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RESEARCH REVIEW No. OS9

# INDUSTRIAL MARKETS FOR UK-PRODUCED OILSEEDS

JANUARY 1995

Price £8.00

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# INDUSTRIAL MARKETS FOR UK-PRODUCED OILSEEDS


by

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This is the report of a **LINK** project under the **Crops for Industrial Use** programme. The work was funded by the Ministry of Agriculture, Fisheries and Food (£30,830), the Home-Grown Cereals Authority (£25,270 - Project No. 0S14/1/93), the National Farmers' Union (£2,780 - in kind contribution) and the Seed Crushers' and Oil Processors' Association (£2,780 - in kind contribution) for a period of six months commencing in November 1993.

# Contents

# Executive Summary

## INTRODUCTION (1.1)

The aims of this study were to investigate the prospects for producing oilseeds in the UK for industrial markets and to make recommendations for research.

## OPTIONS AND OPPORTUNITIES FOR CROP PRODUCTION (1.2.1; 2)

Oilseed rape (OSR) is the main UK oilseed, and the most promising for industrial use. Production systems are well-established. The crop is very amenable to genetic development. Chemical composition can be varied by conventional breeding and non-transformation-based biotechnological methods. Genetic transformation to produce transgenic varieties greatly widens the scope. Several varieties with modified fatty-acid profiles have been developed recently using one or other of all three approaches. Further developments are expected. There are, however, certain technical, economic and political problems which will need to be addressed if these opportunities are to be realised (see 2.4.3, 2.5).

Linseed is already grown for small, but established, industrial markets. The crop may have some advantages over OSR in some circumstances, although it is lower yielding and less amenable to genetic modification.

## CHARACTERISTICS OF INDUSTRIAL MARKETS (1.2.2; 3)

Industrial markets for vegetable oils are as **lubricants, surfactants,** surface coatings (ie **paints** and **inks**), **polymers** and **pharmaceuticals**.

Some 740 000 t of **lubricants** are used in the UK each year. Vegetable oils appear to be less polluting than mineral oils, and seem most promising in 'total-loss' or 'high-risk-of-loss' systems. Their use in offshore drilling muds is the subject of ongoing R&D. Total-loss systems and offshore drilling muds represent estimated potential annual UK markets of approximately 52 000 t oil (c 130 000 t rapeseed, 43 333 ha OSR) and 32-45 000 t oil (c80-133 000 t rapeseed, 27-38 000 ha OSR) respectively.Vegetable oils are, however, more costly than mineral lubricants. Adoption depends on environmental legislation. The actual market is, therefore, limited. Very-high-oleic oils offer the best compromise in terms of technical characteristics.

The world **surfactants** market is large and growing. EU consumption is more static, at approximately 1.7 Mt per year. A shift towards using vegetable-oil raw materials is occurring, partly due to environmental concerns. However, the prospects for UK-produced oilseeds are limited, as tropical oils are technically more suitable and cheaper. The development of a 'pure'-lauric OSR would strengthen the UK's position.

Vegetable oils are used in gloss-**paint** and printing **ink** manufacture, mostly from linseed and soya. For OSR to penetrate the market, new 'drying' varieties (higher in polyunsaturated fatty acids) would be needed. Some 48 000 t of oil (c 120 000 t rapeseed, 40 000 ha of OSR) would supply all gloss paint sold in the UK. There is, of course, a substantial additional potential market for oil and/or paint worldwide.Vegetable oils in printing **inks** appear to be less polluting and toxic, and easier to remove (easing paper recycling), but more costly, than mineral oils. Their use depends on environmental legislation, and consumer demand. Maximum European incorporation of vegetable oils in printing inks is estimated at 84 000t (c 210 000 t rapeseed, 70 000 ha OSR).

The world **polymer** market is some 125 Mt per year, and increasing. Vegetable-oil derivatives are used to modify polymer properties (eg erucamide from high-erucic acid OSR as a slip-agent in polyolefin film), and as reactive ingredients for the manufacture of polyamides, polyesters and polyurethanes. 'In-plant' production of polymers in transgenic OSR varieties is also possible: for example, Zeneca expect to release a 'Biopol' (a biodegradable polymer) OSR variety by 2006, for an anticipated global market of about 100 000 t Biopol per year (c 500 000 t rapeseed, 166 666 ha OSR).

**Pharmaceutical**ly active molecules, or their precursors, are synthesized in certain oilseed species, can be derived from vegetable oils, or could be produced from new transgenic varieties. Product values are high, but markets and potential crop areas are small. Production is likely to be by the pharmaceutical companies, or by a very few farmers under contract.

Markets for the **co-products** of OSR production, meal and glycerine, are established. Use of straw as fuel or fibre may be developed in future years.

## ECONOMIC OPPORTUNITIES (1.2.3; 4)

Industrial oilseeds occupied nearly 185 000 ha of UK land in 1993/94, and there is scope to increase this area appreciably. Growing and using oilseeds for industry in the UK present interesting and potentially profitable opportunities to individual businesses and to the national economy. Both, however, operate within a milieu of constraints and risks. For the economy as a whole, the use of oilseeds in industry is constrained by: the cost of the oilseed-based product *vis a vis* alternatives, including those from the world market; the CAP and GATT; and environmental effects (environmental indicators do not all point in the same direction). For the industry, there are risks and uncertainties associated with: production (on-farm and processing); markets (vegetable oils have to compete with current raw materials, and there is a risk that if specialised oilseeds are produced, the other suppliers to the industry may simply lower their prices); and policy.

## RECOMMENDATIONS (1.3)

This study has identified a need to conduct further pre-commercial, basic and speculative research; to improve communication between researchers, policy makers and industry; and to ensure that GMO legislation commands public confidence, without placing unnecessary obstacles to developing transgenic crops and products.

If the apparent potential of transgenic crops is to be realised, then further basic research will be needed on the synthesis of oil (ie triglyceride) in the oilseed rape plant. The development and application of methods of environmental audit would enable claimed environmental advantages of certain vegetable-oil-based products to be assessed.

Needs related to specific applications include:-

(i) **Lubricants**: research and market development to ensure that the UK can respond to new environmental legislation related to lubricants.

(ii) **Surfactants**: clarification of advantages and applications of vegetable oil adjuvants (and provision of information to farmers).

(iii) **Surface coatings**: audit and clarification of environmental and health benefits of vegetable oils in printing inks.

(iv) **Polymers and pharmaceuticals**: publicly-funded basic research will underpin developments in these sectors, but the development of specific applications will be the responsibility of industry itself.

# Acknowledgements

The authors are grateful to all those who have assisted them in conducting the study reported in this document. Thanks are due, in particular, to those people and organisations who provided information either verbally or in writing (see Appendix V), and to the members of the project's Steering Committee, under the Chairmanship of Frank Oldfield.

The study was part of the 'LINK Crops for Industrial Use Programme', and was funded by the Ministry of Agriculture, Fisheries and Food, the Home-Grown Cereals Authority, the National Farmers' Union and the Seed Crushers' and Oil Processors' Association. The support of these organisations is gratefully acknowledged.

The views expressed, however, are those of the authors and are not necessarily shared by the consultees, the Steering Committee or the sponsors.

# Abbreviations

| | |
|---|---|
| ACP | Acyl Carrier Protein |
| ASPA | Syndicat national des fabricants d'agents de surface et de produits auxiliaires industriels |
| BBSRC | Biotechnology and Biological Sciences Research Council |
| C | Carbon |
| c | Circa |
| CAP | Common Agricultural Policy |
| CoA | Co-enzyme A |
| CMS | Cytoplasmic male sterility |
| $CO_2$ | Carbon dioxide |
| DL | Descriptive List |
| DNA | Deoxyribonucleic acid |
| DUS | Distinctness, Uniformity and Stability |
| EPSRC | Engineering and Physical Sciences Research Council |
| EU | European Union |
| FAO | Food and Agriculture Organization of the United Nations |
| FAS | Fatty-acid synthetase |
| GATT | General Agreement on Tariffs and Trade |
| GB | Great Britain |
| GLA | Gamma-linolenic acid |
| GMO | Genetically Modified Organism(s) |
| ha | Hectare(s) |
| HEAR | High-Erucic-Acid Rape |
| HMSO | Her Majesty's Stationery Office |
| HO | High-Oleic |
| HPRA | High-Palmitic-Acid Rape |
| HGCA | Home-Grown Cereals Authority |
| kg | Kilogramme(s) |
| kha | Kilo-hectare(s) |
| l | Litre(s) |
| LAB | Linear alkylbenzenesulphonate |
| M | Mega |
| m | Metres |
| MAFF | Ministry of Agriculture, Fisheries and Food |
| MEAR | Medium-Erucic Acid Rape |
| Mt | Megatonne(s) |
| NFU | National Farmers' Union (England and Wales) |
| NIAB | National Institute of Agricultural Botany |
| NL | National List |
| OO | Double-low |
| OSR | Oilseed Rape |
| PCR | Polymerase Chain Reaction |
| PHA | Polyhydroxyalkonate |
| PHB | Polyhydroxybutyrate |

| | |
|---|---|
| PHB/V | Polyhydroxybutyrate/valerate |
| POST | Parliamentary Office of Science and Technology |
| PVC | Polyvinyl chloride |
| R&D | Research and Development |
| RL | Recommended List |
| SAC | Scottish Agricultural College |
| SCOPA | Seed Crushers' and Oil Processors' Association |
| SI | Self-incompatibility |
| t | Tonne(s) |
| UK | United Kingdom |
| USA | United States of America |
| USDA | United States Department of Agriculture |
| VCU | Value for Cultivation and Use |
| VHOAR | Very High-Oleic-Acid Rape |
| VOODOO | Vegetable Oils for Offshore Drilling Operations |
| y | Year |
| ZEAR | Zero Erucic-Acid Rape |

# 1 Overview

## 1.1 INTRODUCTION

### 1.1.1 Context

The reasons for considering the production of oilseeds for industrial use are as follows:-

(i) An increasing area of land surplus to present requirements for food production in the UK, combined with reforms of the CAP designed to control surplus production and reduce budgetary costs (The Arable Area Payments scheme allows non-food crops to be grown on Set-aside land - although the Blair House Agreement may impose some constraint on the EU volume of industrial oilseed production.)

(ii) New possibilities for crop production, arising particularly from the application of novel biotechnologies.

(iii) Growing consumer demand for 'green' and 'natural' products and processes, and increasing environmentally related legislation and regulation. (Vegetable oils are already important inputs to many industries, along with mineral oils. 'Green' forces may effect a greater shift towards vegetable oils in these industries, and open up new opportunities.)

(iv) Concern to direct oilseeds R & D more specifically at end-use goals.

### 1.1.2 The issues addressed

The issues addressed by this study were as follows:-

(i) What are the **options and opportunities for crop production**, particularly those arising from new developments in plant breeding and biotechnology, that might increase the potential for industrial use of UK-produced oilseeds? (1.2.1 & 2).

(ii) What are the **characteristics of the industrial markets** in which UK-produced oilseeds might be used, and what are the limitations of such use, in terms of market size and the suitability of UK-produced oilseeds? (1.2.2. & 3). The study's primary focus was on UK production and markets, but it was recognised that the actual market extends to the EU and the world.

(iii) What are the **economic opportunities** for industrial use of oilseeds in the UK, judged from the viewpoint both of the overall economy and welfare of the community, and the profitability of individual businesses? (1.2.3 & 4).

(iv) What **recommendations** arise for publicly and levy-funded research, and what measures might be needed to encourage implementation? (1.3).

### 1.1.3 Methods

The above questions were addressed by review of relevant literature and consultation with interested parties. The literature consulted included trade journals and official publications, previous assessments of markets and scientific publications on some of the processes and developments arising from research. Those consulted included people and institutions actually involved in research, and representatives of industries that currently use or may potentially use vegetable oils. These consultations necessitated degrees of confidentiality as much of the material discussed was of a sensitive nature. A list of consultations is given in Appendix V.

## 1.2 CONCLUSIONS

### 1.2.1 Options and opportunities for crop production (2)

The potential for developing new industrial oilseed crops depends on the scope for genetic modification and the extent of agronomic development of the target species.

The main oilseed grown in the UK, and the most immediately suitable for production for industry, is oilseed rape. The crop's agronomy is well-established, and the UK possesses some climatic production advantages. There are two main products, meal and oil. The market for meal is as a high protein component in animal feedstuffs. The principal market for oil is food, but there is a diversity of non-food uses. These are the subject of this report.

In addition to its agronomic advantages, oilseed rape is very amenable to genetic development, particularly in relation to seed-oil chemical composition. The natural genetic diversity within the brassicas allows a number of varieties with modified fatty-acid profiles to be developed via conventional breeding and non-transformation-based biotechnological methods. Genetic transformation to produce transgenic varieties (with modified fatty-acid profiles, or as a synthetic machinery to make biodegradable polymers and other chemicals) widens the scope greatly. Several new varieties with modified fatty acid profiles have been developed recently using one, or other, of these three approaches. Further developments are expected.

Several factors may affect the practical production of novel industrial oilseed rape varieties. Transgenic varieties will be subject to the restrictions on release into the environment pertaining to Genetically Modified Organisms (GMOs). Adequate provision will need to be made to avoid cross-contamination, especially between food and non-food varieties. This may arise from cross-pollination, but volunteers, particularly resulting from pod shatter, are the main concern. Current efforts by plant breeders to reduce pod shatter should do much to alleviate this problem. As with any crop, rotation may be needed to reduce the effects of pests and diseases. Opinions as to how often oilseed rape can appear in an arable rotation range from once in four or five years to every year. Rotational needs, however, seem likely to place some limit on the total oilseed rape area. Breeders will also seek adequate reward for variety development. Discussions with the Technical Director of the British Society of Plant Breeders concluded that a market for at least 64 000 t of grain per year (from c 21 500 ha OSR per year) would be needed before breeders would invest in developing a new variety.

Other oilseeds, notably linseed and sunflower, can be grown in the UK. Linseed is less amenable to genetic modification than oilseed rape. Its oil yields are lower and, while the English climate is well-suited to linseed, the crop has been much less successful in the rest of the UK. Linseed is more susceptible to weather than oilseed rape. Its principal attraction has been a favourable CAP regime. However, uses of linseed oil and meal are well established, there is growing interest in developing uses for the fibre, and linseed may have some advantages over oilseed rape in some circumstances.

Current sunflower varieties cannot match oilseed rape yields, and are only suitable for the southern half of the country. The development of new varieties (including via biotechnology) may both increase yields and expand the crop's range.

There is substantial expertise, relevant to the development of novel oilseed crops, in the UK, with several internationally recognised centres. This investigation revealed, however, a concern that this expertise be more widely recognised and used and these centres maintained, if the UK is to remain in the 'front line' in the developments described in this report.

### 1.2.2 Characteristics of industrial markets (3)

***Introduction (3.1)***

Oilseeds provide vegetable oils and co-products - straw and meal. Glycerine may also arise, as a co-product from the hydrolysis of vegetable oils. This report is concerned primarily with non-food/non-fuel markets for the oil component of UK-produced oilseeds.

Vegetable oils are, and could be, used in a wide range of industrial processes and products. These can be classified under five broad headings: **lubricants, surfactants, surface coatings, polymers** and **pharmaceuticals**. In these uses, UK-produced vegetable oils have to compete with mineral oils, animal oils and imported vegetable oils (including those of tropical origin). Various forces are effecting changes in the raw materials used in the above sectors. In particular, consumer demand for 'green' and 'natural' products and environmental legislation is increasing the demand for vegetable oils, in, at least, some contexts.

***Lubricants (3.2)***

About 740 000 t of lubricants are used in the UK each year.

Vegetable-oil-based lubricants have the greatest competitive advantage in total-loss systems (eg chain-saw bar oils, two-stroke marine engines, drilling muds, agricultural greases), and possibly in applications where the risk of loss is high (eg certain hydraulic systems). In such cases, their negative impact on the environment is much less than that of mineral-oil-based lubricants. However, they are also more expensive, and their extensive use in these contexts is likely to be dependent on specific environmental legislation (as is the case, for example, in Germany and Switzerland).

Lubricant manufacturers in several European countries have considerable experience of using vegetable oils as base oils in lubricants, and offer a range of products, mostly aimed at total-loss (see above) and high environmental risk markets.

The use of vegetable oils as lubricant base oils is restricted by some technical disadvantages, constraining their use at high and/or low temperatures (depending on the oil). Very-high-oleic oils seem to offer the best compromise in terms of technical characteristics. Modifying vegetable oils (eg via additives or conversion into esters) to overcome these technical problems is possible, and would expand their potential markets, but would also increase costs and may reduce their environmental advantages.

Total-loss systems and offshore drilling muds represent estimated potential annual UK markets of approximately 52 000 t oil (c 130 000t rapeseed, 43 333 ha OSR) and 32-45 000 t oil (c80-133 000 t rapeseed, 27-38 000 ha OSR) respectively.

### *Surfactants (3.3)*

World consumption of surfactants is large, some millions of tonnes, and rising, particularly in newly industrialising countries, although not in the EU or USA. The UK share of this market is extremely small.

Buyers of oils for the production of surfactants operate in an international market, dominated by price. They are mainly very large multinational corporations which monitor markets on a daily basis to ensure the least cost inputs into their products.

A shift towards the use of vegetable oils in the manufacture of surfactants is occurring, partly because some companies wish to project a 'natural product' image and partly due to the increasing availability, at low cost, of tropical vegetable oils (notably palm and palm kernel oil). Tropical oils, in fact, dominate the vegetable oil sector of the market for raw materials surfactant manufacture, due to their compositional suitability and their high productivities and low costs.

Existing varieties of oilseed rape provide less suitable oils at higher costs. Development of high lauric and, ideally, 'pure' lauric oilseed rape varieties might make it a stronger competitor in this market.

### *Surface coatings (3.4)*

Vegetable oils are used in the manufacture of gloss (oil-based) **paints**. 'Drying oils', containing at least 50% polyunsaturated fatty acids, are required. Manufacturers tend to use linseed, tall and soya oils, owing to their high contents of polyunsaturated fatty acids. For oilseed rape to penetrate the market, new varieties higher in polyunsaturated fatty acids would need to be developed; the oil from such varieties would need to 'look like' a blend of linseed and soya oils. The growing of such varieties could significantly increase the use of UK-produced vegetable oils by the paint industry. If all gloss paint sold in the UK were vegetable oil-based, some 48 000 t of oil (c 120 000 t rapeseed, 40 000 ha OSR) would be required. The actual market is, of course, likely to be somewhat lower.

Vegetable oils are used as 'vehicles' in printing **inks**. As with paints, drying oils are required. However, for printing inks, drying properties may not be so important where the level of inclusion of the vegetable oil is low and drying (binding) is effected by other constituents, or where printing is on very absorbent paper (eg newsprint).

The main attractions of using vegetable oils in printing inks are that they are less damaging to the environment, less toxic and easier to remove than traditional vehicles. These features, notably ease of de-inking, are more important as more paper is recycled.

Linseed oil was the main oil used in printing inks in the past. At present, about half the newspapers produced in the USA are printed with ink containing about 10% soya oil, and federal agencies and the USDA are required to use vegetable-based inks wherever possible. Between 1 000 t and 2 000 t of oilseed rape oil are included in printing inks in the UK annually, to supply a limited demand for 'ecologically responsible inks'.

Vegetable oils cannot compete on price with mineral oil vehicles, and their increased use in printing inks is likely to depend on environmentally-based legislation, a greater concern for a 'green' image on the part of manufacturers, printers and publishers, and consumer demand for 'green' inks and printed products. As with paints, increasing the proportion of the market supplied by oilseed rape oil is likely to depend on developing new, 'drying' varieties. The potential maximum incorporation of vegetable oils in printing inks in Europe has been estimated as 84 000 t (c 210 000 t rapeseed, 70 000 ha of OSR).

## *Polymers (3.5)*

### Introduction (3.5.1)

A wide range of different polymers is produced and used in an even wider range of applications. The global market for polymers is approximately 125 Mt per year, and appears to be increasing.

Most polymers are derived from petroleum. Certain products, however, are based on, or incorporate, vegetable oil derivatives, and there appears considerable scope for an expansion of the use of vegetable oils and oilseed crops in polymer production. Vegetable oil derivatives can be used in the manufacture of polymers as non-reactive functional additives (where they alter physical properties) or as reactive ingredients (where they form part of the polymer chain). Further, genetic engineering is opening up the possibility of producing oilseeds that synthesise polymers in the plant itself.

### Functional additives (3.5.2)

Vegetable oil derivatives are used as slip, anti-block, anti-static, and plasticising agents, stabilisers, processing aids and flame retardants in the manufacture of plastics. The principal chemical currently produced and used in this way in the UK is erucamide, derived from high-erucic acid oilseed rape (HEAR) and used as an slip agent in polythene film. The UK industry currently uses the product of some 14 000 ha of HEAR in this way. Current HEAR varieties produce no more that 60% erucic acid in the oil. Increasing the proportion to 80-90% should increase the world market for high-erucic acid oilseed rape oil.

