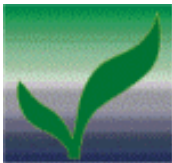


IENICA

REPORT FROM THE STATE OF SWEDEN FORMING PART OF THE IENICA PROJECT

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Preparation of the Swedish Report

The former coordinator for the IENICA project in Sweden, Mr Lars Dahlgren of Federation of Swedish Farmers, invited scientists and technical specialists in different crop areas to submit contributions of the work that has been done in Sweden during recent years, as well as plans for the future. Oral presentations and discussions were held at a seminar in September 1998 in Stockholm with the specialists.

Mr Ragnar Ohlson, formerly professor of Agro-based Chemical Technology at Lund University and chairman of the Steering committee for NUTEK's (Swedish National Board for Industrial and Technical Development) programme "New Environmentally Friendly Products from Renewable Raw Materials" (PROFYT) was asked to write the report. The report has been further edited by Johan Berg, SLR (Swedish Farmers' Supply and Crop Market Association).

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Executive Summary

In Sweden, three crops - potatoes, rapeseed, and wheat - have been the major sources for the production of agricultural raw materials intended for non-food applications, excluding biomass for energy. In recent years interest has also grown for the use of products from linseed, flax and barley. The major non-food products have been developed from either rapeseed oil or starches.

One obvious advantage of using renewable materials is the minimal net effect on global warming. Other advantages include biodegradability of the products and positive effects on agriculture. However, translating these properties into higher market prices remains a challenge.

The report is concentrated on what will happen in the future. Hopefully the results from the various ongoing research programmes will increase the market for agricultural raw materials and the variety of new and improved products. R&D should prepare agriculture and industry for new economical realities in the future. Genetic modification and bioengineering of different crops could certainly have important effects on their composition and yield. In what way this will materialize into new and modified products is, however, a matter of public opinion and law-making concerning genetic modification. Sweden is a country in which the discussion on these issues is rather intensive.

As is the case in other areas, there is a need for new products on the market. This fact is, and should remain, the driving force in the development. Those who are involved in research on, and product development from, crops have a unique advantage. This offers an opportunity for a very close cooperation between the producers of agricultural raw materials and some of their major customers – such as the strong Swedish pulp and paper, packaging and pharmaceutical industries.

The economy and profitability in the production of raw materials for non-food products is often problematic until a certain production volume is reached. One way to overcome this is to use side-streams from the crop in question, when it is grown for food or energy. Combinations where different parts of the crop can be utilized in different ways is also a method. In order to be economically feasible, the crops should generally be harvested with conventional equipment and dried and handled in logistic system similar to that of grain. In establishing a market, there is often a lack of pilot plants or equipment for demonstration. The future of CAP will also certainly have an impact on the economy in growing different crops.

A common problem for most industrial processes based on agricultural crops is the question of secondary products or by-products. Fractionating processes for various crops involving dry and wet methods need to be developed. Creative thinking is required for the secondary or tertiary products. The mass balance of production must be congruent with the balance of sales.

The advantages and general priorities in Sweden for crops grown for non-food uses are as follows:

- a political system that favours environmental protection
- a climate that minimizes the need for insecticides
- skilled farmers and a strong farmers' cooperation organisation
- excellent research and breeding facilities and capability
- a well experienced industry for production of raw materials and products
- a close cooperation between producers and users, such as pulp and paper industry
- the possibility to combine production of industrial products and biomass/energy.

The drawbacks are mainly

- a climate that gives lower production
- no coordinating institution for R&D in "Products from Renewable Raw Materials"
- a lack of pilot-plant facilities and equipment for demonstration
- difficulty of attaining the large production volumes needed for profitability.

Oil crops

The growing of rapeseed in Sweden has decreased substantially during the past few years, being 63,000 ha in 1997, yielding 130,000 tonnes of seed corresponding to 60,000 tonnes of oil. The reason for this decrease is the conditions within CAP.

