IENICA

Interactive European Network for Industrial Crops and their Applications

Newsletter number 9 September 1999

## Bioengineering of Plant Oils for Non-food Uses

The main raw material for the chemical industry today is mineral oil (petroleum) with an annual world consumption of about 200 million metric tonnes. The vegetable oils are the agricultural products that chemically most closely resemble mineral oils, and they therefore have the greatest potential of all biological raw materials to replace these oils in the chemical industry. The production costs of vegetable oils are two- to three-fold higher than the world market price of mineral oil. The chemical processing of the mineral oil to the final product is, however, costly. Thus, a biological product may compete with the mineral oil-based products in cost/performance if its chemical structure is such that it minimises the cost for further processing into the final product. Already today, vegetable oils and fats compete successfully with mineral oil in a number of technical applications. About 15% of all vegetable oil produced (about 15 million tonnes per year) is used in non-food applications. Genetic engineering is a powerful new tool in plant breeding which makes it possible to alter agricultural products in a way that is not feasible with conventional breeding techniques. By using genetic engineering it will be possible to optimise the vegetable oil qualities to better suit various technical applications.

Nearly all our domesticated oil crops contain five dominant ‘usual’ fatty acids. Due to their structure, these acids are of limited value for the chemical industry. However, the plant kingdom shows an enormous diversity of fatty acids in seed oils, with nearly 1000 different fatty acids characterised. A substantial number of these fatty acids would be of large interest for the chemical industry in the production of polymers, paints, lubricants etc if they could be obtained in large quantities and at moderate costs. Only two important commercial oil crops with such ‘unusual’ fatty acids have traditionally been available, coconut and oil palm (palm kernel), yielding fats with medium chain fatty acids. Coconut and palm kernel are the main sources of vegetable oils and fats for the non-food market (soaps and detergents).

By genetic engineering, the biosynthetic machinery for the unusual fatty acids can be transferred from wild species, resulting in the production of these acids in domestic oil crop seeds. In this way, oil qualities particularly suited for various technical applications will be produced at nearly the same costs as traditional vegetable oils. This will significantly improve the market for vegetable oils. The concept has been called ’the plant in the plant’.

The Swedish plant lipid project, supported mainly by The Swedish Foundation for Strategic Research, aims at developing new vegetable oil qualities for technical applications in oil crops by using genetic engineering. Some of the sub-projects are run as collaborative projects with the following research institutes: Brookhaven National Laboratory, New York, USA; CSIRO, Plant Industry, Canberra, Australia; Institute for Food research, Norwich, U.K., and Metapontum Agrobios, Metaponto, Italy.

**Searching for Genes**

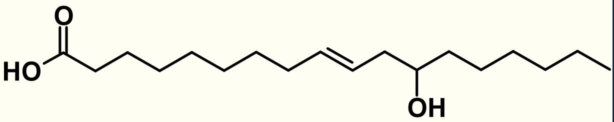
Despite there being almost 1000 different fatty acid structures reported from the plant kingdom it is likely that there are only a limited number of enzymes/genes (perhaps 20-30) that are involved in the synthesis of all these acids. The large number of different fatty acids found are synthesised by different combinations of these genes in the different plant species. Today there is an intensive race between different research groups around the world in order to identify, clone and patent genes involved in fatty acid modification.

**Which Genes are Useful?**

Medium chain fatty acids (fatty acids with carbon chain lengths between 8 and 14 carbons) are widely used in chemical industry. Until recently, coconut and oil palm have been the only commercial sources of these acids. However, using genetic engineering, the U.S. based gene technology company Calgene (now a Monsanto company) has developed a rape seed variety producing an oil containing 50% of lauric acid (a 12 carbon fatty acid). This variety is today in commercial production. Calgene has also strong patent positions for the production of 8, 10 and 14 carbon fatty acids in transgenic plants.

Apart from medium chain fatty acids, there are three main chemical structures possible within a fatty acid chain that are particularly useful in technical applications, and which are not found in the oils of our common oil crops. These structures are hydroxy groups, epoxy groups and acetylenic bonds. Seed oils with high amounts of these fatty acids are found in some wild species, and plant genes responsible for the production of these three chemical structures have now been cloned. Within the Swedish plant lipid program the research group in Svalöv has cloned genes responsible for the synthesis of acetylenic and epoxy fatty acids, whereas Professor Chris Somerville's research group at Carnegie Institute, Stanford, USA, has cloned genes involved in hydroxy fatty acid synthesis.

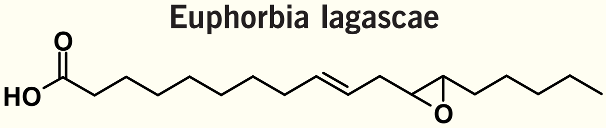
Castor (Ricinus communis)




Ricinoleic acid

All the genes involved in the production of hydroxy, epoxy and acetylenic fatty acids that have been cloned so far are responsible for the modification at carbon atom number 12 on an 18 carbon fatty acid. There are a number of additional plant genes which govern similar modifications of fatty acids at other carbon positions, and the hunt for these genes is now well under way.

