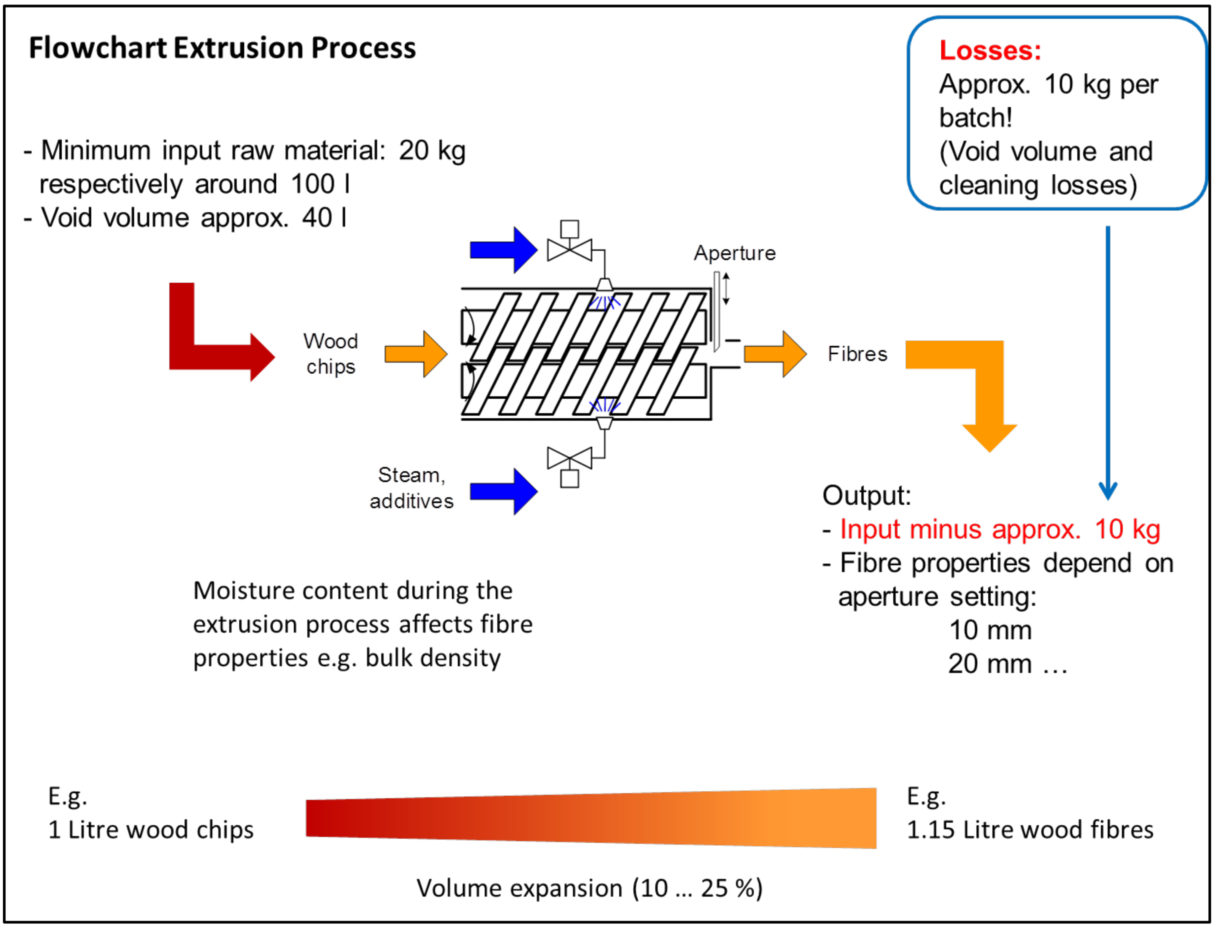

Figure 6. Flowchart showing inputs and outputs of the extrusion process at the ATB pilot plant. (Source: ATB)

Figure 6 shows the simplified twin screw extrusion process the raw material will go through to be processed into fibres. As shown, it is important to have an input of at least 20 kg or rather 100 l of woodchips or other input material depending on the bulk density, since the losses in the process due to void volume and cleaning range around 10 kg. Volume expansion ranging between 10 and 25 % occurs during the extrusion. Within the extrusion process it is also possible to add:

- steam in order to have a higher processing temperature up to 160 °C, which softens the lignin more, resulting in better defibred material,
- water to reduce friction and therefore energy consumption as well as getting a longer fibre
- other additives such as ash, biochar or lime.

The setting of the aperture opening has the greatest effect on the fibre properties. A large opening results in a coarse, long fibre, a small opening in short, small and fine fibre.