### Reactive ingredients (3.5.3)

Vegetable oils can be used as reactive ingredients in the manufacture of polyamides, polyesters and polyurethanes. In this area there exists substantial potential for oils from modified plants, and for using biotechnological processes to convert vegetable oils into polymer substrates. Such developments are necessarily of considerable commercial significance. Enquiries suggest that the organisations concerned are well aware of the potential.

**Direct production of polymers (3.5.4)**

Oilseed crops could provide a direct source of polymers via genetic modification of the plant's biochemistry. Such developments would enable some processing stages to be eliminated with consequent reductions in manufacturing costs. The fatty acid derivative, polyhydroxybutyrate (PHB), is currently produced by the bacterial fermentation of carbohydrate feedstocks, and used to produce the biodegradable plastic, Biopol (Zeneca plc). Current production of Biopol is 1000 t per year and the present price is £7-12 per kg, but the potential market is estimated at 100 000 t per year (c 500 000 t rapeseed, 166 666 ha OSR), providing the price can be reduced to £1-3 per kg. Recently, as much as 15% PHB has been obtained in the leaves of a genetically modified *Arabidopsis thalliana*, and the prospects for obtaining even higher levels and effecting PHB secretion in the seed of oilseed rape appear to be very good. Achieving synthesis of PHB in transgenic crop varieties will considerably reduce the price of Biopol, for which there is already a proven market. Successful application of the technology to produce other polymers would expand the market prospects still further.

***Pharmaceuticals (3.6)***

Pharmaceutically active molecules, or their precursors, are already synthesised in certain oilseed species (eg gamma-linolenic acid (GLA) in evening primrose), be derived from vegetable oils (eg 'Lorenzo's oil from erucic acid) or could be produced from new transgenic varieties (eg 1% levels of interleukin and hirudin have been obtained in transgenic oilseed rapes). There seems likely to be a shift, due to consumer concerns, towards seeking to produce antibodies, for example, in plants rather than animals. In these cases, product values are very high, but market sizes very low. Production is likely to be by the pharmaceutical companies, or by a very few farmers under contract.

***Markets for co-products (3.7)***

Growing industrial oilseed rape gives rise to straw and a high-protein meal. Glycerine may also arise as a co-product of 'splitting' the oil. Markets for meal and glycerine are established, and the use of straw as fuel or fibre may be developed in future years.

### 1.2.3 Economic opportunities (4)

***Introduction***

Economic opportunities for the industrial use of UK-produced oilseeds, relate to both the economy as a whole and to the profitability of particular businesses.

***The economy (4.1)***

For the economy as a whole, the use of oilseeds in industry is constrained by:-

(i) **The cost** of the oilseed-based product *vis a vis* alternatives, including those from the world market. In principle, if it costs more to meet the requirements of industry through a vegetable oil than traditional materials, the economy will be made poorer if industry is forced to use vegetable based products.

(ii) **The CAP**. As things stand, the CAP provides an incentive to grow industrial oilseeds on land set aside from food production. The GATT settlement, however, places limits on the total amount of industrial oilseeds that can be produced on Set-aside land. 'Corrective' action must be taken if EU oilseed meal production from Set-aside exceeds 1 Mt soyabean meal equivalent. There is no clear indication of what this 'corrective' action might be, but the most likely option will be some reduction in Set-aside payments. The UK may need, however, to consider how to obtain the most advantageous share of the permitted area.

(iii) **Environmental effects**. The use of oilseed-based products is sometimes favoured on environmental grounds. Oilseeds are attractive because they are renewable, compared with many traditional raw materials. The consequence of spillages in the environment may be less serious than with other materials. However, the environmental indicators do not all point in the same direction. Similar use of fertilisers and pesticides as required for food crops may be needed. Allergenicity remains an area of perceived concern, requiring further investigation. For some people at least, the extension of the area of oilseed rape may, when the crop is in flower, represent a visual intrusion.

***Businesses (4.1; 4.2)***

For the industry, several aspects of risk need to be taken into account, when considering the potential expansion of oilseed rape production for industrial uses.:-

(i) **Production risks (4.2.2).** On-farm production risks associated with oilseed rape in general include pod shatter, pests and disease. Where varieties with chemical compositions different from those used for food are grown, there is also the risk of cross-contamination in the field or store. For linseed, in addition to these risks, there is the possibility of complete crop loss if the crop does not mature due to unfavourable weather. For the crushing industry, there is the risk that capacity may either be too small to exploit the harvest or too large, incurring heavy fixed costs for which there will be no reward (the present views of the UK crushing industry are that current capacity well exceeds supply, and that it would have no difficulty handling small and varying quantities of different types of seed).

(ii) **Market risks (4.2.3)**. Vegetable oils have to break into markets in which buyers already meet their needs from existing sources. To do so they must offer more value, either in the form of lower prices or of greater suitability for a specific purpose, or some combination of the two. There is a risk, in some cases, that if specialised oilseeds are produced, the other suppliers to the industry may simply lower their prices, so that the combination of raw material cost plus processing cost will still represent greater value to the user.

(iii) **Policy risks (4.2.4).** Policy has to strike a complex balance between conflicting objectives. In relation to oilseed rape and other vegetable oils, two somewhat conflicting objectives can be identified. In order to increase economic efficiency and to cope with the demands, under GATT, of other countries, there is pressure towards the liberalisation of the market. In contrast, concern about the environment, about sustainability and the wish to husband non-renewable resources, points towards encouragement for vegetable-based substitutes for some mineral products. The situation is further complicated because the environmental impact of a switch to vegetable oils is not necessarily wholly beneficial. Thus an industry geared up to produce industrial oils on this basis might find itself facing increasingly restrictive and costly legislation in the future.

## 1.3 RECOMMENDATIONS

Scientific research on oilseeds, in particular oilseed rape, is making a growing contribution to industrial development and wealth creation. The UK has researchers and centres of international standing in this area within both the public and private sectors (in the public sector, for example, there is expertise in enzyme purification and gene cloning; the private sector has expertise in the use of oils and in their processing). It is, therefore, in the public interest that this momentum should be sustained. Public funding is, thus, needed particularly to support pre-commercial, basic and speculative research. (1.2.1 & 3). Some specific directions for this research are identified below.

If the wealth creating potential of this research is to be realised, improved communication among and between researchers, policy makers and industry is needed. It is important to safeguard intellectual property, so that investments can be rewarded, but if communication is unsatisfactory, unintended duplication may occur and important opportunities will be neglected. (4.2.3)

Techniques of genetic transformation, to create transgenic varieties, represent a major source of progress, but they are also the focus of public concern and of a developing regulatory framework. It is important that this regulatory framework reflects the risks and uncertainties associated with GMOs and commands public confidence. At the same time, it should not place unnecessary obstacles in the development of products arising from the application of these techniques. Scientists need to provide clear explanations in non-technical language of the progress made and the risks involved. (2.4.3)

This study has identified a range of industrial markets for UK-produced oilseeds. In many cases, however, the exploitation of these markets depends on the successful development of new oilseed rape varieties with different seed-oil compositions. The most promising route to obtaining new oilseed rape varieties appears to be via genetic engineering to produce transgenic crops (2.4.1; 2.4.3). If this route is to be pursued, then basic research in biochemistry and molecular biology to elucidate the synthesis of triglycerides (ie oil) in the oilseed rape plant (2.4.1; 2.4.3) would be needed. This research would underpin specific developments (which, in view of intellectual property concerns, would necessarily take place in the private sector). The exploitation of a number of industrial markets also depends on the validation and appreciation of the claimed environmental benefits of replacing mineral-oil-based products with vegetable-oil-based products in certain applications (1.2.1; 1.2.2; 2.4.3). This issue would be addressed by the development of methods of assessing environmental impacts and benefits and their application to promising opportunities (1.2.2; 3.2; 3.3.4; 3.4.3; 3.4.4; 3.5).

Recommendations related to specific, current or potential uses of oilseeds for industrial purposes are as follows:-

(i) **Lubricants** (1.2.2; 3.2.5). Environmental regulations, possibly on an EU basis, may result in new opportunities for the use of vegetable-oil-based lubricants in certain sectors. Within the EU, the UK has a strong competitive position in the production of oilseed rape. Government and industry should ensure that research and market development enable it to respond to this opportunity.

(ii) **Surfactants** (1.2.2; 3.3.4). Of the wide range of surfactant products, pesticide adjuvants may present an opportunity for greater use of UK-produced vegetable oils with advantage to the environment and producers, but the benefits have yet to be proven. Research is needed to establish these, and to define where and how any advantages might be obtained. Farmers will then need up-to-date, informed guidance concerning the use of these additives.

(iii) **Surface coatings** (1.2.2; 3.4.3). Environmental concerns and issues relating to the health of people working in the printing industry suggest that a careful audit of the benefits of vegetable oils as a base material for **printing inks** is needed. If substantial advantages can be demonstrated, regulatory mechanisms may be required to shift demand in this direction. Given such a market, the commercial development of more suitable oilseeds should attract resources for applied research.

(iv) **Polymers and pharmaceuticals** (1.2.2; 3.5.3; 3.5.4; 3.6). Polymers represent a diverse and potentially very large market. Pharmaceutical products represent a much smaller, but high value, market. Publicly-funded basic research (eg on triglyceride synthesis, as described above) will underpin developments in both these areas. In view of intellectual property concerns, however, the development of specific opportunities will be the responsibility of industry itself.

# 2 Options and opportunities for crop production

## 2.1 CROP SPECIES

### 2.1.1 Introduction

UK oilseed production centres on oilseed rape and, to a lesser extent, linseed. In addition, very small volumes of oil for specialist pharmaceutical markets are provided by evening primrose and some other minor crops. Sunflower is also grown. Current sunflower varieties cannot match oilseed rape yields and are only suitable for the southern half of the UK. The development of new varieties (including via biotechnology) may both increase yields and expand the crop's range. Certain other crops may have potential in the longer term.

### 2.1.2 Oilseed rape

'Oilseed rape' refers to several *Brassica* species notably *B. napus* (rape) and *B. rapa* (syn. *campestris*) (turnip rape), Indian sarson ecotypes and *B. juncea* (Indian or brown mustard). There are winter and spring forms of *B. napus* and *B. rapa.* Originally, the brassicas were high in erucic acid and glucosinolates, and the oil was used for non-edible applications. Plant breeding effected a reduction, first of erucic acid in the oil, and then of glucosinolates in the meal. These double-low varieties now account for the major part of the market; high erucic acid varieties (HEAR) are grown for industrial markets.

The EU and UK areas of oilseed rape have grown considerably in recent years, with crops for non-food use on Set-aside land accounting for much of the most recent increase in area. During the last 14 years the UK area of oilseed rape rose from approximately 20 000 ha to more than 400 000 ha (6% total crop area), although the 1993 area (377 000 ha) was somewhat less than this. The crop now represents 3% by value of national agricultural output. UK production accounts for some 18% of EU output, making the UK the Union's third largest producer. UK oilseed rape yields and oil contents are at least comparable to those obtained in France and Germany, higher than those of other EU countries, and much higher than in the world's other leading producer countries.

Most of the UK crop is winter-sown, but there has been an increasing interest in spring-sown varieties, which, although lower yielding, offer improved quality and lower fertiliser and crop protection requirements. During the past 2 or 3 years, turnip rape varieties of oilseed rape have been grown in Scotland, owing to their earlier maturity than that of other spring-sown types.

UK farmers have, therefore, gained considerable experience in growing the crop to achieve high yields and high oil contents (oil content increases with latitude, giving UK growers an additional advantage). The UK is well placed to exploit any opportunities for increasing production of oilseed rape for industrial markets.

### 2.1.3 Linseed

Linseed is spring-sown and contains 35-40% oil. The crop is grown in the UK for industrial markets, notably the paint, varnish and linoleum industries. These uses arise from the seed oil's high content of (poly-unsaturated) linolenic acid (40-65%), and consequent rapid drying property. The meal protein (20-25%) is also of interest, but is inferior to other vegetable proteins due to its low lysine content.

Winter-sown varieties of linseed are currently being trialled; these should yield more and enable an earlier harvest than spring-sown varieties. Breeders, using conventional breeding techniques, are endeavouring to produce higher (70% +) linolenic-acid varieties for existing markets, and improved edible varieties with an oil quality similar to sunflower oil. Genes could also be transferred from rape into linseed, but the value and feasibility of this is questionable - linseed is lower yielding, more susceptible to weather, and less climatically adapted (ie linseed performs well in England, but has been much less successful in the rest of the UK) than oilseed rape, and so far neither transformation nor regeneration have been successful.

The main agronomic advantages of linseed are:

(i) it is not a brassica (and would not create, therefore, further pest and disease problems for horticultural and agricultural brassicas, possibly reducing the need for crop rotation);

(ii) it has a lower requirement for inputs of fertilisers and agrochemicals than oilseed rape (with cost and environmental advantages);

(iii) it avoids pigeon problems that plague the over-wintering rape crop each season.

The UK area of linseed in 1993 was about 40% of that of oilseed rape, and its average grain yield about 60% of that of oilseed rape. The harvesting of the crop can be constrained by late maturity or adverse weather conditions.

### 2.1.4 Other species

In the foreseeable future, the only other crop which might be important in the UK is cuphea. This is a rich source of medium-chain length oils (which, currently, can only be obtained from tropical plants). About 2.4 Mha (the current EU oilseed rape area) of cuphea could meet all the European and North American demand for such oils. The species' genetic diversity, in terms of seed-oil fatty-acid profiles, is such that conventional breeding could generate a series of varieties, each one a source of a different medium-chain length oil (eg capric, lauric or myristic). However, the plant presents serious agronomic problems: pod shatter and indeterminant flowering impede harvesting, and its sticky seeds make processing difficult. Non-shattering varieties are now available, but much development is needed before the crop is suitable for widespread adoption. Moving genes from cuphea to a more developed crop (eg oilseed rape) may prove a more successful strategy.

Other species containing valuable oils, but presently low yielding and undeveloped, include: caraway (*Carum carvi*), honesty (*Lunaria* spp.), marigold (*Calendula officinalis*), coriander (*Coriandrum sativum*), fennel (*Foeniculum vulgare*), dill (*Anethum graveolens*), wild spurge (*Euphorbia lagascae*), meadowfoam (*Limnanthes* spp), crambe (*Crambe abyssinica*), *Eruca* spp, *Osteospermum* spp and *Dimorphotheca* spp. These species are of interest, as (i) they could be developed as crops in their own right, and (ii) they are a potential source of genes for introduction into established crops. Both approaches are followed in research programmes in various countries, including the UK.

## 2.2 OILSEED RAPE AND LINSEED VARIETIES

### 2.2.1 Trialling procedures

All new varieties of plants which are to be marketed in the UK must first undergo a system of statutory 'Distinctness, Uniformity and Stability' (DUS) tests and 'Value for Cultivation and Use' (VCU) Trials. If acceptable, the variety is added to the UK National List of Agricultural Varieties (NL), and, in due course, to the EU Common Catalogue of Varieties of Agricultural Plant Species. Alternatively, the variety may be marketed by virtue of its entry to the EU Common Catalogue after addition to a Member State's national list (D A Boreham, pers comm, 1994).

The legislation does allow small amounts of seed of varieties not in the NL or Common Catalogue to be supplied for research or experiment or for purposes other than as seed for sowing (D A Boreham, pers comm, 1994). Varieties which breeders/agents do not intend to market need not be subject to such trialling, but the seed and the whole of any material produced must remain the sole property of the breeder. This covers seed multiplied for use by the breeder and used in demonstration and trial work, and could also apply where a farmer is simply rewarded for providing the husbandry required. This latter approach may be adopted where the potential market for the seed will be small and the returns do not justify entry into the statutory trialling system. However, this is very much the exception and the majority of varieties are entered into the official system. A more detailed account of official trialling procedures appears in Appendix I.

### 2.2.2 Varieties currently being trialled

***National list (NL), Recommended list (RL) and Descriptive list (DL) trials***

Table 2.1 shows the number of varieties of oilseed rape and linseed that were included in NL, RL and DL trials in the UK in 1993 and 1994. Recommended and Descriptive Lists are issued annually by the National Institute of Agricultural Botany (NIAB).

**Table 2.1**

**Numbers of different varieties of oilseed crops included in NL, RL or DL trials and entered on the RL or DL in the UK**

| | Harvest year | Winter oilseed rape | Spring oilseed rape | Linseed |
|---|---|---|---|---|
| Total number of varieties in all trials | 1993 | 88[1,2] | 60[3,4] | 46 |
| | 1994 | 84 | 58 | 48 |
| Number of new varieties entered for all trials | 1993 | 46 | 28 | 13 |
| | 1994 | 48 | 19 | 11 |
| Number of varieties on recommended list (RL) or descriptive list (DL) | 1992 | 17 (RL) | 19 (DL) | 13 (DL) |
| | 1993 | 11 (RL) | 22 (DL) | 16 (DL) |

1 Includes 2 hybrid varieties (3 entered for 1994 harvest year)
2 Includes 2 high-erucic acid varieties (no variety entered for 1994 harvest year)
3 Includes 1 hybrid variety (3 entered in spring 1994)
4 Includes 1 high-erucic acid variety (1 entered in spring 1994)

Source: Adapted from S P J Kightley (pers comm, 1994)

At present, 17 breeding companies are submitting varieties for trialling in the UK, and 10 of these have varieties on the Recommended or Descriptive Lists issued by NIAB.

All the winter, and all but one of the spring, varieties currently being trialled are of the conventional double-low type aimed at the edible oil market. One spring variety, with a high-erucic acid content, has been entered for National Listing for industrial markets. Varieties with altered fatty acid profiles have been entered for National Listing, but the breeders withdrew them because of their low yield.

In contrast to oilseed rape, linseed varieties are predominantly aimed at industrial use, although there are three varieties entered which are new edible oil types.

***Other trials***

Two genetically-engineered varieties of oilseed rape with either a high (40%) stearic acid or lauric acid content, produced by Calgene Inc in the USA, are being trialled by the Scottish Agricultural College, Aberdeen. This organisation is the only one in Europe involved in the study. It is believed that the seed for such crops will be marketed in the USA and Canada in the near future.

The only other known variety which is not being fully trialled within the official system, is a variety of winter oilseed rape which has been entered for DUS, but not VCU. This variety is claimed to have a low-linoleic-acid content.

## 2.3 OBJECTIVES OF OILSEED BREEDING PROGRAMMES

### 2.3.1 Introduction

In the immediate future, all breeders are concentrating their efforts in producing varieties which satisfy existing (mainly edible food) markets. Many favour promotional schemes to emphasise the health advantages of oilseed rape oil compared with other vegetable oils.

### 2.3.2 Royalties

Royalties are a central concern. These are the means by which plant breeders obtain a return on their investment in research and the development of new varieties. Many breeders feel that these returns are not an adequate reward for the risks. Further, the use of farm-saved seeds currently avoids any such payment. Although this will change, the final details have not yet been agreed. The royalty on farm-saved seed is expected, however, to be lower than that on certified seed. The priority of breeders, at present, is to remain competitive in the short-term, and, in general, they believe this means aiming at well-established, rather than uncertain, novel, markets. In the immediate future, interest is, therefore, likely to remain directed largely towards edible oils or dual-purpose varieties with high levels of oleic acid and low levels of linolenic acid.

C Boyce (pers comm, 1994), Technical Director of the British Society of Plant Breeders, indicated that the royalty income from a new variety needed to be at least three times the investment in research to produce it. Assuming a Royalty income of £2000 per t of seed, average sowing rates of 7 kg per ha, average crop yields of 3.0 t of grain per ha, an oil content of 40%, and an average annual cost of variety development of £100 000, the minimum planted area to justify research investment is 21 500 ha per year. This approximates to an annual market for 64 000 t of grain or 25 600 t of oil (see Appendix II).

### 2.3.3 Hybrid varieties

Breeders are investing much effort in developing hybrid oilseed rape varieties. These offer better vegetative growth (with attendant agronomic advantages) and higher yields than current inbred types. If successfully adopted, they would lead to a reduction in the use of farm-saved seed (as seed from hybrid varieties is not true-breeding and would produce variable crops), and maintain breeders' interest in varietal development and improvement.

The first hybrids are currently in National List Trials. These are produced by the use of cytoplasmic male sterility (CMS), and are composites of a male sterile line in admixture with one or more male fertile lines, as pollinator/s. These varieties require effective cross-pollination for adequate seed set. Yields have been hitherto rather variable in official trials.

Some spring oilseed rape hybrids used in Canada depend on a dominant self incompatibility (SI) system. These types also require cross-pollination to set seed, and have again given variable results in the field.

Hybrids based on recessive self incompatible or a fully restored CMS system have the fertility restored in the seed grown by the farmer. They do not, therefore, rely on cross-pollination for seed set. Such types are about to be entered in National List Trials.

The potential benefits of hybrid varieties to both breeder and grower are such that a complete switch of all the oilseed rape crop from inbred to hybrid varieties is likely by the year 2000. Their major characteristics will, however, be similar to those of existing varieties in terms of oil content and composition, but the different growth characters and agronomic requirements may necessitate some minor modification of the official trialling procedures and on-farm agronomic practices.