For many applications, rapeseed oil and its derivatives have better physical-chemical properties than products based on mineral oil. The major non-food uses are as constituents or raw materials for lubricants (chain saw oil, cutting oils and hydraulic oils), paints and coatings, printing inks and surfactants. All these are areas for market expansions. Linseed is grown on an experimental level. Linseed oil is regaining markets in the paint and wood preservation industry.

NUTEK has founded the competence centre "Centre for Surfactants based on Natural Products. The research in the centre is devoted to synthesis, characterisation and application of surfactants based entirely or partly on natural products.

A research programme on "Bioengineering of Plant Lipids" is running within the "Strategic Network for Plant Biotechnology".

Fibre crops

The interest among farmers for growing flax has increased over recent years, mainly due to a favourable EU-policy. Flax fibres have their traditional uses as clothing and blankets. Modified flax fibres are used in non-woven, tissues, absorption products etc. A special grant is given to a project concerning the "Green car". The programme aims at the development of materials based on renewable resources for automotive interior applications. The possibilities to use fibres from reed canary grass are also being investigated.

Carbohydrate crops

The crops grown in Sweden for their high content of carbohydrates are mainly potatoes, sugar beets and wheat. The products are starches and sugars, but also cellulose and hemi-cellulose are of great interest.

Starches have been used in different technical applications for a long time. The main areas of use are found in the paper and corrugated board industries, but starch also finds application for building, as an adhesive and in technical dispersions. Carbohydrates are utilized as substrates for microorganisms producing dextrans, antibiotics etc. Several research programmes aim at process development for the production of organic acids and natural polyesters.

A Nordic research programme on "Plant Cell Biotechnology" has included a successful project on "Analysis of Starch Synthesis for Improvement of Starch Composition". In 1996 a research programme on "Characterisation and Engineering of Starch Metabolism" was initiated within the "Strategic Network for Plant Biotechnology". Many projects on the modification and use of starch are included in the NUTEK programme on "New Products from Renewable Raw Materials". A competence centre, "Centre for Amphiphilic Polymers from Renewable Resources", was founded in 1996. Two companies have a joint research programme on genetically modified potatoes.

Protein crops

The major possible sources for proteins are rapeseed (25 % protein) or cereals such as wheat and barley. Extensive R&D work has been performed for the use of rapeseed protein for human consumption. The vegetable proteins have very interesting physical properties, for instance regarding strength. Applications for protein products can be in the form of fibres and films or as adhesives.

Research on the application of gluten films for packaging purposes has been modest, but this area should be considered for increased future research.

Speciality crops

Plants are known to produce molecules with great variation in specific chemical structure and biological activity. There is on-going research to isolate, identify and characterize plant-derived compounds that can serve as pharmacological tools or drug prototypes.

Oil crops

1. *Opportunities*

1.1 *Science and technology*

The crops that have received the main interest in Sweden are rape (summer and winter varieties of *Brassica napus*) and turnip rape (summer and winter varieties of *Brassica campestris*) as well as mustard seed (*Sinapis alba*), linseed (*Linum usitatissimum*) and crambe (*Crambe abyssinica*).

The products obtained are mainly crude oils and lecithins, but also fatty acids and glycerol are produced. The meal resulting after the solvent extraction and expeller pressing is a valuable feed product with a high content of protein of excellent nutritive value. It gives a substantial contribution to the economy of the rapeseed growing.

The "Swedish Foundation for Strategic Research" initiated a "Strategic Network for Plant Biotechnology" in 1996. The research programme, about 10 MSEK per year (1996-2000), covers three areas:

- abiotic and biotic stress responses in plants
- bioengineering of plant lipids
- characterization and engineering of starch metabolism.

As an example of the research carried out within this programme, the plant lipid bioengineering area involves tailoring oil crops seed fatty acids into advanced raw materials for the chemical industry by genetic engineering. This is done by incorporating genes from wild plant species, possessing seeds with unusual fatty acids, into oilseed crops such as rape or linseed. These unusual fatty acids contain chemical functionalities, such as epoxy or acetylenic groups, that make them easily chemically processed to for instance surfactants or paint binder systems. This research is carried out at the Swedish Agricultural University in Svalöv.

