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Towards Efficient Biomass Chains

In attempts to develop more sustainable industrial processes, renewable plant products are an important option. Plant materials can provide primary metabolites (e.g. fibre, oil, starch or carbohydrates, proteins) or secondary metabolites (e.g. dyes, flavours, medicines) for industrial use.

The use of agricultural products for these purposes is not new. In former colonies and the New World in particular, agricultural raw materials were important export products. Large-scale production of these raw materials declined when alternative raw materials, especially from petro-chemical industries, became available. Nowadays, for some types of materials and applications, there is a renewed interest in raw materials from plant resources. Quality characteristics of raw, half or end products or production chains are decisive. The economic feasibility of the production of raw materials from arable farming, however, has changed, especially in Europe. High costs of labour, land and other production factors and the high costs of converting processing plants to make them suitable to process alternative types of material inhibit the large-scale return to plant resources as a basis for various products. Financial outputs per ha of more than 1000 Euro for the production of 5 to 25 tonnes of dry matter are simply not realistic. Investments of tens of millions of Euro per processing plant are only made when there is an urgent need. These disadvantages will only be overcome when strategies change.

Until recently, strategies for production and use of raw materials were characterised by bulk production of a certain crop to obtain a certain raw material (e.g. rape-seed for biofuel or hemp for fibre). The choice of the crop is determined by the wish to supply a certain market, which needs to be created or captured ("push"). This strategy is unsuccessful. Prices of these bulk products are too low for an economically viable cultivation and the required scale for economically viable processing does not allow a gradual development. Breeders of oil crops, for example, have been successful in creating cultivars with specific fatty acid composition, but their efforts have not been rewarded. Worldwide, such cultivars are hardly grown as the breeding, cultivation, storage and processing must be done separately from the bulk. Thus each part of the entire chain becomes economically less viable, as costs increase without adequate compensation by higher prices or yields. Bulk production is efficient when the agronomically most efficient crops are grown at large scale in areas with high yields, low prices of agricultural land and low labour input. The desired diversification can then be achieved by diversification at the end of the production chain, for example using (manipulated) microorganisms (Table 1). Only very efficient industrial crops producing C5 or C6 molecules (like sugar beet, sugarcane or cellulose crops low in lignin) may be used for that purpose. All necessary conversions can theoretically be done by microorganisms or enzymes, provided the basic raw material provides the required biochemical specificity to allow simple and efficient reactions. The area of land needed for such bulk production of C5 and C6 molecules amounts to millions of hectares, the costs should remain below 10-30 Euro per tonne of C5/C6 material.

Recently a lot of energy is put into the development of systems for integrated plant conversion, based on biocascading. In that case no longer one single crop is grown for one single raw material, but a crop can be used for several processing steps each yielding a specific compound by direct extraction (perhaps followed by derivatisation or upgrading), or indirect use or conversion (e.g. by thermal, thermo-chemical or fermentation processes), followed by profitable waste management (e.g. by burning). In this way a wide range of products can be obtained. Examples are biocascading of grass, sugar beet or hemp. The advantages are that the entire biomass can be used and the economic feasibility is no longer solely dependent on one product or market (Table 1). It is even possible to use multi-input (more sources of raw material, including wastes)/ multi-output (many different products) systems, that will increase the value of the original raw material by up to 100% compared to single use. Breeding and cultivation are more flexible and technology can be altered to use crop and other residues. Areas required for one processing plant are several thousands of hectares Production of raw material can be rotated with high value cash crops. Technology, however, is not commercially available yet.

A third strategy is to use secondary metabolites produced in small quantities by plants (Table 1). They often play a vital role in the physiology of the crop (e.g. as protectants) but can be valuable for man. Examples are flavours, medicines, dyes, biocides and repellents. The demands for such products are often directed by the market (pull). These compounds often have complicated structures, are only produced in specific crop species and synthesised through complex pathways, which are difficult to copy in labs. Sometimes it is possible to produce such compounds by cell cultures or by microorganisms but often the only option is growing a crop. Specific examples are the anti-malaria drug artemisin from *Artemisia annua* or taxol from taxus. If the contents of such compounds are low, considerable areas may be needed, although much less than in the cases described above. Breeding can help to increase the contents and proper crop management can change the physiology of the crop to increase yields of the desired compounds. Such production and processing will be high-tech and profitable. Only when such conditions are met, is the one crop/one product strategy feasible.