### 2.3.4 Biotechnology

Modern biotechnological methods considerably widen the genetic variation available to the plant breeder. In the medium term, novel oilseed cultivars with modified fatty-acid profiles will be produced by non-transformation-based biotechnological techniques (tissue culture, embryo rescue, wide crosses and mutagenesis). In the longer term, genetic transformation will enable a wider diversity in seed oil content in transgenic varieties. Both strategies have profound implications for plant breeders' objectives. The possibilities are discussed in the next section.

## 2.4 PROSPECTS FOR 'DESIGNER OILSEEDS'

### 2.4.1 Introduction

As stated above, biotechnology makes much more genetic variation available for incorporation in the target crop. Of particular consequence to industrial oilseeds is the scope to greatly increase the diversity of seed-oil composition.

The genetic modification of seed-oil composition in oilseed rape is, essentially, the modification of the processes of oil synthesis in the plant. Crude vegetable oils consist mainly of triglycerides (95%) with a mixture of other components such as wax esters, pigments, sterols, terpenes, phospholipids, and sulphur components making up the remainder. Triglycerides are fatty-acid esters of glycerol, consisting of a glycerol 'backbone' to which three fatty acid molecules are attached. The fatty acids occupy three positions, which, for the purposes of this account, are termed top, middle and bottom. The three fatty acids may be all different, two different or all alike.

The synthesis of triglycerides involves two main steps - fatty acid synthesis and triglyceride synthesis.

**Fatty acid synthesis** is effected by two enzyme complexes, namely acetyl-CoA carboxylase and fatty-acid synthetase (FAS). The first complex uses the products of photosynthesis to generate 2 carbon units. The second (FAS), in effect, adds these sequentially to generate a 'pool' of fatty acids. It is the second complex (FAS) that is of greater interest in terms of seed oil modification. In plants, in general, the process of adding $C_2$ groups stops at $C_{18.}$ However, the FAS complex of some plant species contains enzymes that stop the process at shorter or longer carbon chain lengths; identifying and isolating the genes responsible for these enzymes and introducing them into target crop species is an essential stage in the development of transgenic designer oilseeds (eg California bay contains an enzyme that stops the FAS process at $C_{12}$ - this has formed the basis for Calgene's high-lauric oilseed rape variety currently being trialled in Scotland).

A third stage in fatty acid synthesis occurs as a result of the action of **desaturases**. These enzymes control the degree of unsaturation of fatty-acids, and their identification, isolation and incorporation into new varieties is also a central goal in the development of transgenic oilseeds. The first desaturase to be isolated was a Δ-9 desaturase, which is a soluble enzyme responsible for the terminal step in the formation of oleic acid. Two other desaturases are important. These are both membrane-bound and are the Δ-12 and the Δ-15 desaturases which catalyse the final step in the formation of linoleic and linolenic acids, respectively. These three desaturases operate in sequence (ie linolenic (C18:3) is, the result of the action of all three). All the genes responsible have now been cloned. Other desaturases are known which produce unusual fatty acids, such as petroselinic acid.

**Triglyceride synthesis** involves the attachment of fatty acids derived from the above process to the top, middle and bottom positions of the glycerol molecule. The metabolic pathway effecting this is known as the 'Kennedy Pathway', and the enzymes responsible are known as acyl transferases. Different acyl transferases are associated with the three positions. The acyl transferases at the top and bottom positions tend to be non-specific (they will incorporate whichever fatty acids are dominant on the metabolic pool). The enzyme governing the middle position, however, is highly selective and will discriminate against certain fatty acids even if they are the dominant component of the pool. In oilseed rape, this enzyme will only 'recognise' and attach unsaturated $C_{18}$ chains. Hence, while it is currently possible to modify the FAS process to generate a pool of fatty acids of chain lengths shorter (eg $C_{12}$ - lauric) or longer (eg erucic - $C_{22}$) in oilseed rape, the synthesis of oils very high in these acids is constrained by the enzyme controlling the middle position. The identification and introduction of enzymes that allow the attachment of shorter or longer chain lengths at the middle position is, therefore, central to the development of oils very high in single fatty acids. The genetic manipulation of acyl transferases is the goal of major investigations by Calgene in the USA and by Professor Slabas' group at the University of Durham.

The economic significance of this relates to the potential to reduce downstream processing and costs, by supplying the industrial user with chemical feedstocks that are closer to the final product. Most industrial users of vegetable oils buy what is cheapest on the open market. Targeting modified vegetable oils at these users implies providing raw materials that are, in effect, new products, capable of saving processing costs and giving them a competitive edge over other users.

It is important to recognise that designer oilseeds must be capable of growing and providing adequate yields in the environments for which they are intended. Climatic adaptation and agronomic development are essential. This, therefore, favours the genetic transformation of established crops in preference to the development of new crops or less widely grown species. Clearly, oilseed rape is 'out front' in this respect. It is also particularly amenable to genetic modification, and the account below centres on this species. Linseed transformation is in its infancy, sunflower is likely to remain a minor UK oilseed crop and soya bean and maize, although recently transformed with oil-related genes in the USA, are not UK oilseed crops.

### 2.4.2 Non-transgenic oilseed crops

The development of new oilseed rape varieties using non-transformation-based techniques relies on the considerable natural variation present within the brassicas. Recent developments include: very-high (85%) oleic mutants (developed, but not yet commercialised); medium (15-30%) and high (40-55%) erucic varieties (no very high (>60%) erucic cultivars have been produced so far); and 10-20% palmitic varieties. More details are given in Appendix III.

**Advantages** of the non-transgenic route include: relative ease of seed-oil modification with respect to $C_{16}$, $C_{18}$, $C_{20}$ and $C_{22}$ fatty acids; reduced risk of cross-pollination; non-GMO status (the varieties would not be subject to the restrictions on the release of GMOs into the environment, or create concern regarding public acceptability).

**Disadvantages** of relying solely on variation within the brassicas for seed-oil modification include:- variation is limited to a small number of $C_{16}$-$C_{22}$ fatty acids; it may not be possible to produce very high erucic (>65%) cultivars by this method; it is unlikely that very high saturate (stearic or palmitic) cultivars will be produced.

### 2.4.3 Transgenic oilseed crops

***Introduction***

The development of transgenic crop varieties comprises three critical stages:-

(i) **Identification**. The identification and isolation of genes imparting desired properties.

(ii) **Transformation.** The introduction of the isolated 'foreign' gene into the host plant's DNA in order to impart the new property. In simple terms, transformation is successful if the gene 'goes in and stays in'.

(iii) **Regeneration**. Transformation is essentially a process occurring at the cellular level. It must be followed by stable 'regeneration' of a viable whole plant.

Transformation and regeneration systems are developed to an almost routine stage in the case of oilseed rape, but may present limitations on the development of transgenic varieties of most other oilseed crops. Identification is a key stage in all cases, and may still represent a constraint on the development of transgenic oilseed rape varieties.

The variety of seed-oil contents found within plants is enormous, ranging from $C_8$ to $C_{24}$ chain lengths. An even greater variety of lipid structures is available from non-plant species, bacteria and fish. If the synthesis of these novel fatty acids is regulated by a small number of genes (<4), the potential for isolating these genes from the donor species (in which they occur naturally) and inserting them into oilseed rape in order to create a transgenic cultivar with a novel seed-oil profile appears good, and has been achieved in several cases. The challenge is greater as the number of genes involved increases.

A brief survey of progress and prospects with regard to the novel fatty acids likely to be of industrial interest appears below (more details appear in Appendix IV). This is followed by brief comment on regulatory aspects.

***Prospects for transgenic oilseed rape varieties with novel fatty-acid profiles***

The prospects for transgenic oilseed rape varieties containing high contents of particular fatty acids or other chemicals are as follows:-

(i) **Erucic acid (C22:1).** This is already a major industrial feedstock, but current varieties contain only 45-50% erucic acid. There are good prospects that very-high-erucic (60-80%) cultivars will have been developed by the end of the decade.

(ii) **Lauric acid (C12:0).** Vegetable oil high in lauric acid (ie lauric oil) is also an important industrial feedstock. At present, it is largely derived from low-cost, high-yielding coconut and oil-palm crops. New transgenic oilseed rape varieties containing 30-40% lauric acid have been developed in the USA, and are being trialled in Scotland. However, rather than being a realistic alternative to traditional lauric oils, the 30%+ lauric acid oilseed rape may simply give lauric-oil processors an additional bargaining chip in their negotiations with lauric-oil suppliers from the Philippines, Malaysia and Indonesia. The competitiveness of a high-lauric oilseed rape would be very different if a true tri-lauric variety (with lauric acid at all three positions on the glycerol molecule) were developed. Such an oil would be particularly attractive to users due to its very high purity in terms of the desired fatty acid.

(iii) **Ricinoleic acid (C18:1-OH)** has a range of potential medium- to high-value industrial uses. Attempts are being made to clone the required gene from castor and transfer it to oilseed rape. If these are successful, a high ricinoleate oilseed rape should be available by the end of the decade.

(iv) **Petroselinic acid (C18:1 delta6).** Petroselinic acid has some potential uses in the manufacture of surfactants and polymers. Ongoing developments suggest that a petroselinic oilseed rape will be available within the next five years.

(v) **Gamma-linolenic acid (GLA)** is currently derived from evening primrose and borage oils and used in pharmaceutical and health-care products. Field trials of GLA-containing oilseed rape are now underway in France, although further details are confidential. The value of these developments, however, needs to be set against the likely, rather limited, market for GLA and the scope for its derivation from other sources (eg fungi have been bred that overproduce GLA).

(vi) **Epoxy fatty acids** can be used in the manufacture of resins and coatings. Some progress has been made in Sweden, and possibly the USA, towards developing oilseed rape varieties capable of accumulating useful epoxy fatty acids. Although it is unlikely that such cultivars will be produced in the next five years, they could be available by the end of the decade.

(vii) **Wax esters.** Wax esters are uncommon in plants, but make up much of the seed reserve in jojoba. Jojoba wax has a wide range of industrial uses. Progress has been made towards developing an oilseed rape variety capable of accumulating similar waxes rather than triglycerols in its seeds. An informed guess would rate chances of success in this project quite highly with 'jojoba' oilseed rape cultivars possibly becoming available by the end of the decade.

(viii) **Polyhydroxybutyrate (PHB).** This biodegradable polymer is currently produced commercially via bacterial fermentation, and is marketed by Zeneca plc as 'Biopol'. Genes encoding the three requisite enzymes have been transferred to *Arabidopsis thalliana* and, recently, a level of 15% PHB in the leaves has been achieved. Efforts are currently being made to obtain this in the seed of oilseed rape and increase it to a commercial level.

(ix) **Molecular farming** involves the engineering of oilseeds to supply products such as pharmaceuticals where the tonnages required may be relatively low, but the value of the end product is extremely high. Much development work needs to be done, but oilseed rape molecular farming may offer a genuine alternative to conventional microbial fermentation for the production of pure high-value peptides or proteins for a variety of low-volume, high-value end uses, ranging from pharmaceutical peptides, such as hirudin or interleukin, to industrial enzymes, such as cellulases, lipases or proteases.

### *Regulatory aspects*

In addition to the usual National Listing procedures, for varieties produced using genetic transformation, an environmental risk assessment is needed to obtain a consent to release the variety for trial purposes or to market the oilseeds. This requirement will increase costs, and may lengthen the time between variety development and release (R Lowson, pers comm, 1994). However, while an environmental risk assessment is likely to remain a requirement, the speed and efficiency of the procedure should improve as experience is gained.

## 2.5 FACTORS AFFECTING CROP PRODUCTION

### 2.5.1 Introduction

The above indicates the potential for growing and using oilseed rape for industrial use in the UK. There are, however, a number of aspects of crop husbandry and crop production and some possible constraints which will need to be addressed in order to realise this potential.

As referred to above, there is a developing framework of legislation pertaining to Genetically Modified Organisms (GMOs), and transgenic varieties will need to undergo environmental risk assessments. GMOs are the focus of some public concern, and legislation will need to address the risks and uncertainties and command public confidence. The development of 'designer oilseeds' will occur within this context.

While new varieties may be the 'key' to several industrial markets, as stated earlier, breeders may be unwilling to embark on variety development without some assurance of a market for more that an estimated 64 000 t of oilseed rape grain per year.

Measures will need to be taken to avoid cross-contamination (ie between food and non-food varieties). As with any crop, rotational needs may limit the total area that can be sown to oilseed rape. Oilseed rape has been the focus of some public reaction and concern, which may impact on its expansion in area. This has partly arisen from the crop's distinctive colour and smell and obvious impact on landscapes and local environments, but mostly from concerns over its possible allergenicity. Further comments on cross-contamination, rotational needs and allergenicity are made below.

### 2.5.2 Cross contamination

***Introduction***

Where the fatty-acid profile of an industrial oilseed rape variety differs from that of edible varieties, it will be essential to ensure that there is no contamination of seed and oil batches at all stages from the seed producers and supplier to the grower and to the crushing mill. There will be a need for stringent segregation of seed at all stages, and this will have logistic and cost implications. The risk of contamination will be greatest if there is no way of distinguishing the seed of edible and industrial varieties (and may be reduced by the incorporation of genetic 'markers' (eg different seed colours) into new industrial varieties). There are two possible sources of contamination: cross-pollination and volunteers.

***Cross-pollination***

Oilseed rape pollen is self compatible (ie pollen from one plant can fertilise the same plant). Oilseed rape pollen is relatively heavy and not transported efficiently by wind, and the plant relies, to a large extent, on insects, including bees. Pollinating insects do not, on average, fly very far. Although this can be a limitation in the development of hybrid varieties, it has the advantage that it is probable that simple geographic isolation prevents almost all cross-pollination of adjacent oilseed rape fields. Recent research indicates a fairly low level of contamination of double-low oilseed rape by high-erucic oilseed rape. Most samples of the former had erucic-acid contents of 0.5% or less, with maximum recorded values of 2%. The required distance between double-low and high-erucic oilseed rapes has recently been reduced to 50m, and may be reduced further. If a wider range of varieties with different fatty-acid profiles were to be grown, simple zoning of crops would probably be more than sufficient to prevent cross-contamination *via* pollination. This assumes that seed purity is maintained, and more rigorous measures would need to apply to seed crops (as is the case with any crop).

Biotechnology may provide alternative approaches to the problem of contamination. For example, a variety could be engineered to develop asexually at the seed stage (although this would be unattractive from the breeders' viewpoint as farmers could regenerate their own seed).

### *Volunteers*

Contamination of a crop from a previous rape crop, *via* volunteer plants, is a potentially more serious problem than cross-pollination. Even in good harvesting conditions losses of 20 to 50 kg per ha can occur, which is high in relation to the quantity of seed that is planted to establish the crop (6-7 kg per ha), and losses of between 50 and 150 kg per ha commonly occur in less than ideal harvesting conditions (Ogilvy *et al,* 1992). The losses can be considerably greater in poor harvesting conditions, and where the mature crop is subject to windy conditions prior to harvest.

Shed seed can persist in the field for several years before germinating and emerging in subsequent crops. Such volunteers cannot of course be distinguished from sown plants in a subsequent rape crop. The factors controlling the persistence of volunteer oilseed rape seeds are uncertain, and the HGCA is currently funding a project at the Institute of Arable Crops Research, Rothamsted on this subject.

Research to understand and minimise pod shatter is also underway, at Long Ashton, the University of Nottingham and the University of Durham.

The safest procedure to minimise the possibility of volunteer contamination would be to ensure that crops with a given genetic make-up are only grown on land that has not been used in the recent past to produce an oilseed rape crop with a different genetic composition. This again suggests the importance of zoning of crop production to minimise the possibility of contamination of the harvested seed. Severe problems could arise if the oil produced failed to meet the market specification, with the consequence that the sale of the product could be adversely affected or the product may even be unsaleable.

### 2.5.3 Rotational requirements

As with other crops, rotation of oilseed rape crops may be needed to reduce the effects of pests and diseases. Crop rotation may also be needed to enable the sowing of a winter-sown crop early into a fine seedbed conducive to rapid germination. This may be difficult to achieve if the previous crop is harvested late or the soil conditions are not favourable (ie too dry or wet). The problem of pod shatter prior to harvest or seed loss during harvest, and resultant volunteer problems in subsequent crops, as discussed above, are also in part addressed by crop rotation. Opinions as to how often oilseed rape can appear in an arable rotation range from once in four or five years to every year. Rotational needs, however, seem likely to place some limit on the total area that can be devoted to oilseed rape.

### 2.5.4 Allergenicity

The perceived or actual allergenicity of oilseed rape may be a constraint on expansion of its production. A study conducted in Scotland (Soutar *et al*, 1994) surveyed respiratory and other symptoms in random samples of the populations of villages in oilseed-rape-growing and non-oilseed-rape-growing areas. Spring and summer exacerbations of symptoms occurred in 25% of the populations of both areas, with small, but significant, excesses of cough, wheeze and headaches in the oilseed-rape-growing area. The study concluded that it is likely that a proportion of the symptoms occurring in people living in close proximity to oilseed rape is caused by the plant. The excess of symptoms was small and pollen levels low, and the authors concluded that allergy to oilseed rape pollen is uncommon. However, the study demonstrated that oilseed rape produces terpenes similar to those produced by pine trees (and, indeed, mown grass). Pines were prevalent in the non-oilseed-rape area. It was suggested that the increase in spring/summer symptoms in both areas might be partly attributed to these terpenes.

Work at Oxford University, also concluded that reactions to the plant are prompted by a volatile chemical, and not, as previously believed, by a protein.

Further research to clarify this issue, and to identify any allergenic agents or irritants, is needed. Such agents may then be amenable to genetic modification.

### 2.5.5 Conclusions

The rotational requirements and the need for appropriate zoning of crops will be important factors in determining the areas of land which will be suitable and available for producing crops for specific end-uses. The number of such potential different end-uses will influence the complexity of such problems. Again this may have cost implications which could influence the attractiveness or otherwise of producing crops for specialist markets.

# 3 Characteristics of industrial markets

## 3.1 INTRODUCTION

Vegetable oils and their derivatives are, or could be, used in a wide range of non-food products and processes. Vegetable oils, along with animal fats and synthetic compounds derived from mineral oil or natural gas, provide the basic raw materials for the oleochemical industry. A simplified overview of this industry is provided by Table 3.1.

**Table 3.1**
**The oleochemical industry: raw materials, intermediates and end uses**

| Raw materials | Basic oleochemicals | End-use markets |
|---|---|---|
| *Natural* | Fatty acids | Building auxiliaries |
| Tallow | Fatty acid methyl esters | Candles |
| Tall oil | Dimer & trimer acids | Cleaning agents |
| Coconut oil | Fatty alcohols | Cosmetics |
| Palm oil | Fatty amines | Detergents |
| Palm kernel oil | Glycerine | Fire extinguishing agents |
| Soyabean oil | | Flotation |
| Sunflower oil | | Food emulsifiers |
| Rapeseed oil | | Insecticides |
| Other vegetable oils | | Leather |
| | **Oleochemical derivatives** | Lubricants (including drilling muds) |
| | Fatty amides | Paints and inks |
| *Synthetic* | Epoxidised oils & esters | Paper |
| Ethylene | Ethoxylates | Pesticides |
| Propylene | Fatty acid sulphates | Pharmaceuticals |
| Olefins | Fatty acid sulphonates | Plastics |
| | Fatty esters | Rubber |
| | Fatty soaps & salts | Soaps |
| | | Textiles |
| | | Tyres |

Source: Adapted from Howard (1993) and INFORM (1990)

As evident from Table 3.1, industrial markets for vegetable oils are many and various. They arise, however, from a few basic functions of properties of the oils or their derivatives. On this basis, industrial markets for vegetable oils can be divided into five categories, as follows:-

(i) **Lubricants** rely on the ability of oils or derivatives to form a stable interfacial layer, that displays insolubility and non-reactivity with the surfaces it lubricates.

(ii) **Surfactants** exploit the amphiphilic nature of fatty-acid derivatives.

(iii) **Surface coatings** use the insolubility (waterproofing) and polymerisation properties of vegetable oils and derivatives.

(iv) **Polymers**. The use of vegetable oils as raw materials for polymer production relies on the polymerisation characteristics of certain fatty acids and derivatives. Certain other oleochemicals may perform functional roles (eg as surfactants or lubricants) in polymers. Further, polymers may be secreted in new transgenic oilseeds.

(v) **Pharmaceuticals.** Vegetable oils act as inert carriers in many pharmaceutical products. Certain oilseeds are a source of pharmaceutically active oils, fatty acids or other chemicals, and the scope could be considerably widened by transgenic varieties.

These five market sectors are discussed below. Most of these uses rely, at present, on a 'building block' approach. Raw materials from vegetable oils are chemically processed to form the final product. Such an approach is 'driven' by chemistry and chemical engineering. Biotechnology is opening up the possibility for replacing some or most of the processes occurring in the industrial plant by processes occurring in the crop plant, bringing the raw material provided by the oilseed much closer to the final product. Such an approach is 'driven' primarily by biochemistry, molecular biology and genetic engineering. In practice, the two approaches represent either end of a continuum, and most products are the result of a combination of the two. The potential of biotechnology is to shift the 'site' of production from the industrial plant towards the crop plant. Apart from changing fatty-acid composition, the greatest interest, currently, is in the scope for genetic modification of oilseed rape to effect 'in-plant' production of polymers and pharmaceuticals.