NUTEK has founded the competence centre "Centre for Surfactants based on Natural Products", which is located at The Royal Institute of Technology in Stockholm. It is a cooperation between five academic groups and nine industries. The research in the centre is devoted to synthesis, characterisation and application of surfactants based entirely or partly on natural products. The research programme contains four areas:

- developing the natural raw materials (e.g. sterols, proteins, fatty acids)
- synthesis and characterisation - with the following subareas:
 - surfactants based on sterol hydrophobes
 - biochemical synthesis of surfactants
 - physical chemical investigations of alkyl glycosides
 - interfacial properties of new surfactants
 - synergism of surfactant mixtures
 - interactions between sugar based surfactants and enzymes.
- surfactants in pharmaceutical applications
- technical and environmental aspects of surfactants
(emulsification; foams; wettability and cleaning of hard surfaces; hydrotropes)

Research on tribology of products from rapeseed oil is carried out at universities in Luleå and Lund and at the Institute for Surface Chemistry in Stockholm.

1.2 Industry

The growing of rapeseed in Sweden is limited to approximately 65,000 hectares, yielding about 130,000 tonnes of seed corresponding to 60,000 tonnes of oil. The substantial reduction over recent years (from 1993, when it was 145,000 ha) is due to changed conditions within CAP. Rapeseed is considered a good break crop in the growing of cereals. Gross margin for oilseed rape is given in Table 4 (Annexe 4.2).

Processing of rape seed and oil for technical applications is mainly done in the same way as for food oils by Karlshamns AB. The fatty acid production is about 35,000 tonnes.

1.3 *Markets*

For many applications, vegetable oils and fatty acid derivatives have better physical-chemical properties than mineral oil, and esters have physical characteristics that often are superior to currently used base oils in areas such as lubrication. Long chain fatty acids such as erucic acid (C22:1) find application as a slip agent for synthetic polymer processing or as an antifoamant in detergents. Fatty amines are renewable antistatics.

Vegetable oils find major application in the following areas:

- lubricants based on oil crops, for instance
 - chain saw oil based on rapeseed (used in Sweden for 20 years)
 - cutting oils (manufactured and used in Sweden since 20 years)
 - hydraulic oils (manufactured and used in Sweden since 15 years)
- paints and varnishes (linseed oil is growing in the traditional market for wood preservation)
- printing inks (a substantial increase in use over recent years in Sweden)
- solvents; cleaning agents (mainly as methyl esters)
- surfactants (methyl esters of fatty acids are raw materials for synthesis)

Looking at the chemical industry as a whole, the world annual use of petroleum oil is about 200 million tons. However, only about 10 million tons of vegetable oil is used annually. It is obvious that this number could be increased, if the price/performance ratio could be improved for vegetable oils, compared to petroleum. One way that this could be attained is if the vegetable oils would be produced at a higher degree of chemical functionalisation, i.e., with a large degree of chemical functionalisation already "built in" when the oils are produced in the seed. If so, the chemical processing of the oil would be less costly. This scenario is possible to realize with the genetically engineered oils mentioned above (Swedish Agricultural University in Svalöv). The concept has been called "the plant in the plant".

1.4 *Environmental*

The interest for rapeseed oil in non-food applications is mainly due to a need to substitute mineral oil. The main advantages in using vegetable oils are their biodegradability and non-irritability to skin and lungs. The urge for reduction of petroleum based solvents, due to solvents emissions, in paints increases the use of linseed oil. Linseed also has the advantage of being a good solvent for many alkyds.

Life cycle inventory is being carried out on oleochemical surfactants.

The "plant in the plant" concept mentioned above will have positive environmental effects, for two main reasons. First, the beneficial effect on the greenhouse effect of using renewable resources instead of petroleum is obvious. Secondly, since the produced oils will require less chemical processing than ordinary vegetable oils do, this processing also requires less energy and contributes less to air and water pollution.