In conclusion: there are options to use larger quantities of vegetable raw materials, but the strategy depends on the type of product and on the feasibility to use alternative means to upgrade the raw material, either by micro-organisms, by technology or by breeding. Bulk C5/C6 will require changes in processing technology, a diversified production will require development of specific multi-input/multi-output systems and the production of secondary compounds will require additional breeding and agronomic research. If these strategies are properly developed, this will assist in pushing agrification and agricultural production in a new, sustainable direction.

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Table 1. Overview of different types of chains and strategies. (GM = genetic modification)

Type of chain (operationalization)	Type of metabolite (area needed)	Strategy to increase economic feasibility	Barriers	Advantages	Alternatives
Bulk production and processing (push)	primary (Mha)	* yield increase * diversification of raw materials via breeding and GM	* economies of scale * price * market	* renewable * image/profile	* diversification of bulk in end phase
Biocascading (push/pull)	primary and secondary (kha)	* yield increase * breeding for appropriate ratios of desired components * diversification in processing (multi-input/multi-output) * diversification in products	* technology * price * market	* total use * regional chains * flexible	* emphasis on waste management
Fine chemicals (usually pull)	secondary (dha)	* yield increase * breeding for high contents * GM * physiological research	* extremely low yields * small markets	* specific synthesis * image	* export of technology

Non-Food Applications of Crops in Poland

In Poland in 2000, of the 11.1 million hectares that were sown with agricultural crops, industrial crops occupied 5.9% of this area. The major industrial crops in Poland are sugar beet and oilseed rape however their utilisation for non-food industrial production is very limited. The main industrial products obtained from non-food applications of food crops are alcohol and starch, however no data is currently available on how much alcohol is produced for non-food applications.

Cereals

The non-food application of wheat and rye is mainly in the production of alcohol. Domestic production of cereals in 2000, including fodder, was 21.3 million tonnes and industrial utilisation of cereals in was 948,000 tonnes.

To date the only commercial developments for the use of cereal straw are for heating. Straw harvested from 2 ha (yielding 2.5 t/ha) provides enough energy to heat a house of 70 m^2 and the overproduction of cereal straw could provide energy to meet 5% of Poland's demand. Special, small size furnaces are available on the market for burning straw for farms. There are about 20 small boiler rooms and 4 big boiler houses based on combustion of cereal straw but detailed information of utilisation of such units is not available. The majority of the straw produced is currently used for animal bedding or as organic fertiliser.

Potatoes

Cultivation of potatoes in 2000 was 1.25 million ha with a total yield of 24.2 million tonnes. The industrial processing of potatoes is for starch and alcohol.

The production of starch and alcohol in 1999 was 335,000 and 83,000 tonnes respectively. In 2000 a major growth in processing of potatoes for starch was observed up to 800,000 tonnes, but due to unfavourable prices only 15,000–16,000 tonnes of domestic starch was used for non-food application, the remaining 45,000 tonnes was imported, mainly from the EU. The percentage of alcohol production from potatoes decreased considerably in 1999/2000 from 10.1% to only 4.2%. This was connected both with general decrease in alcohol production (from 223 million litres to 180 million litres) and a shift to cereals as a main raw material for alcohol production.

In Poland 80% of raw bio-ethanol is obtained from potatoes. Bio-ethanol is mostly used for combustion in engines as an additive to petrol. High costs of production due to high costs of the raw material (70% of total production costs) limit this application. Over 100 million litres of bio-ethanol are added to engine fuel in Poland.

Rape

Last year (2000) was very unfavourable for rape cultivation and processing and this led to Poland losing its position as one of the major exporters of rape in the world. The cultivation area in 2000 was 436,800 ha with a production of 958,000 tonnes, 15.3% lower than the previous year. Export decreased dramatically from 326,000 tonnes in 1999 to only 28,000 tonnes in 2000. This situation was caused by a combination of drought and very low purchase prices paid to farmers for seeds in 1999. In 2000, 834,000 tonnes of seed was processed, mostly into edible oil and margarine. No data is available currently referring to production of paints and technical oils. There is no commercial production of biofuel from the rapeseed oil despite numerous scientific developments in this field in Poland. The Association of Rapeseed Producers and French partners have prepared a special programme regarding production and utilisation of biofuel based on rapeseed oil that will start next year. As part of a pilot effort in this programme, public transport buses in selected towns have used biofuel in 2001.