Euphorbia lagascae




Vernolic acid

**Transgenic Plants Producing Unusual Fatty Acids must be Viable!**

In order to be commercially viable, transgenic oil crops with altered oil composition must produce these new oil qualities with a yield that is comparable to varieties of the conventional qualities. In order to achieve this, the production of the new oil qualities must not impair seed development or seed germination.

Wild species with naturally high amounts of either medium chain, epoxygenated, hydroxylated or acetylenic fatty acids in their seed oils always have very low amounts of these fatty acids in their membrane lipids. It has been shown that transgenic rape, producing medium chain fatty acids, lacks efficient mechanisms to exclude these acids from the membrane lipids. It can be anticipated that rape and other oil crops lack mechanisms for excluding also certain other 'unusual' fatty acids (e.g. hydroxylated and epoxygenated) from the membranes. High amounts of the unusual fatty acids in membranes will almost certainly lead to disturbed membrane functions, thereby impairing seed development and germination. Therefore, if one wants to make use of 'the plant in the plant' concept, it is not only necessary to identify, clone and transform the genes that are responsible for the unusual chemical structures, but also to avoid accumulating the unusual fatty acids in the membranes. It is likely that this may be more difficult than the insertion of genes for the unusual fatty acids.

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IENICA wishes acknowledge the following for photographs used in this article: NF-2000 Network (FAIR 1904); EU DG VII E FAIR Programme; Ms. C. Galilea, Temuco, Chile; University of Reading, UK: Dept. of Agriculture and Centre for Agricultural Strategy; CPL Scientific Limited, UK.

## Forthcoming Industrial Crops Events

21 - 22 Oct 1999
**Vegetable Oils - Meeting the Needs of Industry**
**An IENICA event**
Wageningen, Netherlands.
Tel: +31 317 484246; Fax: +31 317 484892
E-mail: paul.struik@users.tpe.wau.nl

27 October 1999
**4th Biomass Energy on the Farm Conference**
De Montford University, Grantham, UK
Tel: + 44 (0) 1400 275625; Fax: + 44 (0) 1400 275656
Email: apchick@dmu.ac.uk
Internet: http://www.dmu.ac.uk/ln/itc

For details of these events and others see the IENICA web site: www.csl.gov.uk/ienica or contact Sarah Hugo at s.hugo@csl.gov.uk

## Natural Fibres Performance Forum, 27 - 28 May 1999

Approximately 200 delegates attended this meeting held at The Royal Veterinary and Agricultural University of Copenhagen, Denmark. The conference was jointly organised by the Non-Food Secretariat of the Danish Ministry of Food, Agriculture and Fisheries, the Danish Centre for Plant Fibre Technology, and IENICA. Formal presentations from international speakers were accompanied by poster exhibits and exhibits of products derived from natural fibres. The meeting was commissioned by IENICA to emphasise the industrial potential of natural fibres and to discuss requirements for further development of the industry.

**Current/Future Uses and Limitations of Plant Fibres in Industrial Production**

In the opening lecture 'Perspectives on the Performance of Natural Plant Fibres', Dr Per Ole Olesen reviewed the basic properties of plant fibres in terms of dimension and chemical composition which combine to give plant fibres their unique properties of strength, insulation, combustability, biodegradability, dimensional stability and reactivity. Renewed interest in industrial use of plant fibres falls into two main groups, namely mats for filters, growth media, insulation and geotextiles, and composites in the form of fibre/polymer, fibre/cement and composite product designs. For plant fibre utilisation to reach its full potential a shared understanding of the demands, process economics and plant fibre technology are essential.

Current applications in the automotive and aerospace industries were presented by Dr Thomas Schuh of Daimler-Chrysler and Professor Axel Herrmann of the German Aerospace Centre (DLR). Dr Schuh described how the automotive industry is seeing increasing application of plant fibre composites, again driven by increased environmental awareness. Research has shown plant fibres to be lightweight, strong and flexible. Safety issues regarding worker exposure to glass fibre components also favour use of plant fibres. Currently plant fibre applications in Mercedes-Benz E-Class cars are in the rear parcel shelf, C-pillar trim, seat cushion parts, centre console trim and various damping and insulation parts. External automobile components is a goal for the future. Fibre reinforced plastics originated in the aerospace industry and the DLR Institute of Structural Mechanics has developed biocomposites for industrial applications and found them to be comparable to glass fibre reinforced plastics (GFRP) in terms of mechanical properties. DLR suggest that new fibre/matrix combinations and environmentally compatible flame retardants enable biocomposites to replace GFRP in most cases except environmentally extreme conditions.

Gary Newman of JB Plant Fibres in the UK explained that while agricultural subsidy has led to a resurgence of hemp and flax across Europe, the measures that are needed to ensure sustainable supply without subsidy have not been put in place. Also improvements in the processing and grading technologies have not developed alongside this increased interest in natural fibres.

Professor Ryszard Kozlowsky of the Institute of Natural Fibres in Poland closed this session with a glamorous show of garments fashioned in linen.