2. *Barriers to progress*

2.1 *Scientific*

A major problem connected to the increased use of vegetable oils as lubricants is the low oxidative stability of the oils. This has to be improved by processing or through genetic engineering. On the other hand, directed oxidation is required for use in paints. The aging of linseed paint films must be better controlled. The drier system also needs to be improved to allow for homogenous drying of the paint film

2.2 *Technical*

For crop varieties that are suitable as industrial raw materials, but unsuitable for consumption as food or feed, the growing areas and industrial processing need to be well separated from varieties intended for consumption. This requires care and is sometimes costly. An example is the high-erucic rapeseed, which is well suited for some industrial use, but not for food or feed.

2.3 *Environmental*

A drawback in growing rapeseed is its relatively high requirement for nitrogen fertilization. However, the use in Sweden is lower than in many other countries. The use of insecticides during the growing of rapeseed can also be a problem, even though there is no general spraying of insecticides in Sweden. Insecticides are used only when they are needed, which varies between years. Sometimes there is no need for insecticides in the growing of winter rape in Scandinavia. Linseed cultivation shows fair yield and requires less use of plant protection.

Discussions on the GMO rapeseed, particularly the herbicide resistant varieties, could limit future use. Even if such varieties are accepted for non-food applications, there will be an intense discussion or a problem in keeping the food and non-food varieties separated.

2.4 *Legislative issues*

If the legislation in Sweden followed what is law in countries such as Austria for the use of saw-chain oils, or what is the situation in Germany for the use of hydraulic oils, the market for such products would increase.

If the commonly used phthalates were forbidden as plasticizers in synthetic polymers, a substantially increased market would be opened for epoxidized rapeseed or soya oil, or genetically modified epoxidized oils.

2.5 *Economic issues*

The major problem, to get an overall good economy in the growing of rapeseed, remains. The competition between rapeseed grown and used for food versus for technical products has increased as the rapeseed acreage has been reduced drastically. Therefore, rapeseed oil for technical purposes has to be imported.

Limited funding of research in Sweden will reduce the possibilities or delay the marketing of new or improved products.

Also the level and development of the world market price for mineral oil is of importance for the competition.

It will be necessary to communicate the life cycle analysis implications as an advantage of vegetable-based paints when selecting paint systems, especially for the Do-It-Yourself market.

3. *Prioritisation*

For a discussion of the strengths and weaknesses in growing oilseeds in Sweden, see general priorities in Executive summary.

Fibre crops

1. Opportunities

1.1 Science and technology

The crop species that have attracted particular interest in Sweden are flax (*Linum*) and reed canary grass (*Phalaris arundinacea*).

The research activities at the Swedish Institute for Fibre and Polymer Research in Gothenburg in the field of fibres and polymers from renewable resources are concentrated on

- modified flax fibres for use in non-wovens, tissues, absorption products, packaging materials and fibre-reinforced plastics.
- use of bio-fibres in light construction materials
- biopolymer-based binders and fibres.

A special grant is given to the project “Green car”, which involves development of materials based on renewable resources for automotive interior applications. The summarized objectives are to develop suitable techniques for

- production of fibre structures containing short and long cellulosic fibres such as flax
- application of binders and matrices for these structures
- validation methods for the fibre-reinforced structures.

Regarding *Phalaris arundinacea*, intensive development work covering the whole chain from raw material production to end product has been carried out in Finland and Sweden during the past few years. The on-going European research (1995-1999) is financed by EU. The project consists of a study of fibre production and processing for fuel and paper/board, and is divided into three parts. In the first, the suitability of the new delayed harvesting method (in order to reduce the water content, minimizing the need for drying) for the northern parts of Europe is tested in combination with new breeding lines. The second part of the project deals with intermediate processing; upgrading to chip (stem internodes) and fuel powder fraction (leaves and leaf sheaths). The third part concentrates on the development of an optimal concept to produce high-quality pulp for specific end products. Energy production is also studied, and an economic assessment for the whole chain is made.

The research in the national programmes, as well as in the EU project, has led to promising results: top-quality fine paper can be produced from reed canary grass at a reasonable cost. The production and processing concept developed was tested in pilot scale in the Finnish Agrofibre programme, with positive results. In spring 1999, high-quality board will be produced on mill scale from reed canary grass within the EU project.