In addition to vegetable oil, oilseed crops give rise to co-products, straw and meal. Glycerine, which arises from the 'splitting' of oils may also be regarded as a co-product. Although the main focus of this study was on the production of, and markets for, vegetable oils, some comment on co-product markets is made below.

## 3.2 LUBRICANTS

### 3.2.1 Introduction

In simple terms, a lubricant reduces the friction between two surfaces by forming a stable interfacial film. For effective action, it must not react with either surface, or degrade, at least during its period of action. Lubricants have many applications ranging from engine oils and greases, to oils used for industrial processes. The latter include fluids sprayed onto metal as it is cut or milled, oils used to aid the release of concrete from moulds, and 'muds' piped down to drilling bits on oil rigs.

### 3.2.2 Sources and consumption of lubricants

Lubricants are derived from three main sources: mineral oils; synthetic compounds (derived mainly from petrochemicals); and natural oils. The first is the largest category, by far. Vegetable-oil-based lubricants currently cost up to three times as much as their mineral counterparts (or more if modified). This figure is less than it was five years ago, but the potential for further reduction is limited. Synthetic lubricants tend to be around 5 - 6 times the price of mineral-oil-based lubricants and are, therefore, normally used for very high performance applications (eg lubrication in aircraft engines). Some 740 000 t of lubricants were used in the UK in 1993 as shown in Table 3.2.

### 3.2.3 Advantages and disadvantages of vegetable oils as lubricants

A modern lubricant consists of a base oil (c 90-95% by weight) and a 'package' of additives. The fatty acids in the base oil determine the general characteristics of the lubricant; the additives give specific properties. Lubricant design criteria include:

performance, viscometrics, environmental characteristics (including biodegradability and recyclability) and health and safety (Harold, 1994). Optimum design achieves these criteria and minimises cost. Environmental criteria are of increasing importance. Environmentally driven market forces include: consumer uses/concerns, legislative requirements, eco-labelling proposals, motor manufacturers' demands and promotional features (Harold, 1994). These criteria can be met by choice and development of both base oils and additives. Base oils derived from vegetable oils offer a range of advantages over mineral oils and synthetics, but also present technical constraints. Both the advantageous and disadvantageous features of vegetable oil lubricants vary with the composition of the oil and are amenable to modification. There may be scope in the future for the vegetable oils to provide synthetic compounds, but this technology is far from established.

**Table 3.2**
**Lubricant use, UK, 1993**

| | Quantity<br>t | Proportion of total<br>% |
|---|---|---|
| Engine oils | 279 615 | 37.8 |
| Other industrial oils | 225 999 | 30.4 |
| Hydraulic oils | 98 446 | 13.4 |
| Transmission/speciality/<br>agricultural oils, incl. greases | 63 163 | 8.5 |
| Marine lubricating oils | 57 123 | 7.7 |
| Greases & other uses | 12 951 | 1.7 |
| Aviation lubricants | 3 739 | 0.5 |
| **Total** | **741 036** | **100** |

Source: Adapted from Institute of Petroleum (1994).

The advantages of vegetable oils as base oils over mineral oils include:-

(i) **High biodegradability.** The relatively unstable, linear-chain molecular structure of the fatty acids in vegetable oils allows enzymatic and bacteriological action, necessary for complete rapid biodegradation. Mineral oils and derivatives are composed largely of ring molecules which are much more stable and slow to degrade.

(ii) **Low toxicity.** Vegetable oils seem to offer reduced toxicity compared to mineral oils, although the precise extent of this is unclear.

(iii) **High flash point**. Vegetable oils are less volatile and have higher flash points than mineral oils.

(iv) **High viscosity indices.** The viscosity of vegetable oils changes little with changes in temperature (but viscosity range may be narrower due to oxidation at high temperatures and crystallisation at low temperatures - see below).

(v) **High lubricity.** The lubricity (the ability to reduce friction) of vegetable oils is superior to that of most mineral-oil bases.

(vi) **Compatibility with paints and seals.** Lubricants must not have any chemical or physical effect on the surfaces they lubricate. Vegetable oils show good compatibility with all paints and seals used in standard industry tests.

The main disadvantages of vegetable-oil-based lubricants are:-

(i) **Oxidative instability.** The double bonds in the fatty-acid chain react with oxygen molecules, causing the oil to become sticky. This process is rapidly accelerated at higher temperatures and is known as thermal oxidation. The higher the ratio of double bonds, the greater the thermal oxidation problem. A fatty-acid chain that is already saturated (ie has no double bonds) is too viscous and does not have the flow properties required of a lubricant.

(ii) **Poor low temperature properties.** Vegetable oils are generally inferior to mineral oils at low temperature. Pour points (ie the temperature at which they become solid) are higher, and low temperature viscosities are poorer than those of mineral oils.

(iii) **Hydrolytic stability.** The triglyceride structure of vegetable oils means that in the presence of water, at high temperature, they are prone to hydrolysis.

(iv) **Price.** Lubricants based on vegetable oils are usually between 1.5 and 3 times the cost of the equivalent mineral-derived lubricant.

The problem of thermal oxidation can be addressed (in order of effectiveness and cost) by using oils with a low proportion of double bonds, by the addition of anti-oxidants, or by the conversion of oils to methyl and other alkyl esters. Low-temperature properties can be improved by choosing oils with a high ratio of double bonds, blending different oils, adding pour-point depressants (which prevent the formation of large crystals) and co-solvents (which dissolve small crystals), and by converting oils to esters. Hydrolytic stability can be improved by using oils containing longer-chain, mono-unsaturated fatty acids. Addressing all three technical constraints in one oil calls for some compromise. At present, very-high-oleic-acid oils are favoured as offering a good balance between thermal and hydrolytic stability, and low temperature properties.

As indicated above, esters derived from vegetable oils or synthetic esters offer improved performance at both low and high temperatures. They are, however, less hydrolytically stable and cost between 5 and 10 times as much as mineral oils. They have many similar properties to mineral oils used for lubricants, but retain the biodegradability advantages of vegetable oils. The potential EU market for fatty-acid esters for lubricants has been estimated by as: drilling oils (North Sea) - 80-100 000 tonnes; two-stroke engine oils - 75 000 tonnes; de-shuttering oils - 70 000 tonnes; greases - 100 000 tonnes; metal working fluids - 450 000 tonnes. Fatty alcohols may also be used for similar applications as additives to the lubricant mixture.

The costs of vegetable oils and esters compared with mineral oils means that their use may be possible only through a favourable tax regime or legislation to restrict or prohibit the use of mineral oils in particular applications. Some estimates of the price differences are given in Table 3.3.

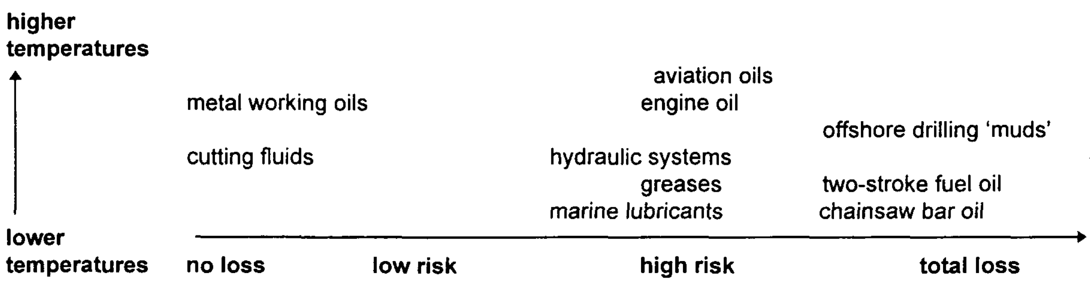
**Table 3.3**
**Approximate prices and differentials for the three main lubricant base stocks**

| Product | Approximate price per gallon ($) | Price differential | Relative costs |
|---|---|---|---|
| Refined mineral oil | 1-2 | 100%-200% | 1 |
| Vegetable oils | 2-4 | 100%-400% | 1.4 - 2 |
| Synthetic esters | 6-16 | 300%-1600% | 4 - 15 |

Source: Adapted from Lai & Carrick (1994) and Naegely (1993).

Vegetable-oil-based lubricants, particularly if based on unmodified oils, are most applicable where the lubricant could be a toxic hazard to users and/or where there is a risk of spillage to the environment, and where neither extreme of temperature is encountered. The risk of loss during, or after, use, and some indication of likely range of working temperature, for the main categories of lubricant are summarised in Figure 3.1. Clearly, the most promising applications are in the lower right-hand side of the diagram. In addition to environmentally driven applications, the high viscosity index of vegetable oils is useful in applications where temperature may change regularly in use, but where it never reaches the point when sticky deposits form, such as in aircraft landing gear.

**Figure 3. 1**
**Risks of loss and working temperature of different lubricant applications**




### 3.2.4 Current production and use of vegetable oil-based lubricants

Lubricants used in speciality applications may provide small volume, niche markets. The reduced toxicity of vegetable oils makes them attractive for the food industry, where any contamination could be serious. Sports pitches and turf production sites may also benefit from use of reduced toxicity lubricants in mowers and other machinery. These and similar markets represent only small volumes; for appreciable markets to develop, a marked change in demand (through willingness to pay for more environmentally protective products, price reduction or legislative changes) will be needed. Fatty-acid esters are now used for a number of high-performance applications where their benefits are sufficient to justify their higher price. Kohashi (1990) reports the use of fatty-acid esters in engine oils optimising their high viscosity, and in hydraulic fluids optimising their fire resistance. When used for industrial processes, they often help to produce a better quality end-product, such as oils for hot and cold rolling steel, cutting fluids, press oils and drawing oils.

The use of high and very-high-oleic-acid sunflower varieties (up to 80% oleic acid) for lubricant base oils is developing in the USA. European development of vegetable oil-based lubricants seems to be centred around standard food grade double-low oilseed-rape oil. In Germany, 70% of biodegradable lubricants sold are based on oilseed-rape oil (Mang, undated). Such oils are generally bought in a refined form ready for mixing with the additive 'package' to make the lubricant fluid.

The widespread use of vegetable oils in lubricants has been most noticeable in European countries. Motivated by environmental concerns, the German government has provided large funds for research into biodegradable lubricants. Various programmes were launched to investigate environmental solutions, largely due to concern about the 6 Ml of chainsaw-bar oil being dropped onto the forest floor every year and the effect this was having on soil quality and water systems. For the EU as a whole, this spilt oil is estimated to amount to 30 Ml per year. Currently, both Austria and Germany prohibit the use of mineral-oil based chainsaw lubricants and Germany has also stopped the use of mineral-oil lubricants on inland waterways and has detailed guidelines to assess the water pollution caused by various substances. As a result of the eco-label 'Blue Angel', currently being used to identify more environmentally friendly products, together with the waste oil recycling obligation borne by lubricant manufacturers, biodegradable lubricants in Germany enjoy a much higher profile and popularity than in the UK.

In Sweden, development of vegetable-based oils has used oilseed rape as the starting point. Sweden is a producer of oilseed rape, but the aspect of home-produced feedstocks is not the only reason for using it. The practice of foresters in Sweden is to form a snow 'wall' around the area in which they work to provide shelter. This causes a 'mist' of oil from the chain bar to form in the air around them and it is hoped that the use of vegetable-based oils will reduce the incidence of respiratory complaints among forest workers.

Large oil companies have invested in the development of 'green' oils to meet growing demand. However, as the business interests of mineral-oil producers are centred around the extraction of crude oil and natural gas and the marketing of these and their derived products, development of markets for non-mineral oils might detract from their main business. Lubricant manufacturers may be reluctant to invest in the new equipment and transport facilities that would be needed for the production of appreciable quantities of vegetable oils until they have convincing evidence of viable markets. But if there is evidence of consumer interest, large companies will be keen to ensure that they have a 'range' of alternatives available to their customers. Most development of the industry appears to have taken place in countries such as Germany and Sweden, where there is more environmental legislation. Multinational lubricant groups with established markets in other European countries, will soon be producing these products in the UK.

Currently, only a limited range of vegetable oils or esters only is used to make biodegradable products in Britain, but this is not the case in the rest of the EU. For example, Robbe, a French company, sell a wide range of products including rape-methyl esters, oxidatively polymerised oils (blown oils) and high erucic, refined oils as lubricant bases. The German group, Fuchs Petrolub, are currently marketing a range of products including greases for agricultural and other machinery, two-stroke oils, hydraulic oils and chainsaw oils, manufactured from oilseed rape oil or esters. In the USA, part of the international lubricant group Lubrizol is marketing a very-high-oleic-acid sunflower oil for use as lubricant base oil. In the European marketplace the range of biodegradeable lubricant products from oilseeds now includes 2-stroke lubricants, hydraulic oils, engine oils, low temperature gear oils, compressor oils, greases and corrosion protective oils. This market is likely to develop, both in the UK and the EU as products are improved and environmental pressure intensifies.

### 3.2.5 Potential markets for vegetable-oil-based lubricants

As stated earlier, the most promising markets for vegetable-oil-based lubricants are where loss to the environment is total (and hence the risk of environmental pollution very high) or risk of sudden loss is high and where operating temperatures are relatively low. According to Mang (undated), total-loss systems account for 7% of the lubricant market in Europe. Assuming the same proportion for the UK, total-loss systems represent a potential market for about 51 800 t oil per year (equivalent to c 129 500 t rapeseed or 43 166 ha of oilseed rape).

The markets most suited to the use of biodegradable lubricants as determined by nature of total loss and operating temperature are as follows:-

(i) **Chainsaw-bar lubricants.** Being a total loss system (all the lubricant is lost to the environment during use), a high degree of biodegradeability is desirable. No problems arising from oxidation of the oil are encountered, due to the rapid use of oil by the saw. Operating temperatures rarely rise significantly above ambient temperatures, and so problems associated with thermal oxidation are irrelevant.

(ii) **Hydraulic systems.** Biodegradeability is an advantage in hydraulic systems. Spillage from breaks in a hydraulic system can potentially leak 1000-2000 l of oil in a few minutes. Although rare, such leakages may occur in areas such as quarries, forests, dredging operations and other potentially sensitive environments. While the rapid biodegradation of vegetable oil-based lubricants may cause an excessive depletion in the oxygen content of water systems, this pollution will be very short lived compared to a mineral-oil spillage and will avoid toxic compounds reaching watercourses where environmental impact can be severe.

(iii) **Offshore drilling.** The contamination of water systems by mineral oil makes the use of vegetable-oil-based lubricants in offshore drilling very attractive. North Sea drilling platforms use mineral or synthetic oils as lubricating 'muds' to remove drilling cuttings, provide lubrication, prevent 'blow-outs' and cool the drill bit (Wilkinson, 1994). There is on-going research and development of oilseed rape-based lubricants for this purpose. The work, known as the 'Vegetable Oils for Offshore Drilling Operations' (VOODOO) Project, is being conducted by the Institute of Offshore Engineering at Heriot-Watt University, Edinburgh in a LINK programme funded by the Scottish Office, HGCA, International Drilling Fluids Ltd, Enterprise Oil plc and Carless Refining and Marketing Ltd.. The potential market for these drilling muds has been estimated at 40 000 - 50 000 t for the UK (Wilkinson, 1994). Estimates of current use are that between 80 000 and 100 000 t of drilling oils are used annually in the North Sea. Assuming the oil content of these drilling muds ranges from 80 to 90%, Wilkinson's (1994) estimate equates to between 32 000 and 45 000 t of oil (c 80 - 133 000 t rapeseed, 27 - 38 000 ha

OSR). Expansion into European markets may also be possible if the end product proves effective and competitive in terms of price.

(iv) **Two-stroke systems.** Lubricants are available for use in two-stroke engines as fuel additives. The oil passes to the environment as unburnt or partially burnt oil. Two-stroke engines, by nature of their high power output for limited weight, are often used in situations where environmental pollution may be particularly damaging such as outboard motors, chainsaws, garden equipment and motorcycles. The use of environmentally friendly two-stroke oils on inland waterways is a legal requirement in Germany, as a means of reducing pollution. In the future, the UK may also find itself under pressure to follow the line of other countries through EU legislation, as environmental pressure groups gather momentum. At present UK consumers are reluctant to use these products probably because of the extra cost, coupled with a lack of knowledge about the advantages offered.

As the EU develops a scheme for eco-labelling, and there are ever stronger attempts to force polluters to bear the full cost of their actions, the extra cost of biodegradable lubricants may become less important as a hindrance to sales. Companies wishing to promote a 'green' image, or who may have incurred large fines for polluting, may then find that these new products 'pay for themselves'. The benefits of using legislation as an environmental tool need to be carefully assessed by Government before application. The question of who should bear the extra costs of biodegradable lubricants is one for policy makers, and may have a strong influence upon legislation. Life-cycle analyses may provide a useful insight into the true benefits of using oilseeds as lubricant bases. However, public opinion seems set on 'environmental justice and accounting'. Estimates by a lubricant manufacturer (outlined in Tables 3.4 and 3.5) of the potential markets in the EU for biodegradable lubricants seem rather modest.

**Table 3.4**
**Existing opportunities for vegetable oil-based lubricants in the EU**

| | |
|---|---|
| Standard '00' OSR oil (00) | 900-1900 t/y |
| High Oleic OSR oil (HO) | 500-1100 t/y |

**Table 3.5**
**Potential opportunities for vegetable oil-based lubricants in the EU**

| Lubricant Application | Oil | Potential Volume (t/y) |
|---|---|---|
| Universal tractor transmission | 00 or HO | 350 |
| Hydraulics | 00 or HO | 350 |
| Greases | HO | 700 |
| Chainbar | 00 or HO | 350 |
| Diesel fuel additive | ? | 350 |
| Food Equipment | HO | 350 |
| Forming oil | ? | 350 |
| 2-Cycle (Water-cooled) | HO | 300 |
| Biodegradable viscosity modifier | 00 or HO | 330 |
| Release agent | HO | 330 |
| Other | HO | >1200 |
| Total | | >4960 |

00 - double low oilseed rape HO - high oleic oilseed rape or sunflower

### 3.2.6 Supplying potential markets

The estimates for potential market volumes above show that, initially, growing for lubricants will not need large areas of oilseed rape. With time, as markets grow and technology develops, demand could well become more appreciable, and changes in environmental legislation would help accelerate this process. The production of very high-oleic-acid oilseed rape at competitive prices will also help to ensure that the UK becomes a European, if not world, centre for the manufacture of these products. Competition from sunflower producers for the very high-oleic-acid oil market may become fierce if demand for vegetable oil-based lubricants increases. Countries such as Spain and Portugal, and Eastern European countries may look to their sunflower crops as a means of capturing a lucrative market. As the market for biodegradable lubricants grows, UK producers will need to ensure that they can compete with production from comparable vegetable oils. While oilseeds for industrial use are currently boosted by the CAP regime, this may not be security enough for the future.

### 3.2.7 Conclusions

The benefits of using lubricants based on vegetable oils are clear - low toxicity and high biodegradability, coupled with the fact that they are a renewable resource. There are also several areas where such lubricants (either using vegetable oil as a base, or after processing them into esters or fatty alcohols) offer technical advantages. However, the constraints to using oleochemical compounds prevent their use in larger-volume markets. The development of lubricant technology around oleochemicals is on-going and may overcome many difficulties. As volumes increase, prices will fall making biodegradable lubricants more competitive. The development of very high-oleic oils is likely to stimulate growth in the industry. The UK should take care not to lose out on this new area to sunflower producers, either in the EU or the USA. The true costs and benefits of biodegradable lubricants need assessing.

## 3.3 SURFACTANTS

### 3.3.1 Introduction

Surfactants are substances with dipolar, amphiphilic molecular structures, consisting of a hydrophobic part (normally a hydrocarbon) and a hydrophilic part (an ionic or strongly polar group). This characteristic structure imparts the peculiar property of surfactants, namely interfacial activity (hence **surf**ace **act**ive **agents**). In solvents such as water, these amphiphilic molecules concentrate at the interfaces, with the hydrophilic part in the water and the hydrophobic part outside. Where the interface is with air, a surface film forms with the effect of reducing surface tension. Where the interface is a contact surface between two liquids (eg oil and water), the molecules gather at the surface to create a bond between the two liquids, thus reducing interfacial tension and facilitating the formation of emulsions. When the concentration of surfactants in an aqueous solution is sufficient to saturate the interfaces, the excess molecules gather in aggregates known as micelles (Piorr, 1987; ASPA, undated).

Surfactants can be effective in all processes that take place at interfaces enabling these processes to be simplified, accelerated or made more economic (Piorr, 1987). Interfacial activity is central to the action of surfactants, but the specific modes of action vary and, hence, the range of applications is considerable. ASPA (undated) classified surfactants according to their main function as:

(i) **Detergents** (including soap) where surfactants facilitate the removal of stains and dirt and their dispersion in water in the washing and cleaning process.

(ii) **Dispersing agents** which increase the stability of suspensions of small solid particles in a liquid.

(iii) **Emulsifiers** which facilitate the dispersion of one liquid in another (eg oil and water), and thus increase stability.

(iv) **Wetting agents** which further the spreading of a liquid on a solid surface or its rate of penetration into porous materials (eg leather, cotton and paper).

(v) **Foaming and anti-foam agents** which cause or prevent the formation of foam, respectively.