**New Design Opportunities for Plant Fibre Products**

Dr Laurence Mott of Perstorp A/B Sweden, argued that the mechanical and chemical properties of natural fibres are poorly understood and this limits performance of biocomposites. There are many sources of natural variability in plant fibres, and these all contribute to performance of biocomposites. However there is nothing that can be done to improve inherent performance of these fibres and to optimise their use in composites an improved understanding is essential.

Mr Jorn Behage of Proterra, Netherlands discussed rudimentary cost-benefit analysis for cellulose fibre based composites, technical and economic effort when balanced against added value give a measure of product value. On this basis geotextiles have low added value with minimal technical and economic effort, while automotive parts for example have relatively high added value, but also high technical and economic effort. Issues like the aesthetics and environmental benefits of biocomposites will increasingly affect this equation.

**Realising the Full Performance Potential of Plant Fibres**

Dr Jan van Dam, of ATO-DLO Wageningen stressed the importance of understanding the relationship between the properties of a raw material and its production processes, and quality of the end product as all stages in the production of plant fibre products and composites have an influence on the end-product price and performance. Understanding the whole chain and assessing where improvements can be made at the lowest cost is essential. The introduction of quality control in the agro-industrial chain is therefore crucial, backed up with policies to ensure guaranteed supplies of specific products to industrial buyers.

Dr Mark Lowther described findings from international research which shows that the method of processing plant fibres significantly affects the surface properties of a fibre and therefore quality of biocomposite. The formation of a good interface between fibre and composite is crucial to the quality of biocomposites, hence surface characteristics are of the utmost importance. Chemical, physical or enzymatic modification were suggested as measures to improve basic properties of biocomposites. As suggested earlier in the conference - only until plant fibres are fully characterised will it be possible to progress and make high quality high value applications.

Dr Jamie Hague, Biocomposites Centre UK continued to say that much evidence relating to the (lack of) success of plant fibres in biocomposites points to damage during processing. Hemp and flax fibres seem to be very prone to damage at this stage and, while in certain applications like thermoplastics this is less important, in brittle biocomposites like thermoset resins, toughness is very important. Processing and manufacturing strategies which minimise damage at this level must be developed for this type of biocomposite to be competitive.

Dr Johannes Klumpers of DGXII of European Commission reviewed EU-financed research on non-traditional industrial uses of biological fibres in terms of projects funded in the past and future projects. Over the last 10 years the EC has funded about 25 projects representing 36 million EURO on research into non-wood natural fibres. Data produced by DGVI of the Commission indicate that of the 53 million hectares of agricultural land in the EU-15, only 1.95 million hectares are used for production of industrial crops, of this 650,000 hectares is devoted to industrial fibres. The Fifth Framework programme aims to contribute to the establishment of a bio-based economy, and to the development of marketable products by the year 2007 and to establish a new and durable relationship between farmers and the renewables industry. Barriers to development of the industry are political and technical. Technical barriers are being addressed with various EU-funded projects, fibre projects account for 12% of this funding. Political barriers are more difficult to address - the availability and prices of raw materials vary strongly, fossil fuels are easily available and at low cost, there is no long term political framework to support the industry, and industrial end-users and farmers hesitate to change until these barriers have been overcome.

The final session of the conference looked to the **Future** with presentations on marketing of natural fibre products. Mr Leif Nørgaard of Novotex A/S in Denmark presented a case study of the Green Cotton brand T-shirt, a fully "ecologically committed" product, following all regulations for the EU 'green sector'. This was held up as a success for an EU regulatory system based on sustainable development, which could be applicable to other industries. Professor Rudolf Kessler of the Institute fur Angewandte Forschung, discussed requirements for a "Strategy for a Sustainable Future of Fibre Crops". While many car manufacturers use natural fibre reinforced parts, the raw material in the main comes from Eastern Europe and Asia at far cheaper prices than can be found in Western Europe where wages are relatively high. The basic dilemma facing agri-products is their low value. The requirements for technical applications are consistency of quality for low cost - natural fibres compete poorly with man made fibres at this level. While much work has been done developing high performance composites on the laboratory scale, very little progress has been made in marketing and high level processing. To implement a sustainable future for the natural fibres industry requires cooperation between farmers, fibre producers and product manufacturers whereby quality, quantity, price, and market promotion can be developed competitively.

Dr Claus Felby of Novo Nordisk described experiences developing natural binders. These can take the form of conventional adhesive types based on lignin, protein or hemicellulose which is added to a composite, or may be an enzyme which can activate the surface of a fibre enabling fibre-fibre bonding. Currently there are no commercial applications for natural binders/adhesives, as processes have higher energy consumption than conventional adhesives (based on phenol, urea, melamine, isocyanates, formaldehyde), and the process takes longer due to necessary enzyme activity. These problems have all been encountered in upscaling production from laboratory to pilot plant scale and development work is ongoing.

The proceedings of this meeting will be available at a later date. Report provided by Sarah Hugo, IENICA. For further information please contact: s.hugo@csl.gov.uk.

The IENICA project is funded by DGXII of the European Commission under the FAIR programme. IENICA involves 14 states in the EU.

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