1.2 *Industry*

The growing of flax/linseed in Sweden today is 15,000 ha. The increase during the last few years is due to the favourable conditions within CAP.

Regarding processing, new fibre extraction techniques, such as steam-explosion and extrusion techniques, are promising tools for the production of a uniform quality of fibre raw material for technical applications.

For *Phalaris*, the logistics problems related to fibre production have, in many cases, limited the use of non-wood fibres in paper production. The substantial raw material supply requirements for a chemical pulp mill of an efficient size is difficult to guarantee at a reasonable cost. Therefore, in Scandinavia the reed canary grass line is recommended to be integrated into a kraft pulp mill producing hardwood and softwood pulp. This allows the use of the synergy and scale benefits of a large mill.

Delayed-harvest reed canary grass contains leaves rich in silica and dirt, which are removed with fractionation. This increases the bleachability of pulp, improves its drainage and decreases the silica content of raw material. The leaves fraction is used as an energy source in the mill or, upgraded to pellets, as a commercial fuel.

1.3 *Markets*

The major "traditional" uses so far have been for clothing, in linen and blankets for hospital beds, due to large water absorption capability. However, it is clear that natural materials from renewable resources, for instance agro-cellulosic fibres, are becoming increasingly interesting for non-textile and non-paper applications.

The largest single application today is the use of natural fibres in automotive parts. However, there are growing markets in other fields such as medicine, fibre filled plastics, sports gear, boats etc. The existing and potential technical applications can be classified by use, such as geotextiles, filters, sorbents, structural composites, non-structural composites, moulded products and packaging.

Opportunities for application for plant fibre products in building and construction materials are obvious, as are applications in papermaking. Use in composites and in reinforcement for different polymers are other examples.

For *Phalaris*, the key driving forces behind the development of this non-wood technology is the overproduction of food in the EU countries and the simultaneous growth of the demand of short-fibre (hardwood) pulp at an annual rate of 2-3 % in Western Europe. For strategical reasons, the reed canary grass project in Sweden has been carried out in close co-operation with energy research, since the scaling-up of reed canary grass production is more realistic to be driven from the energy sector than from the paper industry.

1.4 *Environmental*

The need for fibres in non-food applications is due to an interest to substitute existing mineral oil in different applications. An agro-cellulosic fibre has ecological advantages over polymers based on mineral oil. Advantages include biodegradability of the products as well as positive effects on agriculture. However, translating these properties into higher market prices remains a challenge.

2. *Barriers to progress*

2.1 *Scientific*

The effect that genetic engineering could have on fibre crops in the future is still mostly unknown. It is a scientific challenge to combine the two different linseed/flax crops, normally grown for oil and fibre, respectively, into one single plant.

The knowledge on biopolymers is only just emerging. Biopolymers are usually more polar and have more rigid chains than synthetics. Due to interactions such as hydrogen bonding and hydrophobic attraction, the behaviour of biopolymers is highly complex. A new branch in polymer science and technology has to be developed.

Other gaps in fibre research include the relative lack of knowledge of fibre extraction technology, chemical and physical fibre characteristics, possible modification of fibres, processing techniques of the fibres, and the relation between processing technology and the end product.

2.2 *Technical*

There are some essential requirements that need to be fulfilled by a raw material in order to make it an alternative to synthetic and glass fibres in technical applications. These include continuity and consistency of supply, as well as high and reliable quality. These issues, along with more specific ones such as the sensitivity of natural fibres to moist environments and the heat sensitivity, need to be addressed.

Objective test methods are not available for the determination of relevant fibre characteristics. This obstructs, to some extent, the introduction of plant fibres as industrial and technical raw materials. There is a need for rapid analytical methods for determination of the fibre quality, possible to use at an early stage in the production chain.

Modifications of fibres for decreased moisture sensitivity and flammability, as well as increased chemical resistance and temperature resistance need to be carried out. Tests are being made with the stem fraction from reed canary grass in paper production.

2.3 *Legislative issues*

The growing of hemp is not allowed in Sweden.