(vi) **Solubilisers** which increase the apparent solubility in water of slightly soluble substances.

These functions of surfactants are exploited in a wide range of consumer products and industrial processes. In the first case, the surfactants are used as the basic ingredient of cleaning products; in the second case, surfactants facilitate a wide range of industrial processes. A classification of these appears in Table 3.6.

**Table 3.6**
**Applications of surfactants**

| |
|---|
| **In consumer products** |
| Detergents |
| Dishwashing agents |
| Cleaning agents |
| Personal products |
| **In industrial applications** |
| Foods |
| Pharmaceuticals |
| Plant protection and pest control |
| Agriculture |
| Textiles and fibres |
| Chemical industry |
| Plastics industry |
| Paints, lacquers |
| Cellulose and paper |
| Leather and furs |
| Metal processing |
| Adhesives |
| Road construction and building materials |
| Fire fighting |
| Mining and floatation |
| Oilfield chemicals |

Source: Adapted from Piorr (1987).

### 3.3.2 Sources and consumption of surfactants

The structure of the world surfactant industry is extremely complex; there are thousands of surfactant compounds available to the user industries listed in Table 3.6. Surfactants are derived either from natural fats and oils of animal, vegetable or marine origin (ie oleochemicals), or from synthetic raw materials derived from petrochemicals. Some can only be derived from one type of raw material; others can be derived from either synthetic or natural raw materials.

In the case of natural feedstocks, the oils or fats provide the basic raw material for surfactant manufacture. The most important raw materials are coconut oil and palm kernel oil; tallow, palm, soya, oilseed rape, sunflower and marine oils may also be used. The most important intermediates are fatty alcohols, but fatty amines, fatty acids, methyl esters and glycerol may be the precursors of some surfactants. Synthetic raw materials include ethylene (from natural gas) and paraffins, olefins and benzene (from petroleum); intermediates include linear alcohols and alkyl benzene.

Surfactants are normally classified by type of hydrophilic group (in volume order) into anionic, nonionic, cationic and amphoteric. Anionic surfactants include soaps, sulphonates (including the most widely used detergent surfactant, linear alkyl benzene sulphonate), sulphates, carboxylates, phosphates and phosphonates. Nonionic surfactants include ethoxylated fatty alcohols, fatty acids, fatty amines, alkylphenols, polypropylene glycols, polyol-esters and ethers. Cationic surfactants are fatty amine salts. Amphoteric surfactants are alkylaminoacids or betaines.

The consumption of surfactants by application type in Europe is indicated in Tables 3.7 and Table 3.8. Some indication of the consumption of surfactants by type is provided by values for France in 1989 (Table 3.9).The latter shows the proportion of the world market accounted for by benzene- and fatty alcohol-based and other surfactants and indicates how the relative proportion is changing.

**Table 3.7**
**Consumption of surfactants by sector in Europe, 1989.**

| Application | Mt | % total |
|---|---|---|
| Institutional and household cleaning | 870 000 | 51 |
| Body care products, cosmetics and pharmaceuticals | 164 000 | 9.5 |
| Textiles, furs and leather | 154 000 | 9 |
| Chemicals and polymerisation | 128 000 | 7.5 |
| Metallurgy, mining and oil industries | 86 000 | 5 |
| Pesticides and fertilisers | 47 000 | 3 |
| Food processing | 40 000 | 2.5 |
| Construction and public works | 37 000 | 2 |
| Paper | 23 000 | 1.5 |
| Pigments, paints and varnishes | 20 000 | 1 |
| Miscellaneous | 134 000 | 8 |
| **Total** | **1 703 000** | **100** |

Source: Adapted from ASPA (undated).

Published values for world consumption of surfactants vary considerably, but it seems clear that use is increasing, particularly in developing countries, in response to growing demand for detergents and industrial development. According to Vogel (1993), in 1991 the world demand for surfactants themselves was 3.1 Mt per year; this is expected to rise to 4 Mt by the beginning of the next century. In contrast, Gray (1993) stated that 15.5 Mt of surfactants were used worldwide.

**Table 3.8**
**Consumption of surfactants by the three main sectors of use, Europe, 1989.**

| Use | '000 t |
|---|---|
| Household products | 870 |
| Industrial uses | 669 |
| Cosmetics | 164 |
| Total | 1703 |

Source: Adapted from ASPA (undated).

**Table 3.9**
**Consumption of surfactants by type, France, 1989**

| Type | % total |
|---|---|
| Anionic | 66.6 |
| Nonionic | 24 |
| Cationic | 9 |
| Amphoteric | <1 |

Source: Adapted from ASPA (undated).

Although world demand is growing, regional changes are more subtle. In the USA and Western Europe demand is relatively stagnant and even in decline, while in East Asia and the Pacific Rim, demand is increasing. Use of home-produced inputs rather than imported mineral oils is obviously preferable for the developing industries of these countries. The installation of modern processing plants and relatively low labour costs enable these economies to supply their home markets with surfactants and begin to look to exporting semi- or fully-processed surfactants and surfactant-based products.

Trends in Western Europe and North America, in particular, are towards more concentrated household cleaning products and a consequential decline in detergent volume consumption. This, in itself, should not affect the consumption of the active surfactant chemicals in these new products, as the same or better 'cleaning power' is being demanded. Of greater significance is the impact of environmental concerns about the fate of products in disposal and the original source. These not only require biodegradability, but may also call for a reduction in surfactant volume per 'unit' of cleaning power. For personal-care products in particular, 'natural ingredients' are increasingly preferred. One effect of these concerns may be an increase in the use of fatty-alcohol-based surfactants and nonionics in preference to alkylbenzene sulphonates (a shift that is already occurring as indicated by Figure 3.2). More broadly, these concerns seem likely to increase the demand for natural raw materials, and perhaps vegetable oils in particular, in preference to synthetics.

The last decade has seen a convergence of prices for oleochemical and petrochemical surfactant products, and a general trend towards price stability for both. Changes in the consumption of oleochemical rather than petrochemical sources have come about for a number of reasons. In addition to the price convergence, the vast increase in the production of palm oil, leading to a much greater availability of palm kernel oil, has helped to stabilise vegetable oil prices. Palm kernel and coconut oil prices are likely to react similarly to any change in the availability of the other. Movements in coconut oil prices, previously very volatile and unpredictable, are, hence, much less able to move independently. Animal products, derived from tallow, are restricted mainly to soaps (as distinct from detergents and cleaning products) and production is concentrated in those countries where tallow is widely produced (ie the USA and Western Europe).

### 3.3.3 Vegetable oils as feedstocks for surfactant manufacture

What are the implications for raw material supply of the patterns and trends in the consumption of surfactants in terms of the volumes and types described above? What, in particular, is the present and potential role of vegetable oils compared with synthetics and other natural oils and fats and what scope is there for vegetable-oil demand being supplied by UK-produced oilseeds?

Trends in surfactant consumption imply some increase in demand for raw materials, although this seems likely to be modest in Europe and North America. They also suggest a shift towards more 'environmentally friendly' chemicals, which may favour natural as over synthetic raw materials. The increasing demand for 'natural' products, notably in the personal-care sector, will also increase the demand for raw materials of plant rather than animal or marine origin.

Surfactants derived from natural oils are usually manufactured by processing oils with a high content of lauric acid (C12). C14 (myristic) and C16-C18 (palmitic and stearic/ /oleic) fatty acids are also used. Most products incorporate a blend of fatty acids, adjusted according to the product and the price of raw materials. Medium-chain fatty acids (C12-C14) are included to provide good lather and water solubility and longer-chain (C16-C18) molecules provide detergency and are softer on the skin. Medium-chain-length oils (ie 'lauric' oils) come from coconuts and palm kernels. The longer chain-length oils are derived from other vegetable oils, such as palm, and animal fats, such as tallow. In addition to using blends of oils, manufacturers may also 'top and tail' oils in order to remove higher or lower molecular-weight constituents to bring the oil closer to the required specification.

Natural oils provide part of the total input of raw materials to the surfactant industry. Vegetable oils represent the largest part of this input and are particularly important for personal care products. Most of this requirement is supplied by tropical oils, notably palm, palm kernel and coconut. There may be potential to incorporate oleic acid from oilseed rape (mostly C18) into detergents but, currently, its inclusion is small and oleic acid is supplied by the fractionation of the tropical oils. In future, production of tropical oils is set to increase as new plantations come into production. In general, manufacturers buy these, and other oils, on the international market.

The leading surfactant in detergent manufacture is linear alkylbenzenesulphonate (LAB). As with most surfactants, this is produced from petrochemical sources but is biodegradable. However, fatty alcohol sulphates (and other fatty alcohol based surfactants) are becoming preferred by consumers. These are most commonly derived from natural sources. There is little to chose between the two in terms of effective washing. LAB has one disadvantage compared with fatty alcohols, in that it will only biodegrade aerobically which can cause oxygen depletion if discharged into water systems; fatty alcohols biodegrade more easily and cause less oxygen depletion. Gray (1993) estimated that the market for fatty alcohols will increase, taking the market share of both benzene based surfactants and other surfactant types as shown in Figure 3.3.1.

Apart from the 'limited' biodegradability of LAB, the argument that naturally-derived surfactants are more environmentally friendly may not be as strong as some may wish for there is little other evidence that there is an 'environmental' difference in the production and use of petrochemical and oleochemical surfactants. A life-cycle analysis conducted by Vogel (1993) concluded that there was little difference between the two when comparing biodegradability, energy, waste, $CO_2$ and risks to plant, animal and human life.

Further, as suggested above, natural oils can only provide a limited proportion of the total range of surfactants used today. Petrochemical routes are often the only means of making many commonly used surfactants. The fact that natural oils are a sustainable resource may go in their favour, but predictions are that we have 200 years' supply of crude oil remaining. The components of crude oil used for the manufacture of surfactants will still be available as the other oil fractions are used for other purposes in the remaining time. The question of sustainability is always important. However, when seeking long-term answers to demand for surfactants, it should be borne in mind that oilcrops may face pressure from other issues such as energy and food production.

Traditionally, inputs of vegetable oil have centred around coconut oil, but recently there has been increased use of palm and, particularly, palm-kernel oil. Current production of the 'lauric' oils is concentrated around the Pacific Rim. Countries such as Malaysia and Indonesia are constantly developing their plantations and processing facilities, and they have protected their home processing industries with export taxes on raw oils and tax incentives for new plant.

The production of high lauric acid oils by temperate crops such as genetically modified oilseed rape faces two main problems if they are to compete with tropical oils. First, temperate crops yield much less oil per hectare than tropical crops (eg 1.2 t per ha from oilseed rape compared with 3.7 - 4.6 t per ha for palm). Thus, production costs put temperate oilseeds at an immediate disadvantage. Second, the European processing industries are largely geared to production based on petrochemical inputs. Those manufacturers who do use vegetable oils either use specific oils for specific products or buy inputs for cheaper products, such as soap, where feedstocks are bought on commodity markets and the cheapest available input at the time is used. In the case of soap, this frequently means using tallow, which is cheap and could become cheaper still if forced, as it is largely a by-product of meat production.

### 3.3.4 Market potential for UK-produced vegetable oils for surfactant manufacture

#### *General potential*

The above discussion suggests that there is very limited scope for UK-produced oilseeds to supply the surfactant industry. In simple terms, there are two barriers that would need to be overcome. First, natural oils would need to win a greater share of the market from petrochemicals and second, UK-produced oils would need to compete effectively with tropical oils.

With regard to the first point, the surfactant industry as a whole is still dominated by petrochemical products. This is partly due to technical factors (many surfactants can only be made from petrochemicals) and partly price-driven (in many cases the choice between oleochemical and petrochemical sources is made on price). However, vegetable-oil products are very important in some sectors, notably personal-care products and can, in some situations, compete with petrochemicals in terms of price. There are also indications that a shift from synthetic and animal raw materials to vegetable oils is occurring in response to environmentalism and the demand for 'natural' products.

The second barrier is far greater. Surfactant manufactures visited made it clear that their essential raw material purchase criterion was price, that processes were adjusted to accommodate different raw materials in order to minimise input costs, that they did not wish to enter into contracts (indeed one company did not even offer guaranteed markets for the products of its own plantations), and were not keen on vertical integration. These users would be very interested in considering UK-produced oilseeds if they were price competitive with tropical oils and offered the right compositional specification.

However, as indicated above, the yield of tropical oils (notably palm oil) is higher and production costs, and hence prices, are appreciably lower. Volumes of supply are considerable and set to increase further. Palm/palm kernel oil production has increased by 150% over the last 10 years,and should rise by a further 50% over the next ten years. These oils, generally, meet the surfactant industry's specifications much more closely than do current varieties of oilseed rape and other temperate oilseeds.

Unless UK-produced oils can compete with tropical oils on price or offer advantages that significantly improve quality, they will not be able to enter the market. Factors such as environmental acceptability or technical suitability may improve the attractiveness of UK-produced oils, but the industry will need convincing that they will pay.

The development of oilseeds with purer oils in terms of fatty-acid content (eg tri-lauric oil) could give UK producers a competitive edge, by providing manufacturers with raw materials that meet their requirements more closely than do tropical oils. The developments discussed in Chapter 2 may make this possible, but would need to be set against the yield advantages of tropical oils and the future application of techniques of genetic engineering to oil palm, coconut and other tropical and sub-tropical oilcrops. Development of such crops using these techniques is, at present, behind that of oilseed rape, would require considerable investment, and is further slowed by the ten years or so that it takes to establish, for example, an oil palm crop. Nevertheless, it is understood that the Malaysian Government, for example, is initiating a programme, and it is possible that in 10 -15 years 'designer oil palm' varieties may be available.

There may be greater scope for UK-produced oilseed for surfactant niche markets. Of greater interest are pesticide adjuvants and polymer additives. Polymer additives, such as erucamide, are discussed in the section on polymers.

***Adjuvants***

It is claimed that the combination of double-low oilseed-rape oil with surfactant compounds and agents to promote leaf cuticle penetration, spread of the spray over the leaf and its adhesion to the leaf, allows reduced application rates of the active pesticide agents for the same benefits.

Increasing concern about how food is produced and about effects of agrochemicals on human health, makes the reduction of concentrations of pesticide attractive. Savings made on buying the active pesticide chemicals will also be welcomed by producers. The safety of the food from sprayed crops is promoted by the use of food quality '00' oilseed rape oil.

One adjuvant company has estimated the total market for pesticides that **could** be used with adjuvants to be as much as 19.2 M sprayed hectares annually. Each hectare of land sprayed requires 2.5 litres of adjuvant. Thus, a total of 48 M litres of oil would be required; as the density of vegetable oil is in the region of 0.8 kg/l, 38 400 t of oil (c 96 000 t rapeseed, 32 000 ha OSR) would be required if adjuvants were used for all possible applications.

However, what appears to be a very beneficial product has been slow to catch on so far. This is due, in part, to the comparative size and market share of the agrochemical industry, legislative restrictions requiring all new adjuvant products to be registered, costing time and money, and because of a change of technique needed for adjuvant use. The successful application of the pesticide in an adjuvant relies on constant agitation of the mixture. Some farmers trying adjuvants may not have fully realised this, casting doubt on the efficacy of the new products. The slow uptake may also be due to continuing questions regarding the agronomic advantages of pesticide adjuvants. Further scientific investigation may be needed.

## 3.4 SURFACE COATINGS

### 3.4.1 Introduction

'Surface coating' refers to any material that may be applied as a thin, continuous layer to a surface and includes paints, varnishes, lacquers and inks for various forms of printing. Traditionally, 'drying oils', containing at least 50% polyunsaturated fatty acids, are used in surface coatings. It is the oxidation of the double bonds in the fatty acid that gives these oils the drying qualities used in coatings.

Vegetable oils used for surface-coating applications may be processed from the crude oil that is produced from seed-crushing to produce:-

(i) **Refined oils**. These oils are filtered to remove any physical impurities and then caustic soda is added to remove any free fatty acids (fatty-acid molecules not bonded to a glycerol molecule to form a triglyceride). As an alternative, free fatty acids can be removed by steam distillation under a vacuum. The oil may then be bleached, with bleaching earth, and, possibly deodorised.

(ii) **Blown oils.** These oils are heated to temperatures of approximately 200$^{o}$ C and have air blown through them. This causes oxidative polymerisation; varying the temperature and length of processing will produce varying degrees of polymerisation, and hence oils of various viscosities. During this process, bonds are formed between carbon atoms in the fatty-acid chains of the triglycerides, from double-bonded carbon atom to double-bonded carbon atom via oxygen atoms.

(iii) **Stand oils**. Using a similar process to that used for blown oils, the triglycerides of the oil are polymerised. This time the refined oil is heated in a vacuum, so oxidative polymerisation does not occur, and dimer and trimer polymers are formed through thermal polymerisation, again at the carbon atoms with double bonds. As with blown oils, the extent to which the process is continued determines the viscosity of the oil.

(iv) **Specially treated oils.** Some oils, particularly linseed and wood oil, are 'cooked' with resins to form oleoresinous compounds used in varnishes. These are diluted with petrochemical solvents.

The different levels of unsaturation in various oils provide different qualities. Too much unsaturation on a fatty-acid chain leads to yellowing of the paint, whereas too little increases drying times.

### 3.4.2 Paints and varnishes

***Introduction***

Paints that incorporate vegetable oils include household gloss paints and a variety of 'industrial' paints. Most modern household paints are predominantly water-based, rather than based on oils and other solvents as used in the past. Water-based paints are cheaper to produce, less toxic in use and spillage/disposal and brush cleaning are easier and cheaper. However, gloss paints (alkyd paints) still rely on the unsaturation of the fatty-acid chains present in vegetable oils to produce a gloss finish. Industrial applications of alkyd paints usually require tough, long-lasting finishes, such as exterior applications where maintenance of painted surfaces is difficult or expensive.

***Sources and consumption***

In the UK, the oils used most frequently for domestic alkyd paint manufacture are linseed, tall (derived from softwood tree processing) and soya. These are used in different proportions according to their relative prices at time of purchase and the mixture of oils required. Approximately 100 Ml (approximately 80 000 tonnes) of alkyd paints are sold in the UK per year. This constitutes about 25% of total paint sales by volume and 60% by value. Half of all alkyd paint sales are for trade rather than domestic use. It is estimated that the UK market for linseed oil for use in paint manufacture is currently about 10 000 tonnes per year, and the world market about 100 000 tonnes.

### *Advantages and disadvantages of vegetable oils for paints and varnishes*

The comparative ease with which manufacturers can substitute one of these oils for another means that they are bought mainly on commodity markets. The proportion of linseed oil used is usually substantially lower than that of tall and soya oil due to the yellowing effect of the high linolenic acid content of linseed oil. The linoleic and linolenic acid contents of the oils need to be balanced by blending the proportions of the oils used in the paint mixture. The drying oils and resins used in paint manufacture combine in the paint and form cross-links between chains through oxidative polymerisation. This cross-linking is what forms the skin on the paint as it dries. Currently, long-chain fatty acids ($C_{18}$) are used as they are more hydrophobic (having a longer, hydrocarbon chain). The development of water-based gloss paints may be possible in the future based on the principle of polymerising shorter-chain molecules.

### *Potential markets*

If all gloss paint sold in the UK were vegetable oil based, some 48 000 t of oil (c 120 000 t rapeseed, 40 000 ha OSR) would be required. The actual UK market is likely to be somewhat lower.

The variety of natural oils and technological developments have renewed interest in the use of vegetable oils as components in paints for a variety of applications, particularly where a degree of flexibility is required. Speed of drying may also be a 'selling point' for vegetable-oil-based paints. For most professionals using alkyd paints, drying times are crucial. Currently, to apply two coats of gloss paint takes two days, as the time needed for recoating is effectively 'overnight'. A paint formulation which significantly reduced recoating times would command a very strong position in the marketplace.

The degree of unsaturation of the fatty-acid constituents of the vegetable oil is, as stated above, a key determinant of drying and polymerisation characteristics. For oilseed rape to penetrate the paint market, new varieties higher in polyunsaturated fatty acids would need to be developed. The oil from such varieties might 'look like' a blend of linseed and soya oils.

## 3.4.3 Printing inks

### *Introduction*

Inks are available in different forms for use in many different processes. They consist of dispersions of insoluble colourants or solutions of dyes in a varnish or vehicle (Leach & Pierce, 1993). The term 'printing ink' refers specifically to that used in press-printing. In the most widely-used method, offset-lithographic printing, ink is applied to a plate which then 'offsets' it onto a rubber blanket, which then transfers it to the paper. Modern inks also contain additives to improve adhesion and drying time, prevent foaming and to ensure even flow. Modern 'non-contact' printing methods such as inkjets are usually based on high-performance synthetic compounds.

As with paints, drying oils are required for printing inks. However, drying properties may not be so important where the level of inclusion of the vegetable oil is low and drying (binding) is effected by other constituents, or where printing is on very absorbent paper (eg newsprint).

### *Sources and consumption*

Before the post-war 'petroleum-boom', linseed oil was the main binding agent used in inks because of its drying qualities. High-erucic acid rapeseed, sunflower and soya oils are also used in printing inks, but linseed is often seen as preferable, although its high level of unsaturation may make it a little too fast-drying.