3.2 Basic information about energy consumption and throughput

The processing capacity of the extruder (drive power 90 kW) in the ATB pilot plant is set around 300 kg/h (dry matter). This value only applies if the whole setup is perfect and the raw material has properties comparable to agricultural silages such as corn silage (high water content above 50 %). The usual throughput is below 300 kg/h, commonly between 200 kg/h and 250 kg/h (dry matter). The more water is added to the process, the faster material passes through because the friction is reduced also resulting in reduced energy consumption and a lower milling effect. Therefore more material can be fed but at the cost of particle size (Figure 5). Higher moisture content, leading to longer fibres with more throughput and less energy could therefore be a win-win.

Several extruder settings are adjusted during the process, such as aperture, screw speed, feeding speed and filling level. The optimal settings will depend on the input material characteristics and the characteristics required of the output material.

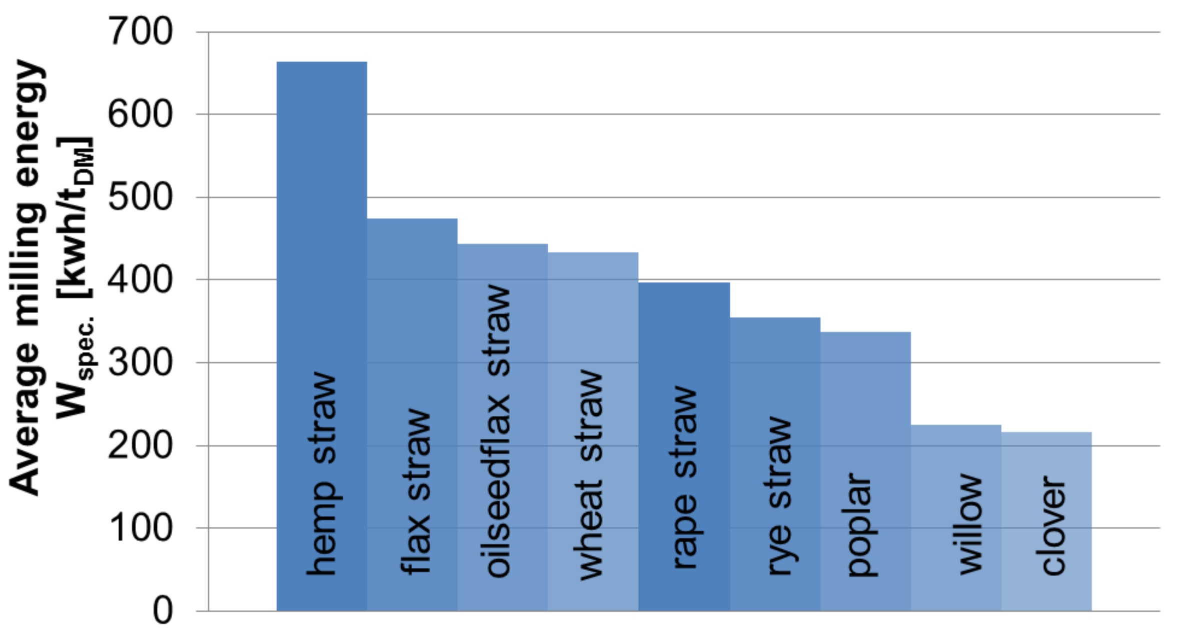

Figure 7 Average milling energy consumed by the extruder in kWh/t_{DM} at moisture content of approx. 40 % for various types of input material (Source: ATB)

As shown in Figure 7, the specific energy consumption ($W_{spec.}$) by the pilot extruder at ATB ranges between 210 kWh/t_{DM} for clover and 660 kWh/t_{DM} for hemp straw. The moisture content for each material in this study was set at approximately 40%. The machine parameters were not changed during these trials.

3.3 Conclusions

All this opens the opportunity to make fibres ‘to measure’ based on the needs as an additive to phase-out peat and vermiculite in growing media and the most suitable wood resources as inputs in different European countries.

However, in order to get a fibre that has a specific quality, it is quite difficult to adjust the extruder the right way. As described, different settings of the extruder as well as properties of the raw material both influence the fibre. This results in a high number of tentative tests to be able to adjust the pilot plant extruder to a specific setting.

Therefore, in the future, we will test further agroforestry material available to us and plant residues supplied by Organic-PLUS partners to demonstrate and fine-tune the effect of different raw materials and sources, and explore how they can be processed in the pilot plant, recording the parameters discussed in this technical paper.

Fibre characteristics for various raw materials and extruder settings will be studied in the further work within task 5.3 of the Organic-PLUS project. Promising fibres will then be studied during composting within controlled conditions at IRTA and characteristics of the composts for peat replacement will be studied. Fibres as a direct replacement of peat in growing media will also be studied.

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