2.4 *Economic issues*

There is concern as to what will happen when the CAP subsidy for growing flax is abandoned. The relatively high price for the flax fibre is a drawback for its use. This is also generally the case for fibre crops in Sweden: due to the small-scale production and the high R&D costs, at present almost all biopolymers are too expensive to be price competitive with commodities. However, this situation is gradually changing, but upscaling of production is not always enough. Development of new technology or use of cheaper resources is essential.

In order for the pulp and paper industry to invest in new production lines, large volumes and a reliable supply of reed canary grass is needed. These can only be obtained in production for bioenergy, which therefore has to be established first. As the major developing line is to fractionate reed canary grass into two separate fractions, i. e. mainly the leaves (for energy) and the stems (for pulp), a market for the energy fraction must be at hand in order to make pulp production viable.

3. *Prioritisation*

For a discussion of the strengths and weaknesses in growing fibre crops in Sweden, see general priorities in Executive summary.

Carbohydrate crops

1. Opportunities

1.1 Science and technology

The crop species that are grown in Sweden, for their high content of carbohydrates/starches, are primarily potatoes, sugar beets, barley and wheat. The products obtained are mainly different starches and sugars, but cellulose and hemicellulose are also of interest.

The "Nordic Programme on Plant Cell Biotechnology" (1990-95) included a project on "Analysis of Starch Synthesis for Improvement of Starch Composition by Biotechnology", as a cooperation between industry and universities. The idea of the programme was to use bioengineering instead of using modification. This would offer a better starting material for the food processing, brewing, fermentation, paper, and textile industry, as well as an environmentally friendly, non-petroleum component for the chemical-technical industry. The objective for the programme period was to develop the "tools" necessary to make it possible to modify starch biosynthesis. The programme included a subproject dealing with "Cloning, Characterisation and Modification of Genes Encoding Starch Branching Enzymes in Barley Endosperm", coordinated by Department of Biochemistry at University of Stockholm.

In 1994 NUTEK initiated a three year research programme on "New Products from Renewable Raw Materials" (PROF) with a budget on 5 MSEK per year. The results were evaluated by an international team in 1996 and found to be of very high standard. This programme has been followed by a new programme (PROFYT) with a closer cooperation between research on cellulose products and new agrobased materials. It is also combined with an applied programme, "Future Surfaces for Paper Products". Altogether the budget is 8 MSEK/yr. The aim of PROFYT is to build up important knowledge for the chemical, agro, and pulp and paper industries on new renewable/recyclable materials from materials such as starches and other biopolymers.

In 1996, NUTEK also founded a competence centre, "Centre for Amphiphilic Polymers from Renewable Resources" at the Lund University, in close cooperation with industry. The main goal for the research at the centre is to understand the behaviour of amphiphilic polymers (molecules with hydrophilic and hydrophobic segments) prepared from renewable resources such as cellulose, starch, and other types of naturally occurring macromolecules. The research program is divided into five sub-areas:

- synthesis, chemical modification, and characterisation of starch and cellulose
- amphiphilic polymers in solution
- amphiphilic polymer gels
- organisation of amphiphilic polymers at interfaces
- properties and processing of biopolymers.

The two companies Lyckeby Stärkelsen and Svalöf Weibull are funding a research programme on genetically modifying potatoes. There are three different lines of development for potato varieties with

- a very high content of amylopectin (on the market in 1999)
- a high content of amylose (on the market in a few years)
- a generally higher content of starch

Svalöf Weibull has also succeeded in developing a variety of barley with a high content of amylopectin through conventional breeding.

1.2 *Industry*

Today, the growing in Sweden of crops for industrial non-food use is limited to potatoes 50,000 hectares for potatoes and 2,000 hectares for sugar beet. The gross margin for potatoes is given in Table 4 in Annexe 4.2.

1.3 *Markets*

Besides its applications in textiles and as paper, cellulose has many bioplastics applications. Examples are cellophane, celluloid, and cellulose triacetate (which can easily be converted into cellulose diacetate). The mechanical properties of these plastics are very good, they are water proof, and high quality colourless and transparent products can be obtained.