Mispreuve (1994) highlighted the oil crises of the mid-1970s and of the early 1980s as being a major influence on the US printing industry looking for replacements for the petroleum compounds in inks. Further, the Gulf war occurred at a time when environmental pressure was increasing and having a similar effect. The production of large volumes of soyabeans for animal feed in the USA may also have encouraged the development of soya-based inks as a means of using the oil that was produced along with the protein-rich meal.

According to the American Soybean Association, inks used for newspaper printing traditionally used 55-85% petroleum-based vehicles. Since 1987, however, soya oil has been included in various amounts to produce new inks. The current proportion of oil in the ink is around 10%. Changes in legislation have increased demand for these inks as federal agencies and the USDA are required to use vegetable-based inks whenever possible. About half of the newspapers in the USA are printed with ink containing soya oil.

It is estimated that between 1000 and 2000 tonnes of oilseed rape oil are currently incorporated into printing inks in the UK annually, to supply a limited demand for ecologically-responsible inks (ie inks based on renewable resources). Current consumption of vegetable oil for printing inks in Europe (Mispreuve, 1994) is 12 000 - 15 000 tonnes per year; he forecasts that this could reach as much as 25 000 tonnes in three years' time.

### *Advantages and disadvantages of vegetable oils used for printing inks*

Two of the main problems of printing, namely recycling and toxicity, may be relieved by using vegetable-oil-based inks:-

(i) **Recycling.** The remarkable growth of interest in recycling paper in recent years has been hampered by the difficulties of removing the ink from the paper to be recycled. Inks are designed to bond chemically to the paper, so that they stay there and do not smudge or come off on the reader. The ability to remove ink from paper without using harmful solvents, which cause a disposal problem and negate the environmental benefits of recycling, would mean that the whole area of paper recycling could be re-examined. There is potential for use of vegetable oil as the vehicle in inks which may allow an enzymic action to aid the de-inking process: the process may take time, but ink removal may be more complete, and problems of solvent disposal will not be created. (Alternatively, the increased biodegradability offered by vegetable-oil-based inks means that, if not recycled, the residue left after the product has degraded is significantly reduced as the ink vehicle would be totally biodegradable.)

(ii) **Toxicity.** Currently, many printing inks contain carcinogens in the form of polycyclic aromatic and volatile organic compounds. The replacement of petrochemical vehicles will reduce the toxicity of wastes from printing works and reduce the hazard to those working in the industry. Inks incorporating vegetable oils allow for easier and safer cleaning and operation of printing machinery. The mist of volatile petrochemical oils that forms around a fast-running press can cause respiratory and skin problems and the chronic effects of long-term exposure are only now beginning to be fully realised. The solvents used for cleaning printing machinery present similar hazards, and can mean complicated storage systems due to fire risk.

Vegetable-oil-based inks are also attractive to those wishing either to buy or to be seen to use ecologically-responsible paper and printed material. Ink components, other than the vehicle, may be derived from vegetable oils, but volumes used are small since these compounds are just ink additives (eg stearates used as lubricants and pine oil used as a defoaming agent). Varnishes included in inks to help the dispersion of pigment and aid bonding to the paper, may be derived from linseed or other oils high in polyunsaturated fatty acids, heat treated to increase their viscosity (a process known as heat-bodying). It is the unsaturation in these oils which, as with paint, is the desirable feature. The cross-linking that occurs as the oil undergoes oxidation dries the ink, and when bodied or blown (a process whereby air is blown through heated oil), the increased viscosity and general tackiness ensure good adhesion of ink to the press.

### *Potential markets*

Mispreuve (1994) estimated the 1990 production of printing inks in Europe (without ex-Eastern bloc countries) as 530 000 tonnes of which 350 000 tonnes would not be suitable for vegetable-oil incorporation. He further calculated that of the remaining 180 000 tonnes, the maximum incorporation of vegetable oils in ink would be 84 000 tonnes (210 000 t rapeseed, 70 000 ha OSR). When considering the potential to replace mineral-oil components globally, he estimates that 400 000 tonnes could be replaced in the USA, and 120 000 tonnes in Japan. The price-sensitive nature of the market for ink is such that further incorporation of vegetable oils will be slow unless consumer pressure gathers momentum or legislation requires their use.

### *Supplying potential markets*

The potential for use of vegetable-oil-based inks in the UK is limited by a lack of technology to produce inks of known reliability, their uncompetitive price and a general lack of consumer demand. The advantages of vegetable-oil-based inks are becoming better known, but do not yet carry enough weight to stimulate action on the part of industry. Estimates made by the American Soybean Association claim that if all newspapers in the USA were printed using inks made from soya bean oil, it would utilise 800 000 t of soyabeans annually. The same reasoning applied to Europe gives an estimate of 100 000 t of soyabeans, but no indication of the percentage inclusion was given in this figure. Soyabeans produce about 20% oil compared with 40% from oilseed rape. This figure of 100 000 t of soyabeans can therefore be translated into 50 000 t or 50 000 ha of oilseed rape (calculated on the basis that oilseed rape yields about 2-3 t per hectare and produces 40% oil and 60% meal by weight). This estimate is double that of Mispreuve (1994).

Currently, UK ink manufacturers appear reluctant to incorporate vegetable oils into their formulations. The ink market is fiercely competitive and price sensitive and manufacturers are not yet persuaded that their customers believe the benefits of the more expensive vegetable-oil-based inks to be worth paying for. However, the small volumes used at the moment are growing as interest in their use and the issues they address grows.

Withey (1994) pointed out that the quantities of mineral oil used by the printing ink industry are 'infinitesimally small' compared with other industries. He went on to suggest that in terms of benefit to the environment, the cultivation of oilcrops cannot be counted as environmentally neutral. The benefits gained from a small marginal reduction in mineral-oil consumption through supplementing its use in inks need to be weighed against the environmental costs of producing the vegetable oil to replace it.

As mentioned earlier, neither rapeseed oil nor linseed oil provides quite the right level of unsaturation. High-erucic-acid rape could be improved by increasing the percentage of erucic acid produced, as desirable qualities in an oil for printing are a high molecular weight (hence the $C_{22}$ chain) and two double-bonds in the chain. Such an oil would be ideal for incorporation into printing inks.

***Conclusions***

There are good prospects for the incorporation of vegetable oils as the vehicle in printing inks. The advantages of incorporating vegetable oils in inks extend not just to the environment, but directly to human health. This, coupled with the environmental argument, will be a strong driving force in bringing about developments in this industry.

### 3.4.4 Surface coatings - conclusions

There exists the potential to use much more vegetable oil than at present with no change in technology. The driving forces will not be founded on price, or even on performance, but rather on regulation of substances hazardous to workforces, environmental concerns arising from disposal or recycling of end products and about sustainability. There is also potential for the development of new oils which could result in a new range of products. Again, these products will, to a large extent, rely on environmental and toxicity concerns for their success. There is clear evidence that public opinion and even public willingness to pay are swinging towards 'environmental' products. UK oilseed producers and processors should be ready to take up such opportunities as arise in the surface-coatings industry.

## 3.5 POLYMERS

### 3.5.1 Introduction

Most polymers are derived from petroluem. Certain products, however, are based on, or incorporate, vegetable-oil derivatives, and there appears considerable scope for an expansion of use of vegetable oils and oilseed crops in polymer production. Vegetable oil derivatives can be used in the manufacture of polymers as non-reactive additives (where they alter physical properties) or as reactive ingredients (where they form part of the polymer chain). Further, genetic engineering is opening up the possibility of producing oilseeds that secrete polymers in the plant itself.

Global consumption of all polymers is approximately 125 Mt per year (P A Fentem, pers comm, 1994). The use of polymers in everyday applications is growing steadily. For instance, Pryde & Rothfus (1989) reported that polymers make up about 25% of the bodyweight of cars today, compared to 7% in the 1970s. As use of, and demand for, polymers increases, so will the demand for functional additives, raw materials and polymers with new properties.

### 3.5.2 Functional additives

Vegetable-oil derivatives are used as slip, antiblock, antistatic, and plasticising agents, stabilisers, processing aids and flame retardants in the manufacture of plastics. The market for functional additives seems likely to increase as the market for plastics expands.

Slip and antiblock agents are examples of additives functioning as lubricants. Certain oleochemicals combine characteristics of polymer incompatibility (ie they are insoluble in the polymer) and lubricity, enabling them to act as external or internal lubricants. Slip agents are external lubricants that ease the passage of layers of film past one another. The principal chemical currently produced and used in this way in the UK is erucamide, derived from high-erucic acid oilseed rape (HEAR) and used as an slip agent in polythene film. The present UK erucamide industry uses the product of some 14 000 ha of HEAR. Erucamide's function as a slip agent in polyolefin film derives from the combination of characteristics described above: its insolubility in the polymer matrix means the amide migrates to the film surface in time, and the erucamide layer on the film surface eases the passage of film layers past one another (Leonard, 1990). Anti-block agents also act externally and prevent layers of film sticking together. Examples are stearamide and behenamide, also used in polyolefin film.

Certain oleochemicals may act as internal lubricants. For example, a small amount of calcium stearate is added to polyvinyl chloride (PVC) to reduce melt viscosity and frictional heat build-up. Apart from the fatty amides mentioned above, a range of other oleochemicals are used as lubricants for plastics, including metallic stearates, bisamides, fatty acids, and fatty acid esters (Leonard, 1990).

In addition to their use as lubricants, oleochemicals may perform several other functions in plastics. Alkyl amines derived from fatty acids are incorporated as antistatic agents to protect packaging materials from static electricity preventing the products sticking together in use. Epoxidised soya bean oil and mercaptoethyl oleate are proven plasticisers/stablisers for PVC, and vegetable oils provide several other plasticisers for plastics used for food packaging and medical uses (Pryde & Rothfus, 1989).

### 3.5.3 Reactive ingredients

Polymerisation involves like molecules being joined together to form new, larger molecules with properties different from, but related to, the components. Polymers may also have reactive, functional groups attached to the main chain, with the effect of altering the polymer's characteristics. Final products (ie plastics) will consist of polymers plus various additives (including those described above), fillers etc.

Commercial production of vegetable-oil-based polymers is very limited, at present, mostly to certain specialist plastics. For example, castor oil provides a plastic used in printed circuit boards and electronic encapsulation. A much wider range of possibilities has been explored, however, and the properties of a number of polymers derived from vegetable oils has been extensively investigated. Interest has been especially focussed on polyamides (ie nylons), but there is also scope for deriving polyesters and polyurethanes (via polyols) from vegetable oils. Polyvinyls look less promising in this respect.

An important starting point for polyamides and polyesters, and possibly other types of polymer, are dibasic acids (ie dicarboxylic acids or 'dioics'). A reaction common to all polyunsaturated straight-chain fatty acids and their alkyl esters is self-condensation to form high molecular weight dibasic and polybasic acids. In the right conditions, one molecule of an unsaturated fatty acid will react with another to form a dicarboxylic acid with double the original molecular weight (Leonard, 1990). The commercial version of this process is know as 'dimerisation' and involves the heating of unsaturated $C_{18}$ fatty acids in the presence of special clay catalysts. The result is a complex mixture with about two thirds of the desired $C_{36}$ dibasic acids plus higher polymers and monomeric acids. Dimer acids are used, mainly, in the production of polyamide resins. Dimer-based polyamides are highly flexible, film-forming, tough, adhesive and water- and corrosion-resistant (Luhs & Friedt, 1994). Dimer acids are also used in the production of polyester resins and other products.

Shorter-chain dicarboxylic acids can be produced by the oxidative cleavage of unsaturated fatty acids. For example, cleavage of oleic acid ($C_{18}$) gives rise to azelaic acid (a $C_9$ dicarboxylic acid) and pelargonic acid; cleavage of erucic acid ($C_{22}$) yields brassylic acid (a $C_{13}$ dicarboxylic acid) and pelargonic acid. Azelaic acid has been used to produce nylon-9 (the numbers refer to the length of the repeating unit in the chain), a polyamide with low moisture absorption particularly suited for use in the electrical and electronic industry. Nylons-613, -13, and -1313 have been produced from brassylic acid. These longer-chain nylons exhibit better dimensional stability and dilelectric properties, and lower moisture absorption than petroleum-based polyamides (mostly $C_6$ polyamides based on adipic acid).

Regarding the future of these vegetable-oil-based polyamides, Luhs & Friedt (1994) commented that, in addition to their use in electronics, they were expected to have continuing uses in the replacement of metals in the automotive industry and of other materials in building construction. They also commented that the commercial development of $C_{22}$ oleochemicals depended largely on the future acceptance of brassylic acid derived nylons as engineering plastics.

The main constraint on the development of these polymers is the high cost and environmental unacceptablility of the process to achieve oxidative cleavage commercially, known as ozonolysis. Further, this process gives only a 50% yield of the desired product, although there are some uses for the other acids. Luhs & Freidt (1994) commented that there would be no significant commercial development as long as there was no alternative to ozonolysis.

Recent developments suggest that there might be an alternative to ozonolysis, and one with the potential to widen considerably the scope for deriving polymers from vegetable oils. A process is being developed by Unilever and the University of Durham in a LINK programme with 50% funding from BBSRC. This involves the microbial (yeast-based) transformation of fatty acids to yield dicarboxylic acids of the same chain length. Essentially, the methyl group is oxidised. The process could give rise to a range of dicarboxylic acids, both saturated and unsaturated, capable of providing the building blocks for a 'new generation' of polymers (including polyamides and polyesters) with new and interesting properties. In particular, the relatively long repeating carbon chain associated with these compared with cleaved vegetable oils or petroleum-based polymers, will give rise to unique properties.

Some 2 Mt per year of adipic acid derived from petroleum are used to produce nylon worldwide, and there is little scope for vegetable oils to compete in this market. To compete, vegetable-oil-based polymers must offer special properties. It is understood that alongside the development of microbial transformation of vegetable oils to produce dicarboxylic acids, the polymer industry is investigating the range of polymers that could be derived from these acids and evaluating (or wishing to evaluate) their properties. A key issue, at present, is the provision of sufficient material to enable a full assessment of characteristics and applications.

In addition to the yeast-based process described above, it is understood that work in the Netherlands is progressing on a bacterial transformation process for vegetable oils, yielding a range of PHA (polyhydroxyalkonate) plastics.

Polyols are an important precursor for the production of polyesters and polyurethanes. In a LINK programme jointly funded by EPSRC and Associated Electrical Industries Ltd, GEC-Henley Division, Mid-Kent College in collaboration with South Bank University investigated a method of catalytic hydrolxylation to produce a range of new polyols from oilseed rape oil. Research on the hydroxylation process is now complete, one patent application was filed in May 1994 and another is under consideration (B R T Keene, pers comm, 1994).

### 3.5.4 Direct production of polymers

Oilseed crops could provide a direct source of polymers *via* genetic modification of the plant's biochemistry. Such developments would enable some processing stages to be eliminated with consequent reductions in manufacturing costs.

The fatty-acid derivative, polyhydroxybutyrate (PHB), is currently produced by the bacterial fermentation of carbohydrate feedstocks, and used to produce the biodegradable plastic, 'Biopol' (Zeneca plc). Current production of Biopol is 1000 t per year; the current price is £7-12 per kg. In the short term, Zeneca aim to reduce the price to around £3 per kg by expanding fermentation operations. In the longer term, they aim to produce the polymer in oilseed rape at a price of £1.00 per kg. At a price of £1-3 per kg, Zeneca estimate the potential world market to be some 100 000 t per year (c 500 000 t rapeseed, at 20% PHB; 166 666 ha OSR).

Recently, as much as 15% PHB has been obtained in the leaves of a genetically modified *Arabidopsis thalliana* by a group in the USA. In a LINK research programme (with 50% funding from BBSRC), Zeneca, in collaboration with the University of Durham, have, so far, achieved 0.1% PHB in the leaves of oilseed rape and their current target is 20% in the seed. They anticipate achieving this by 1996, although not necessarily in a commercially useful plant. By 2002 the characteristic will be present in a viable inbred, hybrid variety available for NIAB trialling and GMO assessment. At the same time the plastic will be available for testing and approval for commercial production and use. At present, they envisage commercial crop production and Biopol manufacture as starting in 2006.

Zeneca envisage supplying the world market for Biopol with oilseed rape produced in the UK and Europe. While 100 000 t is only a small fraction of the world polymer market, at a level of 20% in rape seed this would require some 150 - 200 000 ha of oilseed rape.

### 3.5.5 The future of vegetable oil-based polymers

The above has shown that vegetable oils have a potentially significant role to play in the polymer industry. Total consumption of polymers seems set to increase, and technological, and particularly biotechnological, developments have the potential to increase the proportion of polymers derived from vegetable oils or produced in oilseeds.

Evironmental issues may also enhance the scope for vegetable-oil-based polymers. Some consumers express concern at the large tonnages of plastics the world produces annually, for two reasons. First, plastics account for a large volume use of mineral-oil derivatives and as such use non-renewable resources. Second, the plastics, once produced and used cause considerable disposal problems. Polymers produced from oleochemicals, and in oilseeds, may offer considerable advantages, in particular biodegradability. In addition, the lower toxicity of oleochemical rather than petrochemical additives means that they are useful for incorporation in plastic films used with food products, where in recent years concern has been increased as to possible seepage of toxic petrochemical compounds.

The ability to add functional groups to the fatty acid chain in the plant, rather than trying to incorporate reactive sites after the oil has been produced and refined would enable the use of vegetable oil triglycerides for a wide variety of applications. New polymer formulations may be possible, offering the physical flexibility obtained from polymerising long- rather than short-chain molecules, but with the strength of bonds between groups that are currently only possible through petrochemical routes. These new oleochemical polymers would have the same benefits of biodegradability and reduced toxicity as other oleochemical polymers, giving them distinct advantages over the currently produced mineral polymers.

### 3.5.6 Conclusions

The role of vegetable oils and their derivatives in polymers of various types is currently a minor part of the overall picture of polymer consumption. However, the advances made in both oleochemical processing and plant biotechnology may provide considerable markets in the future. Polymers currently, and in the future will be a focus for increasing environmental responsibility, both from the point of view of sourcing and perhaps more importantly of disposal. Biodegradable and reduced toxicity products will be more in demand as public opinion continues to swing against pollution.

## 3.6 PHARMACEUTICALS AND INDUSTRIAL ENZYMES

Vegetable oils are used as carriers in many pharmaceutical products. Certain vegetable oils, such as olive, castor, sesame and sunflower oils, are incorporated into pharmaceutical products as demulcants, laxatives, lubricants and emollients.

Of greater interest is the scope to derive a number of pharmaceutically active molecules from oilseeds. These may be:-

(i) already synthesised in particular plant species;

(ii) derived from the biological or chemical processing of oilseed-derived feedstocks;

(iii) produced in new, genetically modified crop varieties.

The best known example of the first of these categories is probably gamma-linolenic acid (GLA). This uncommon fatty acid is secreted in the seeds of evening primrose and borage and is used in the treatment of, for example, atopic eczema and diabetes. Trials of a transgenic GLA-containing oilseed rape variety are underway in France.

An example of the second category is provided by the production of 'Lorenzo's oil' from high-erucic acid oilseed rape oil. This is used to treat a rare nervous disease known as adrenyleucodystrophy. It is also understood that erucic acid provides the starting point for a number of other pharmaceutical products. Recent investigations indicate the possibility of treating acne with dicarboxylic acids derived from the microbial transformation of vegetable oils (a process referred to in Section 3.5.3).

Developments in the third category, refer particularly to the production of pharmaceutically active peptides in transgenic oilseed rape varieties (as well as other plant species, such as potato, tobacco, and turnip). A recent development by which these peptides are synthesised as fusion products attached to the oleosin proteins which coat seed oil bodies has greatly facilitated their extraction (see Appendix IV). So far, levels of approximately 1% of interleukin and hirudin (an anti-coagulant used in surgery), have been achieved in transgenic oilseed rape. The secretion of other peptides, including antibodies, is being investigated.

The value of these products is of course considerable, but global demand is small (eg about 1 t per year for hirudin and 8 t per year for human serum albumin). It is likely that such products would be developed and produced by pharmaceutical companies, with the crops being grown under glass. They represent little opportunity for farmers.

The production of industrial enzymes may provide greater, though still modest, opportunities. A transgenic oilseed rape secreting quite large amounts of the the high-value enzyme phytase (used as a dietary supplement in animal feed) has been developed in the Netherlands. Other enzymes are being examined.

## 3.7 MARKETS FOR CO-PRODUCTS

The main co-products from the production of industrial oilseed rape are straw produced at harvest and meal from seed-crushing. Glycerol, produced if oils are 'split', can also be regarded as a co-product.

**Straw** produced from oilseed rape can be used as animal bedding or for feed purposes. As a source of fibre, it is inferior to crops such as flax, hemp or linseed, but superior to cereal straw (and, hence, suitable for some low-grade fibre uses). There is, however, no established use for oilseed straw currently, although some developments in the use of crop fibres for paper, centred around flax and hemp are developing (Carruthers *et al*, 1994).