Sugar Beet

The area of sugar beet cultivation in Poland in 2000 was 333,000 ha, producing over 13.1 million tonnes of sugar beet, which was processed in 76 sugar plants. The majority of sugar (940,000 tonnes) is for domestic consumption. About 605,000 tonnes were utilised by the food industry and 45,000 tonnes in other fields.

Medicinal Plants

The area of medicinal plants cultivated in Poland is less than 20,000 ha. The total amount of raw material obtained from this area is 17,000-22,000 tonnes. Additionally 3,500-5,000 tonnes are obtained from wild collection.

The top ten herb species grown in Poland are milk thistle *(Sylibum marianum)*, chamomile *(Matricaria recutita)*, cumin *(Carum carvi)*, coriander *(Coriandrium* *sativum)*, salvia *(Salvia officinalis)*, arnica *(Arnica chamisoni)*, mint *(Mentha piperita)*, thyme *(Thymus vulgaris)*, *Echinacea purpurea*, St-John's-wort *(Hypericum porforatum)*.

The domestic market of plant-based drugs exceeds 3,000 different preparations and occupies almost 50% of the middle and eastern European market. This also places Poland as one of the top ranking producers of medicinal plants and manufacturers of medicinal plant products in Europe.

Fibre Crops

The two fibre plants cultivated and processed in Poland are flax and hemp. Despite the potentially vast applications of flax and hemp most of these applications remain theoretical (furfural, cellulose), or at very small scale (insulation material, non-wovens, etc) and the main products are yarns and fabrics. The area of flax cultivation in Poland in 2000 was 5,100 ha (fibre flax 4520 ha, linseed 600 ha). The approximate mill consumption of fibre in the linen industry is 2,500 tonnes per year.

Linen yarn and fabrics are mainly exported to EU countries. However, this export is being reduced from year to year due to subsidies and higher quality of EU products. In 1999 the Polish linen industry manufactured 1,574 tonnes of linen yarn and 6,430 thousand metres of fabrics. These figures also include processing of imported fibre (1,230t of long and 402t of short fibre).

Hemp production in Poland

Fibre Hemp	Area Harvested [ha]			
	1996	**1997**	**1998**	**1999**
World	57,807	58,687	59,008	59,015
Poland	1,296**	240**	158**	101

Source: FAOSTAT Database Results – http://apps.fao.org
*** Polish Flax Foundation, Institute of Natural Fibres, Poznan, Poland*
****INF data (130ha in 2000; 170ha in 2001)*

In the past few years hemp has been grown only for seed. The straw, being a by-product in this case, was used for production of tow, which is used for production of twine and non-woven materials. In 2001 a small area was sown for fibre (about 40 ha) and in 2000 145 tonnes of short and 6 tonnes of long hemp fibre were produced.

Willow (Wicker)

The cultivation area of willow is approximately 1000 ha. The yield obtained annually is estimated at 4000 tonnes. Willow is used mainly for the production of household goods, such as baskets, fancy furniture, etc.

Other Crops

Additionally, different R&D units conduct research on alternative crops as a potential source of valuable raw materials. The most important ones are *Miscanthus sinensis* and *Sida hermaphrodita*, high biomass crops offering also a valuable raw material for pulp and paper industries. Research conducted at the Institute of Natural Fibres, indicates that the average yield of Miscanthus is almost 17 tonnes/ha under Polish conditions. The content of cellulose varies from 39-44%. The content of cellulose in *Sida* is 53%. Both species can be grown for 15-20 years.

Generally, for all crops discussed here, with the exception of medicinal plants, a steady decrease in cultivation area is being observed. In the case of some species, e.g. rape this decrease has been quite dramatic. It is possible that some industrial applications could be taken over by the new, alternative crops under investigation.

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