Starches have been used in different technical applications for a long time. The main areas for use are in

- paper industry (a major Swedish industry; increasing 2% per year)

Cationic starch is used in wet end applications to improve the paper strength and retention (EU: 230,000 tonnes/yr). It is also used in surface application for surface sizing and coating to improve surface strength and printability.

- corrugated board industry

In this industry starch is used as an adhesive between different layers in the production.

- building industry

Starches are used for sizing glass fibre fabrics and in gypsum and concrete to control the water retention and the flow properties.

- technical dispersions

Starch is used for stabilisation of AKD and ASA, which are products for internal sizing of paper.

- adhesives

Starch is used to improve the rheological properties, to control the drying time and the adhesion to different materials.

- materials

Starch is used as a component in plastics, as a filler, or to give the material special properties.

A starch with a high content of amylopectin would be used in paper production both in wet end applications and in coating colours, stabilisation of dispersions for paper sizing and in hot melt adhesives.

A “starch” with a high amylose content will be used as a substitute for synthetic polymers in materials, as films and also as a flocculant in industrial applications.

For sugars, use as detergent co-builders is another growing area. Starch and sugar are also important substrate sources for microbial production of a number of substances. Antibiotics and dextrans are currently produced in Sweden. One on-going project aims at producing polylactic acid.

2. Barriers to progress

2.1 Scientific

A proposal for initiating a “Biopolymer Competence Centre” affiliated to the Lund University with a “Graduate School on Industrial Products from Renewable Raw Materials” was prepared in 1996. However, the funding was not released. The research activities of the centre would have included

- physical, chemical and biotechnical methods to modify biopolymers
- characterization of modified biopolymers with respect to molecular structure and relevant physical, chemical and biological properties
- technically feasible processes for biopolymer modification, blending and processing. In the case of biopolymers, technological properties are less well understood. Research in application engineering is of prime importance.

2.2 Legislative issues

Restrictions on the growing of genetically modified potatoes may delay their introduction.

3. Prioritisation

For a discussion of the strengths and weaknesses in growing carbohydrate crops in Sweden, see general priorities in Executive summary.

Speciality crops

1. Opportunities

1.1 Science and technology

Plants produce molecules with great variations in chemical structure and biological activity. Man has used natural products for various purposes, for instance to cure diseases, as detergents, stimulants or contraceptives. Some of these molecules exhibit biological activities that are of relevance in the present biomedical research and in the development of drugs.

The research in the Faculty of Pharmacy at Uppsala University involves methods to isolate, identify and characterize plant-derived compounds that can serve as pharmacological tools or as drug prototypes. Important aspects of this research include the development of fractionation protocols and separation methods that permit isolation of minute quantities of bioactive substances from plant biomass. Structure determination of isolated substances and characterisation of biological properties of isolated substances on organ, cell and enzyme level are also important. A special research project is focused on isolation and characterisation of biologically active plant polypeptides. The newly created "Centre for Applied Pharmacognosy" at Uppsala University is also engaged in R&D.

The PROFYT programme contains a research project at Institute for Surface Chemistry on fillers and pigments from renewable resources.

1.2 Industry

Most major pharmaceutical industries, such as the companies Astra and Pharmacia Upjohn, are engaged in pharmaceutical research. There is also a strong industrial involvement and support for the competence centre mentioned above and for PROFYT.

1.3 *Markets*

An accelerated interest in traditional drugs (herbal drugs) and foods with health effects (nutraceuticals, functional foods) can be seen in Europe, USA and Japan. New types of foods are introduced in health stores and supermarkets with health-boosting effects. These designed foods represent a significant opportunity for food-processing industry and biotechnology companies as the market is estimated to be several hundred billion dollars in USA and Europe.

1.4 *Environmental*

There is strong environmental pressure to replace the nonylphenol ethoxylates in surfactants formulations. For this, surfactants using other hydrophobes than nonylphenol may be used; particularly interesting is the possibility to use fatty acids from natural oils. However, it has to be realized that the nonylphenol ethoxylates are not easily replaced, since they combine high-level performance with a competitive production cost.

2. *Prioritisation*

For a discussion of the strengths and weaknesses in growing speciality crops in Sweden, see general priorities in Executive Summary.