Currently, **meal** from oilseed rape is used in the production of animal feeds. The feed value of meal from novel oilcrops, resulting from genetic modification, is as yet unknown. Farmers producing industrial crops on Set-aside land need to be aware that the value of the meal used for animal feed must not be greater than the value of the industrial crop that is grown. This may become relevant with the development of new crops and niche (perhaps unpredictable) markets for novel oilseed crops.

Glycerine is produced when whole oils are 'split' by hydrolysis to obtain free fatty acids. As a guide, 1 tonne of typical C-18-rich vegetable oil typically gives 957 kg fatty acid, and 105 kg glycerine (F D Gunstone, pers comm, 1994). Glycerine markets are not growing globally. However, production is greater than demand at the moment. Gray (1993) predicted that a 2% substitution of rapeseed methyl ester in diesel fuel in Europe would mean an extra 200 000 tonnes of glycerine per year coming onto the market in Europe

The markets for co-products may develop in future years, as 'whole-crop utilisation' gains popularity, Currently, however, other than those uses illustrated above, there are no developments in uses for co-products.

# 4 Economic opportunities

## 4.1 THE ECONOMIC CONTEXT

### 4.1.1 Introduction

Oilseed crops (ie oilseed rape and, to a lesser extent, linseed) represent a potentially profitable way of using some UK agricultural resources. Oilseeds provide vegetable oil and a high-protein meal used as animal feed. The use made depends upon oilseed characteristics, which vary with crop species and variety and which are amenable to genetic modification, especially in the case of oilseed rape.

### 4.1.2 Markets for oilseeds

The main market for rapeseed oil is in human food (eg in margarines or cooking oils), where its principal competitors are oils from soya, sunflower, maize, olives and tropical crops, such as coconut and palm. The processing industry combines these oils, taking account of both price and composition, to offer products which have saleable characteristics. These differ, but health issues (eg absence of ingredients associated with heart disease) are among the more important claims made for vegetable-oil products.

Industrial uses are also potentially important. As shown earlier, rapeseed oil can be used in the production of lubricants, surfactants, polymers and surface coatings. Within these broad categories the range of possible applications is very large. Here, specific characteristics, which may be quite different from those valued by food manufacturers, are of great importance. In so far as plants may be tailored to match these requirements they can be made more attractive. However, if they are to command a share of the market they must be available at prices that are competitive with other materials which, although they may be less convenient, can with modifications introduced in processing, meet the purchasers' requirement.

Industrial users of oils have to make a continuous calculation of the cost to them of alternative oils in relation to the value of the products they sell, balancing oils of mineral, animal and vegetable (tropical and temperate) origin, and assessing processing costs and impacts on final product quality. Because prices change, this cannot be a once-for-all calculation; it has to be reviewed at each stage that fresh raw materials are required.

If there is to be an expanded use of UK-produced vegetable oil, principally oilseed rape, it has to displace some of these existing oils in terms of the value it offers to the manufacturer. In principle, it could do this by offering lower price or superior quality. In the absence of subsidy, the price at which rapeseed is available cannot, in the long term, be forced below the costs of production. However, competitive forces within farming will always tend to push prices of commodities down to this level. Assuming that prices reflect such costs, then the route to additional uses would appear to depend upon higher productivity on the farm, or on an increase in the quality of the product to a point at which it captures markets from other less suitable oils. Interest in oilseeds for industrial purposes has been stimulated by the prospects that oil fatty acid composition can be modified. If 'designer' rape seeds match manufacturers' requirements better than other oils they will be able to command a premium price.

### 4.1.3 Production of oilseeds

***Oilseed rape production in the UK***

Table 4.1 shows UK production of oilseed rape in relation to that of the EU and the world. In 1992, UK oilseed rape occupied 2% of the world area and 18% of the EU area, but comprised 4.4% of total world production and 19% of total EU production. In the same year, average yield in the UK was 4% higher than average EU yield, and 114% higher than the world average.

**Table 4.1**
**Production statistics for oilseed rape, 1992**

| | Area (kha) | Average yield (t/ha) | Total production (kt) |
|---|---|---|---|
| UK | 422 | 2.76 | 1 166 |
| EU | 2 334 | 2.65 | 6 176 |
| World | 20 736 | 1.29 | 26 661 |

Source: Adapted from FAO (1993)

Within the UK, in 1993, oilseed rape occupied 377 000 ha, equivalent to 8.3% of the total cropped area. Provisional figures show that the output of oilseed rape made up just over 2% of the total UK agricultural Gross Output for 1993 (MAFF, 1994).

***Factors affecting the production of oilseeds for industrial purposes***

Current interest in industrial oilseed from the Set-aside regulations introduced as part of the arable reform package of 1992. This required farmers, with farms above a certain minimum size, to set aside a proportion of the land they had used for cereals, protein crops and oilseeds (15% in 1993/94) to qualify for compensation payments. Strict rules were laid down concerning what could be done with Set-aside land. Among these was permission to use the land to grow industrial crops, provided there was a contract for the whole crop with a non-food or non-feed industrial user. This opens up a route for the farmer which may offer some profit in the short term and may ease his problems in maintaining land in good condition when it is brought back into his normal arable rotation. In effect, the farmer need only be certain that the revenue he receives for the crop will exceed his variable costs.

Although the Set-aside scheme encourages the production of industrial oilseeds, it must be noted that, since the GATT settlement of December 1993, another consideration has to be borne in mind. As part of an agreement with the USA relating to trade on soyameal, the European Union (EU) undertook that if the production of industrial oilseeds exceeded one million tonnes soyameal equivalent, corrective measures would be taken. This point has not been reached, but if it were, it seems possible that either some system of allocating the permissible area between producers would be required or that the 'corrective action' would take the form of a lower price. If supply control were the route chosen, the basis of allocation is likely to relate to existing production levels. Thus, in a rather paradoxical way, the present system encourages governments and farmers within the EU to expand their share of the market as rapidly as possible.

While to the farmer, the production of industrial oilseed rape may be encouraged by the current conformation of policy, so that oilseed rape plays a larger part in the total oil requirements, the value to the nation of such an expansion has to be assessed against the real costs of supplying these needs through other means. If the substantial investment required in producing varieties of oilseed rape for industrial purposes is to be justified, there needs to be a prospect that the profitability of the product will depend solely on the fragile conformation of existing EU policy. This means that the oils produced must be able to compete for resources with other domestic industries, and in the market places, with imports or with oils from non-agricultural sources.

In assessing the real costs of production, attention has to be given to the environmental as well as the market values involved. One of the attractions of biological products is that they may be more renewable. They may also cause less pollution, particularly if they effect a reduction in greenhouse gas emissions. A comparison in terms of wildlife habitats or of biodiversity may be less positive. Well-managed Set-aside may do more for these environmental assets than an annual crop, which may require inputs of agrochemicals if it is to achieve acceptable productivity. A comparison with longer-term Set-aside, trees or leisure goods, is even less likely to be favourable (although these could change local ecology fundamentally, and may lower rural employment).

For society as a whole, it is important that these components of cost and return are reflected in the incentives offered to farmers and others who may invest in the expansion of oilseed production for industrial uses.

***Current and potential production of oilseeds for industry in the UK***

In 1993, 40 613 ha of oilseed rape for industrial markets were grown on Set-aside land. in. High-erucic acid varieties accounted for c 16 000 ha, and double-low varieties for c 24 000 ha (Walker, 1994). The main use of the former was in the production of erucamide, for use as a slip-agent in polyolefin manufacture. A smaller quantity was used in the production of a flow improver for waxy crude mineral oil to improve its flow. According to Walker (1994), the main use of industrial double-low oilseed rape was in the pharmaceutical industry. In the same year, a total of 156 047 ha of linseed were grown, 11 576 of which was on Set-aside land. The total area of non-food crops on Set-aside in 1993 was 53 572 ha, and on all land was 200 864 ha (POST, 1995).

Provisional figures for 1994 show a considerable increase in the area of non-food crops on Set-aside land, with an area of 108 415 ha, although the total area of non-food crops on all land only increased to 204 247 ha. The main increase was in industrial oilseed rape, with 92 209 ha grown, all on Set-aside land. The linseed area increased on Set-aside to 14 756, but the total area declined to 92 281 ha (POST, 1995).

The availability of land in the UK for industrial oilseeds depends on a range of technical, economic, environmental and social factors. The area under crops (4 519 000 ha in 1993) probably represents a theoretical upper limit of technically suitable land, but the most immediately available land resource is that under Set-aside. In 1993, the theoretical maximum area that might have been set aside under the current arangements was very approximately 3 Mha and the minimum area, if all land under crops (apart from horticulture) were to have come into the Arable Area Payments Scheme, was approximately 650 000 ha. In fact, the latter area was exceeded in 1993 (when 702 800 ha were set aside) and 1994 (when some 722 000 ha were set aside).

Assuming Set-aside and the crops currently grown on it, apart from oilseed rape, remain at their 1994 levels, the area of Set-aside theoretically potentially annually available for industrial oilseed rape, ranges from approximately 175 000 ha (assuming oilseed rape can only be grown one year in four) to 705 000 ha (assuming cultivation every year).

## 4.2 ECONOMIC OPPORTUNITIES: A GENERAL BACKGROUND

### 4.2.1 Introduction

All investment involves risk. Because the outcome of present decisions lies in the future, this cannot be avoided. The investor has to find a balance between projects which may be relatively certain and offer a modest return, and those which in prospect may seem potentially very rewarding, but where the outcome is more uncertain. This report describes a number of potential markets for industrial oilseeds, which vary in terms of the risks attaching to them. This section, first, considers some of the more general risks associated with such an expansion, and, second, reviews a number of specific potential new or expanded uses in terms of their strengths and weaknesses.

### 4.2.2 Production risks

The technique of growing oilseed rape is well established in the UK. Many producers have all the equipment needed already on their farms. Any major expansion of production involves the probability that there will be an increase in pests and diseases associated with that species. Methods of controlling such outbreaks imply additional costs. In the future, these may be expected to rise if the area of rape grown increases.

The development of 'designer' plants introduces the risk of cross-contamination with existing varieties. This may be important not just to the 'designer' crop, but because some of its features may render the 'ordinary' crop unsuitable for the food purposes for which it is intended. Whilst skilful management may minimise such risks, they imply constraints which themselves could add to the cost of production.

### 4.2.3 Market risks

Much of the evidence presented suggests that the extension of the industrial market for oilseed rape depends upon its ability to be manipulated to offer characteristics of special value to the user. Two questions emerge. Can other sources of oil be adapted to capture the same favourable characteristics? Can other sources offer rival raw materials at such low cost that after processing has been taken into account, the ultimate cost of the product will be lower using the 'less suitable' raw material?

Advances in biotechnology, which form the basis of the prospect of 'designer' plants, cannot be confined to one country. Whilst the early applications have been to products grown in rich, mainly temperate, countries, the same techniques can offer improvements to crops grown in the tropics. The strongest competitors in the vegetable-oil market are the tropical oils, palm, palm kernel and coconut. Progress in manipulating these tree crops is likely to be slower than in annual crops such as oilseed rape. However, it now seems clear that the producers of these tropical products are well aware of the potential and intend to undertake the relevant research. Given that the productivity per hectare of these tropical oils is very much greater than that of temperate crops - up to more than three times - there is clearly a risk that, in the long term, they will be able to capture these markets on the basis of lower cost.

For those who produce oilseed rape, strength lies in their ability to respond more quickly to market needs than can tropical tree-crop producers. UK-produced oilseeds may also have a related advantage where bulk production is not a key issue in the market. This suggests that the greatest profit may lie in exploiting a number of relatively specific markets rather than attempting to compete with mainstream uses where any advantage is likely to be lost as the types of oil available from the tropics catch up. To develop this into a long-term strategy demands a continued commitment to research.

For many industrial purposes the strongest competition comes from the petrochemical industry. Here, the very heavy fixed costs involved in exploration and extraction mean that, faced by competition from vegetable oils, the businesses concerned are likely to reduce selling price in order to retain market share. In an unregulated market, prices might be depressed below the point of profitability for most growers of vegetable oils. In so far as the market for vegetable oils is limited, either by their availability or their suitability for particular purposes, mineral-oil producers may prefer to retain higher prices and accept some loss of market share. However, any very large expansion of vegetable oil production might be expected to encounter strong competition from this sector.

A major market risk arises from the difficulty of securing the intellectual property embodied in a designer oilseed. If this cannot be secured it is impossible for the market to reward the very considerable research and development costs involved. Without reward such developments are unlikely to take place. Several strategies have been proposed in order to safeguard intellectual property. One approach is for there to be contract arrangements whereby the industrial user provides the seed and collects the entire output. Another suggests that the improved varieties may be hybrids and hence not capable of further reproduction. The introduction of improved diagnostic methods so that the origin of seed can be precisely identified, means that where a legal framework is effective, unauthorised use of varieties can be detected and penalised. However, such measures may be of limited effect in international piracy of intellectual property.

In this area as in any other area, concern to protect intellectual property generates another type of economic risk. Because, understandably, businesses are not prepared to indicate progress they are making in research and development, there is a considerable risk that duplication of effort may occur whilst some potentially rewarding areas remain unfunded. To the economy as a whole this represents an economic cost - the wastage of valuable resources which could be better applied to other uses. These difficulties are especially acute where public funds, or funds collected from the industry as a whole, are made available to prosecute research relating to industrial crops.

### 4.2.4 Policy risks

The use of resources in the agriculture of the EU is strongly influenced by the CAP. If returns to production were not manipulated through this policy the pattern of production, and the availability of crops and animals would change. In considering the prospects for any one enterprise, it is necessary to take account, not only of the regime relevant to that product, but also the whole range of other activities which may compete for resources or affect markets. The present outlook for agriculture hinges upon the shape of the CAP and the agreements reached between the EU and the US in the Uruguay round of GATT negotiations.

As suggested earlier, the production of industrial oilseeds is, to some extent, stimulated by the reformed regime for arable crops. The policy risks stem from possible changes which may take place because of either internal or external pressures. By its nature discussion of such possibilities is speculative. Present considerations suggest four sorts of change which might be of importance:-

(i) The present arable regime involves substantial and very visible transfers to farmers through the compensatory payments system. Criticism of such payments, particularly where the recipients are on relatively large farms, is unlikely to be avoided. Attempts to limit them, or to redirect them in a more 'socially equitable' manner by placing ceilings on individual receipts might change the total rewards available from arable production and lead to an overall reduction in investment and therefore to a situation in which the assumption that industrial crops grown on Set-aside land could be assessed on the basis of variable costs alone was no longer tenable.

(ii) The accord over cereals reached in the GATT settlement, imposes quantitative as well as monetary limits on the amount of subsidised crops the EU is allowed to export. The implications of this arrangement depend on developments in consumption and production within the EU. If less is consumed or more produced within the EU than the Commission assumed when settlement was reached, further adjustments in the CAP policies may be expected. Some commentators regard the Commission's calculations as optimistic, especially in terms of the longer-run trend in crop yields. In principle, should problems arise, the EU might face a choice between moving in the direction of removing subsidy from production or of intensifying supply control. If the supply control route were adopted, the implication would be a further increase in the amount of land upon which industrial crops might be grown. If much of this were used for oilseed rape, the market price of the product might be expected to fall.

(iii) For farmers, the most notable achievement of the GATT round was the inclusion of agriculture within this framework of international trading relationships. The implication is that, in common with other sectors, there will be a continued pressure towards the reduction of both tariff and non-tariff barriers to trade in future negotiations. For the economy of the EU as a whole international trade is of immense importance. Therefore, it is likely that, as in 1993, despite opposition from farming interests, further progress towards the liberalisation of agricultural trade will occur in the next century. In so far as the profitability of industrial oilseed rape is based upon the present protective structure of EU agriculture its long-term future may be at risk.

(iv) There is growing concern about the environmental impact of industrial activity. In Europe, this extends to attempts to regulate agricultural practices so as to minimise their polluting effects. It also encourages governments to support agricultural developments which seem to offer a 'green dividend'. In some countries this has encouraged support for biodiesel. In the UK, some environmentalists tend to favour longer-term set aside rather than annual crops. Such long-term set-aside may be used for example, as forest or for trees to provide coppice woodland. It may diminish the area available for industrial crops as such. The UK Government does not favour any one option over another, recognising the roles of long-term Set-aside, annual crops and annual fallow, but believes that most Set-aside is likely to be rotational.

## 4.3 ECONOMIC OPPORTUNITIES - THE RESULTS SO FAR

Tables 4.1 - 4.5 summarise the strengths, weaknesses, opportunities and threats pertaining to the main potential industrial markets for vegetable oils from UK-produced oilseeds.

**Table 4.1**
**Characteristics of lubricants derived from UK-produced oilseeds (1.2.2 & 3.2)**

| | |
|---|---|
| **Strengths** | 1. Vegetable base oils are more environmentally benign than mineral base oils<br>2. Demand for environmentally-friendly lubricants for some application sectors may increase<br>3. Vegetable base oils are of comparable quality in certain suitable uses to currently used mineral base oils<br>4. Some new products are available now (eg chainsaw bar oils, hydraulic oils, two-stroke oils)<br>5. Some products are expected within 5 years (eg offshore drilling muds)<br>6. Costs of vegetable oil drilling muds may be comparable to current mineral-based muds<br>7. There is ongoing development of manufacturing technologies and product improvement |
| **Weaknesses** | 1. Vegetable-oil-based lubricants are more costly than those derived from mineral oils, at present by 150 - 300% (apart from drilling muds)<br>2. Markets are dependent on environmental legislation |
| **Opportunities** | 1. Replacement of existing mineral-oil-based products, in environmentally sensitive application sectors<br>• Total-loss systems (eg chain-saw bar oil, two-stroke oil) -Estimated annual UK market: 52 000 t oil (130 000 t grain, 43 333 ha OSR)<br>• High-risk-of-loss systems (eg hydraulic oils)<br>• Offshore drilling muds -Estimated annual UK market: 32-45 000 t oil (80-113 000 t grain, 27-38 000 ha OSR) |
| **Threats** | 1. 'New generation' 'environmentally friendly' mineral base oils<br>2. Competition from other, non-UK, vegetable oils (eg sunflower, soya, tropical oils)<br>3. Possible constraints on oilseed rape production (2.5) |

**Table 4.2**
**Characteristics of vegetable oils from UK-produced oilseeds as raw materials for surfactant manufacture (1.2.2 & 3.3)**

| | |
|---|---|
| **Strengths** | 1. 'Environmentally-friendly'/'natural' product benefits<br>2. Vegetable oils are already established raw materials for surfactant manufacture, and technology developed<br>3. Use of vegetable oils as raw materials for surfactant manufacture is increasing<br>4. Development of 'pure' (ie single fatty acid) oilseed rape oils would offer higher quality raw material than currently available<br>5. There is ongoing development of manufacturing technologies and product improvement |
| **Weaknesses** | 1. UK-produced vegetable oils, at present, are more costly than tropical vegetable oils<br>2. UK-produced vegetable oils, at present, are of poorer quality, than tropical vegetable oils |
| **Opportunities** | 1. Replacement of some existing mineral-oil-based and other vegetable-oil-based surfactant products<br>2. New surfactant products based on new 'pure' oils<br>3. Pesticide adjuvants |
| **Threats** | 1. Increased competition from tropical oils due to increased production, and genetic development<br>2. Competition from 'new generation' 'environmentally friendly' mineral-based surfactants<br>3. Possible constraints on oilseed rape production (2.5) |

**Table 4.3**
**Characteristics of vegetable oils from UK-produced oilseeds as raw materials for paint manufacture (1.2.2 & 3.4.2)**

| | |
|---|---|
| **Strengths** | 1. Manufacturing technologies are available now<br>2. There is ongoing development of manufacturing technologies and product improvement |
| **Weaknesses** | 1. Market opportunity totally dependent on development of new varieties of oilseed rape<br>2. Oilseed-rape-based raw materials likely to be more costly than current raw materials |
| **Opportunities** | 1. Replacement of currently used raw materials with oilseed rape oil from new varieties<br>• In gloss paint<br>-Estimated annual UK market: 48 000 t oil (120 000 t grain, 40 000 ha OSR)<br>2. New products, based on new oilseed rape oils, should attract a premium<br>3. Quality of new oilseed-rape oils would be higher than existing raw materials |
| **Threats** | 1. Competition from synthetic products<br>2. Competition from other, non-UK, vegetable oils (eg sunflower, soya, tropical oils)<br>3. Possible constraints on oilseed rape production (2.5) |

**Table 4.4**
**Characteristics of vegetable oils from UK-produced oilseeds as base oils in printing inks (1.2.2 & 3.4.3)**

| | |
|---|---|
| **Strengths** | 1. Vegetable oils have environmental advantages over presently used mineral oil vehicles (eg facilitation of de-inking and paper recycling)<br>2. Vegetable oils are less toxic than mineral oils (and, hence, would improve print room working environments, and reduce toxicity of printing wastes)<br>3. Some vegetable oils of comparable quality to mineral oils as vehicles in printing inks<br>4. Manufacturing technologies are available now<br>5. There is some ongoing development of manufacturing technologies and product improvement |
| **Weaknesses** | 1. Expanding the market (ie via more widespread use in the printing industry and higher levels of incorporation in inks) is dependent on development of new varieties of oilseed rape (ie with greater 'drying' properties)<br>2. Vegetable oils are more expensive that mineral oils and the market may be mostly dependent on environmental legislation |
| **Opportunities** | 1. Replacement of currently used raw materials with oilseed-rape oil -Estimated annual EU market: 84 000 t oil (210 000 t grain, 70 000 ha OSR) |
| **Threats** | 1. Competition from existing mineral base-oils<br>2. Competition from other, non-UK, vegetable oils (eg soya)<br>3. 'New generation' 'environmentally friendly' mineral base oils<br>4. Possible constraints on oilseed rape production (2.5) |