Protein crops

1. Opportunities

1.1 Science and technology

An extensive R&D programme was carried out in Sweden during the 1970's. The main reason for this was the ambition to develop an industrial process for producing RPC (Rapeseed Protein Concentrate) for human consumption. Also rapeseed protein isolates for spinning were prepared. This RPC programme gave a substantial amount of scientific information and knowledge, that can also be used for development of rapeseed protein products for industrial use.

1.2 Industry

Proteins are polymers of amino acids that can have very different side chains, ranging from highly polar, water-soluble to hydrophobic, insoluble. The specific amino acid composition can greatly influence the physical and chemical properties of the materials. Proteins can be rigid and tough or flexible materials. The mechanical properties of the products are in the same range as the common synthetic polymers. Proteins can be processed in dispersions to yield coatings and paints, but also in thermal processes such as extrusion or injection moulding.

Examples of proteins produced today are wheat gluten and soya protein isolate. Vegetable proteins can be processed into plastics with excellent properties

1.3 Markets

Vegetable proteins such as soya protein or soya meal are used in various non-food applications, for instance as adhesives in engineered wood instead of products containing formaldehyde, and in coatings. Proteins have very good barrier properties, making them valuable components for barrier packaging or oxygen barriers.

Their application as bioplastics is, at present, limited.

3. Prioritisation

For a discussion of the strengths and weaknesses in growing protein crops in Sweden, see general priorities in Executive Summary.

Annexes

Annexe 4.1 Cropping patterns for Swedish Agriculture 1970-1997

Table 1: Distribution of arable land by crop, 1000 hectares

	<i>1970</i>	<i>1975</i>	<i>1980</i>	<i>1985</i>	<i>1990</i>	<i>1995</i>	<i>1996</i>	<i>1997</i>
Wheat	226	303	297	287	349	261	335	344
Barley	657	649	694	710	492	453	469	483
Oats	546	497	484	475	388	278	284	315
Potatoes	65	43	40	38	36	35	37	36
Sugar beet	40	52	52	52	50	58	59	60
Rapeseed	96	173	177	173	168	105	73	73

Table 2: Crop production 1975 – 1995, 1000 tonnes

	<i>1975</i>	<i>1980</i>	<i>1985</i>	<i>1990</i>	<i>1995</i>
Wheat	1 481	1 193	920	2 243	1 793
Barley	1 937	2 171	2 156	2 775	2 478
Oats	1 345	2 257	2 156	2 775	2 478
Potatoes	837	1 084	1 286	1 186	1 074
Sugar beet	1 991	2 257	2 156	2 275	2 478
Rapeseed		323	371	422	198

Table 3: Crop production. Yield per hectare, tonnes/ha

	<i>1975</i>	<i>1980</i>	<i>1985</i>	<i>1990</i>	<i>1995</i>
Winter wheat	5.18	4.19	5.08	6.56	6.26
Spring wheat	4.13	3.98	4.35	5.22	4.98
Barley	3.21	3.35	3.46	4.54	3.96
Oats	2.91	3.47	3.75	4.31	3.48
Potatoes, industry	23.56	32.68	39.05	40.09	38.33
Sugar beet	38.08	44.90	41.90	55.80	43.60

Source: Yearbook of Agricultural statistics, Statistics Sweden, Örebro 1998

Annexe 4.2 Cropping patterns for Swedish Agriculture 1970-1997

Table 4: Gross margin in SEK for some Swedish non-food crops, 1995/96 per hectare

	<i>Yield, tonnes/ha</i>	<i>Output</i>	<i>Tot. variable cost</i>	<i>Gross margin</i>
Winter oilseed rape	3.0	5 550	2 923	2 627
Spring oilseed rape	2.1	3 885	2 920	965
Potatoes	44.0	24 200	10 920	13 280
Winter wheat	6.6	7 590	3 620	3 970
Spring barley	4.1	4 305	2 379	1 926

Source: Swedish University of Agricultural Sciences

Annexe 4.3 Contacts in Sweden

4.3.1 Key Contacts

All aspects

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4.3.4 Other Interest Groups

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