**Table 4.5a**
**Characteristics of vegetable oils from UK-produced oilseeds as raw materials for polymer production (1.2.2 & 3.5.3)**

| | |
|---|---|
| **Strengths** | 1. Vegetable oils can provide longer-chain repeating units than mineral oils, with different and advantageous properties<br>2. Some manufacturing technologies are available now<br>3. There is ongoing development of new manufacturing technologies (microbial transformation, catalytic hydroxylation) and products<br>4. Possible environmental advantages and/or better environmental 'image' |
| **Weaknesses** | 1. Vegetable-oil-based materials are more costly than current mineral-oil-based polymers in applications where they compete |
| **Opportunities** | 1. Specialist plastics derived from vegetable oils (eg engineering plastics)<br>2. New vegetable-oil-based plastics arising from the development of microbial transformation techniques<br>3. New polyols from vegetable oils (for production of polyesters and polyurethanes), derived from new chemical hydroxylation processes<br>4. Plastic manufacture in regions where imported oil is expensive, but vegetable oils are relatively cheap |
| **Threats** | 1. Competition from synthetic products (where they exist)<br>2. Competition from other, non-UK, vegetable oils<br>3. Public objection to oilseed rape as a crop (due to environmental or health concerns |

**Table 4.5b**
**Characteristics of plant-produced polymers from UK-produced oilseeds (1.2.2 & 3.5.4)**

| | |
|---|---|
| **Strengths** | 1. Environmental advantages (eg biodegradable polymers)<br>2. 'In-plant' production is expected to be less costly than fermentation-based production (partly due to lower capital costs)<br>3. There is ongoing development of new polymer oilseed varieties |
| **Weaknesses** | 1. Crop variety development is still at a relatively early stage (an anticipated 10 years to first commercial production) |
| **Opportunities** | 1. 'Biopol' (biodegradable plastic based on polyhydroxybutyrate) -Estimated annual world market: 100 000 t (c 500 000 t rapeseed, 166 666 ha OSR).<br>2. Other polymers with new properties |
| **Threats** | 1. Competition from synthetic products<br>2. Competition from other, non-UK, vegetable oils<br>3. Public objection to oilseed rape as a crop (due to environmental or health concerns |

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# Appendix I: Trialling procedures

Varieties of oilseed rape and linseed which are to be marketed in the United Kingdom must be accepted onto the UK National List of Varieties which is administered by the four UK Agricultural Departments, or the EU Common Catalogue of Varieties of Agricultural Plant Species. This involves the submission of a National List application to MAFF which then undertakes a series of DUS tests to determine that the seed of the variety is distinct, uniform and stable, and VCU trials to indicate that it has a value for cultivation and use. These statutory tests and trials, which are funded by the Agricultural Departments and/or the breeders entering the varieties, are conducted over a 2 year period (D A Boreham, pers comm, 1994). The DUS tests are conducted by the National Institute of Agricultural Botany (NIAB) and funded by the breeders. The VCU trials are carried out by NIAB for England and Wales, the Scottish Agricultural College (SAC) in Scotland, and on certain breeders' sites which have been officially licensed by the Agricultural Departments. They are funded jointly by the Agriculture Departments and the breeders.

Many breeders also make applications for UK Plant Breeders' Rights on their variety. Providing the application is acceptable and the variety is found to be DUS the protection granted enables the breeder to recover some of his costs in producing the new variety by way of a royalty charge on sales of certified seed (D A Boreham, pers comm, 1994).

Following a variety's addition to the National List additional trials may be carried out to provide advisory services to growers, merchants and processors. These trials are carried out on the better varieties selected from those which have been accepted on to the National List. The work is funded from the levy administered by the Home-Grown Cereals Authority (HGCA), and is co-ordinated by NIAB with trials being carried out by NIAB, SAC and other independent trial operators (D A Boreham, pers comm, 1994).

Varieties included in these trials are considered for addition to the Recommended List for winter oilseed rape upon completion of two years of trials and to the Descriptive List of Spring Oilseed Rape and linseed after three years of trials. The Recommended and Descriptive Lists are issued annually by NIAB Council.

Other trials are undertaken by organisations (agronomy groups, advisory services, breeders etc) to provide information on selected varieties and particularly to investigate their response to different input levels. This provides information of interest to those involved in growing crops in the UK.

# Appendix II: Cost-benefit relationship of variety development

C Boyce (pers comm, 1994), the Technical Director of the British Society of Plant Breeders, indicated that to make an adequate return on investment of 10-12% in a steady state in which there is an income flow and research expenditure, the royalty income from a variety should be at least three times the investment on the research to produce it.

The level of royalty income from a variety is determined by the relevant breeder and the figure takes account of the expected sales of the variety and the development costs. The resulting figure must be reasonable to all parties. It has been assumed in this report that, at present, an average royalty payment for oilseed rape varieties is £2000 per tonne of seed. Assuming average sowing rates of 7 kg per ha, average crop yields of 3.0 t of seed per ha, an oil content of 40%, and an average annual cost of variety development of £100 000, the minimum planted area to justify research investment is 21 500 ha per year. This approximates to an annual market for 64 000 t of grain or 25 600 t of oil. In practice, it seems likely that the target market will need to be somewhat higher, perhaps 100 000 t of grain, in order to justify breeders' investment.

Breeders might target smaller potential niche markets if the royalty return could be increased. This may arise due to the value of the product in the market, if the variety was produced as a "spin-off" from a larger programme with other objectives, or if the costs could be spread across a number of programmes. The increasing use of biotechnology to develop new markets and the costs of satisfying legal requirements before marketing (particularly relevant with GMOs where risk evaluations have to be undertaken) will increase input costs to the breeders. Furthermore, limitations are placed on breeders wishing to compete if the market potential is dubious or unproven.

One way breeders may become involved in such niche markets might be if the seed sown and the resultant crop remains the property of the contractor (breeder) at all times. The grower would simply provide the husbandry to grow the crop for a pre-arranged fee. A variety would not be required to be entered for statutory trialling but the breeder would still have to satisfy the relevant bodies that the produce (both oil and meal) complied with all regulations regarding safety for use.

To be attractive to the grower such an approach would have to give an adequate financial return which would reflect that obtainable for other crops and the fact that growing a specialist oil crop could restrict the options for cropping both before and subsequent to the crop in question. Pollination limitations would make it necessary to ensure appropriate separation distances as discussed in the previous section.

It may be concluded that breeders will endeavour to satisfy market opportunities if an adequate return can be obtained. In some instances major market opportunities may arise but in many cases the more likely situation will be a number of small niche markets. To be economically feasible, restriction in the availability of seed to selected growers and prearranged markets for the produce are likely to reduce the risks to breeders and growers especially when markets are dubious or unproven.

# Appendix III: Prospects for non-transgenic oilseed rape varieties

The oilseed brassicas include rape (*Brassica napus*), turnip rape (*B. rapa*), cabbage (*B. oleracea*), Indian mustard (*B. juncea*), Ethiopian mustard (*B. carinata*), black mustard (*B. nigra*), white mustard (*Sinapis alba*) and crambe (*Crambe abyssinica*). Most natural brassicas contain a medium-high erucic (25%-45%) seed oil, but this can be altered relatively easily and quickly using advanced breeding methods as shown in Table AIII.1.

The strategies for achieving inter-specific and even inter-family crosses often rely on modern biotechnological methods, including molecular marker-assisted selection, for the rapid introgression of useful traits (eg high erucic acid) into elite breeding lines via backcrossing. These methods have been reviewed recently by Murphy (1994) and Murphy & Mithen (1994). Conventional zero-erucic edible oilseed rape cultivars now typically contain about 50-60% oleic, but very-high oleic (VHOAR) mutants with over 85% oleic have recently been developed by several seed companies, although the latter have yet to be commercialised. Medium- (15-30%) and high- (40-55%) erucic varieties are available, but no very high (>60%) erucic cultivars as yet. Very recently, a *B. oleracea* variety containing up to 35% erucic acid on the $C_2$ position of its seed triacylglycerol has been reported (Taylor *et al*, 1994). If this variety could be improved and crossed with a high erucic *B. rapa*, a resynthesised oilseed rape with a seed-oil content of 70-80% erucic could potentially be produced by a non-transgenic route. Such a strategy should receive the immediate attention of UK researchers and plant breeders.

Oilseed rape breeders have also recently produced high palmitic (10% and even in a few cases, 20%) and very low alpha-linolenic (<3%) varieties. Similarly, zero, medium and high-erucic cultivars of turnip rape and indian mustard have been developed, mainly in Canada, over the past few years. In the next few years it is likely that a range of seed oil variants of the remaining brassica oilseeds will begin to become available.

From the point of view of UK industrial crops, the most promising targets here are high or very-high erucic and very high-oleic cultivars. Although in the UK these varieties have only been developed in *B. napus*, there is, in principle, no problem about developing such traits in other oilseed brassicas for future UK cultivation. For example, in the USA the major source of high-erucic seed oil is crambe, which grows better than oilseed rape in the local climatic conditions (Leonard, 1993).

**Table AIII.1**
**Brassica oilseed fatty-acid profiles**

| | | 16:0 | 18:0 | 18:1 | 18:2 | 18:3 | 20:1 | 22:1 |
|---|---|---|---|---|---|---|---|---|
| *B.napus* cv. Tobin | ZEAR | 4.3 | 1.7 | **52.7** | 24.5 | 14.2 | 1.2 | **0.6** |
| *B.napus* | MEAR[4] | 3.8 | 1.6 | 39.2 | 20.5 | 9.2 | 11.7 | 14.9 |
| *B.napus* | HEAR[1] | 3.0 | 0.8 | 9.9 | 13.5 | 9.8 | 6.8 | 53.6 |
| *B.napus* | HPAR[7] | 10.0 | 1.0 | 51.0 | 19.0 | 13.0 | 1.0 | tr |
| *B.napus* Stellar (lo 18:3)[7] | | 5.0 | 2.0 | 64.0 | 24.0 | <3.0 | 1.0 | tr |
| *B.napus* VHOAR mutant[1] | | 3.0 | 1.6 | 85.4 | 3.6 | 3.9 | 1.3 | 0 |
| *B.rapa* Tobin | ZEAR | 3.8 | 1.2 | 58.3 | 24.0 | 10.3 | 1.0 | 0.3 |
| *B.rapa* Echo | MEAR | 2.5 | 1.0 | 32.5 | 18.8 | 8.9 | 12.0 | 23.5 |
| *B.rapa* R-500 | HEAR[1] | 2.5 | 1.0 | 13.0 | 13.5 | 10.1 | 5.5 | 51.1 |
| *B.oleracea*[5] | | 6.3 | 1.0 | 7.8 | 13.9 | 11.1 | 2.5 | 54.9 |
| *B.juncea* Zem I | ZEAR[6] | 3.6 | 2.0 | 45.0 | 33.9 | 11.8 | 1.5 | 0.1 |
| *B.juncea* Indian mustard cutlass | MEAR[6] | 3.3 | 1.2 | 17.2 | 21.4 | 14.1 | 11.4 | 25.8 |
| *B.juncea* Tabor | HEAR[3] | 2.4 | nd | 15.5 | 14.8 | 12.6 | 11.1 | 40.6 |
| *B.carinata* Ethiopian mustard | HEAR | 3.2 | 0.9 | 9.8 | 16.2 | 13.9 | 7.5 | 41.6 |
| *B.nigra* Black mustard[8] | HEAR | 0.7 | nd | 8.0 | 14.0 | 18.0 | 7.0 | 43.0 |
| *S.alba* White mustard[2] | HEAR | 2.5 | nd | 22.0 | 8.5 | 10.5 | 8.5 | 42.0 |
| *Crambe abyssinica* | HEAR | 2.0 | 0.7 | 18.0 | 9.0 | 6.0 | 3.0 | 59.0 |

ZEAR, zero erucic acid rapeseed; MEAR, medium erucic acid rapeseed; HEAR, high erucic acid rapeseed; HPAR, high palmitic acid rapeseed; VHOAR, very high oleic acid rapeseed

Sources: Adapted from Auld *et al* (1992), Downey & Bell (1990), Downey & Rimmer (1993), Hilditch & Williams (1964), Stefansson & Hougen (1964), Taylor *et al* (1994), Vaughan *et al* (1976) and Zadernowski & Sosulski (1978).

# Appendix IV: Prospects for transgenic oilseed rape varieties

## INTRODUCTION

The variety of seed oil contents found within plants is enormous, ranging from $C_8$ to $C_{24}$ chain lengths, and includes industrially useful functionalities such as conjugated and non-conjugated double bonds, hydroxyls, epoxides and waxes, as shown in Table AIV.1 and Figure AIV.1. An even greater variety of lipid structures is available from non-plant species, including cyclic and branched fatty acids and polyhydroxybutyrate (PHB) from bacteria, and very-long-chain polyunsaturates from fish. Providing that the synthesis of these novel fatty acids is regulated by a small number of genes (<4), it is feasible to consider the isolation of these genes from the donor species (in which they occur naturally) and their insertion into oilseed rape in order to create a transgenic cultivar with a novel seed oil profile.

In a few cases, these provisos appear to be well-founded (see below), but even here only modest success in altering oilseed rape oil has been achieved. For example, Calgene have only produced about 30% levels of lauric and stearic acids respectively in their transgenic oilseed rape, whereas industry demands much higher purities if such oils are to be considered as commercial feedstocks. In other cases, such as petroselinic acid from coriander, initial expectations that a single $D_4$ desaturase gene transfer would suffice have now been questioned following recent biochemical studies (Cahoon & Ohlrogge, 1994 a,b; Dörmann *et al*, 1994). The isolation and transfer of 3 or 4 fatty acid-related genes in order to create a high petroselinic oilseed rape cultivar makes this particular piece of genetic engineering somewhat more challenging than was at first thought (Ohlrogge, 1994), although some progress has been made, for example, in the USA.

There follows below a survey of the major novel fatty acids (including PHB) of likely industrial interest, together with an up-to-date account (as of May 1994) of the progress in the isolation of the relevant genes, their transfer into oilseed rape and the release of the transgenic varieties.

## ERUCIC ACID (C22:1)

Although this is already a major industrial feedstock, the best available varieties of high-erucic oilseed rape contain only 45-50% erucic acid in their seed oil. The reason for this is that erucic acid is effectively excluded from the C2 (middle) position of the triacylglycerol molecule, as the relevant acyltransferase fails to recognise erucic acid as an efficient substrate. Several laboratories in Europe and North America are attempting to rectify this problem by cloning genes for acyltransferases which do recognise erucic acid efficiently (eg from *Limnanthes* spp) and inserting these into oilseed rape. If successful, these efforts may result in the production of transgenic oilseed rape varieties containing over 90% erucic acid, which would greatly stimulate the market for erucic-derived oleochemical feedstocks (Leonard, 1993).

An alternative route may be to use the recently described *B oleracea* genotypes that can accumulate up to 35% erucic acid on the C2 position (Taylor *et al*, 1994) in order to create resynthesised *B. napus* lines with enhanced erucic levels which can then be backcrossed into elite *B. napus* cultivars.

To summarise, there are reasonably good prospects that very-high-erucic (60-80%) oilseed rape cultivars will have been developed by the end of the decade. It is also feasible to consider the development in the UK of alternative very-high-erucic brassica oilseed crops, such as crambe or mustard species. This could be achieved, in fact, either by a transgenic or a non-transgenic breeding programme. However, both these crops would require considerable agronomic development before they are suitable for widespread commercial production.

## LAURIC ACID (C12:0)

Lauric acid is an important industrial feedstock in the detergent and surfactant industry, as well as having some edible applications. New transgenic oilseed rape varieties containing over 30% lauric acid have recently been produced in the USA (Voelker *et al*, 1992). This lauric-containing oilseed rape has an additional thioesterase gene obtained from the California Bay plant, which normally accumulates short-chain fatty acids in its seed oil. The widespread commercial use of this novel oilseed rape variety will probably depend upon a further increase in the proportion of lauric acid from 30% up to the values of 50% and beyond that are present in competitive sources of lauric acid such as coconut and palm kernel oil.

These tropical oils are produced with far cheaper labour and chemical inputs at far higher yields per hectare than UK oilseed rape oil which more than offsets their relatively modest transportation costs from the Far East to Europe. It is, therefore, unlikely that a 30-50% lauric oilseed rape oil produced in the UK will compete with traditional lauric oils in the short-medium term.

The theoretical benefits of these developments are, therefore, to diversify the sources of lauric acid, to accommodate a shortfall or reduced accessibility of supply of traditional sources. Neither of these situations seem likely at present. Malaysia and Indonesia, for example, are producing increasing quantities of lauric oils at low prices, and are, of course, anxious to maintain and increase their shares of the world market. Therefore, rather than being a realistic alternative to traditional lauric oils, the 30%+ lauric oilseed rape may simply give lauric processors, like Unilever or Procter & Gamble, an additional bargaining chip in their negotiations with lauric suppliers from Malaysia and Indonesia.

The competitivity of a high-lauric oilseed rape would be very different if a true tri-lauric variety were developed, the oil of which would consist of triglycerides at all three positions, and would be particularly attractive to users due to its very high purity in terms of the desired fatty acid.

## RICINOLEIC ACID (C18:1-OH)

This is a 12-hydroxylated derivative of oleic acid which constitutes up to 90% of castor seed oil and has many medium-to-high value industrial uses in products ranging from cosmetics and pharmaceuticals to polymers and high-grade lubricants. Several industrial and academic groups in the USA and Europe are attempting to clone the oleate hydroxylase gene from castor for transfer into oilseed rape in order to produce a high ricinoleic oilseed which can be grown in the temperate climatic zones of Europe and North America, where castor cultivation is not possible (Murphy *et al*, 1994). This gene has proved very difficult to clone, but recent findings that oleate hydroxylase may resemble oleate desaturase open up new research strategies, such as homology-based Polymerase Chain Reaction (PCR) (Murphy, 1993). Providing that oilseed rape acyltransferase will accept ricinoleic acid to form triacylglycerols *in vivo*, the isolation and transfer of the hydroxylase gene could well be achieved within the next few years. If so, a high ricinoleate oilseed rape cultivar may be available by the end of the decade.

## PETROSELINIC ACID ($C18:1_{\Delta6}$)

This is an isomer of oleic acid with the double-bond in the $D_6$ rather than the $D_9$ position. Petroselinic acid has the potential to be an extremely useful industrial feedstock in the manufacture of detergents and adipic-acid based polymers. Adipic acid is a major bulk chemical with an annual global market in excess of 2.2 M tonnes. The production of adipic acid from petroselinic acid via an environmentally clean process represents an attractive alternative to the present manufacturing techniques, whereby adipic acid is produced from non-renewable petroleum feedstocks in a process which gives rise to substantial emissions of the ozone-depleting greenhouse gas, $N_2O$ (Draths & Frost, 1994). A desaturase gene believed to be responsible for petroselinic acid formation has been cloned by groups in the USA and UK from coriander (Cahoon *et al*, 1992; Fairbairn *et al*, 1992). This gene has been inserted into oilseed rape with the aim of producing transgenic plants containing a high petroselinic seed oil. Recent biochemical studies in the USA indicate that two additional genes (ie those for ketoacyl synthase II and acyl-ACP thioesterase) may be involved in petroselinic formation in coriander (Cahoon & Ohlrogge, 1994a,b; Ohlrogge, 1994). However, the same group was able to obtain petroselinic synthesis (albeit in small amounts) in transgenic tobacco following the transfer of the desaturase gene alone (Cahoon *et al*, 1992). In the UK, a MAFF-funded project at Norwich has resulted in the transfer of the desaturase gene from coriander to oilseed rape and analysis of the transgenic seed oil will be possible in the latter half of 1994. Whether a single desaturase gene will suffice, or the transfer of three or four genes is required, it is likely that transgenic petroselinic-containing oilseed rape cultivars will be available in the next five years.

## GAMMA-LINOLENIC ACID (GLA)

This is the 'active ingredient' of evening primrose and borage oils, which are widely marketed as therapeutic agents. Such oils command relatively high prices, but are only consumed in relatively small quantities compared with oilseed rape oil. Although GLA-oils are taken orally, they are not, strictly speaking, food products and the production of a GLA-rich oilseed rape oil may represent an attractive niche market for UK farmers. The enzyme responsible for GLA formation is a $D_6$-linoleate desaturase. Its gene has been cloned from a cyanobacterium by a group in Texas (Reddy *et al*, 1993) and inserted into oilseed rape by a major French company. Field trials of GLA-containing oilseed rape are now underway in France, although further details are confidential.

## EPOXY FATTY ACIDS

Epoxy fatty acids can be used in the manufacture of resins and coatings, such as paints. Several plants contain large amounts of epoxy fatty acids in their seed oils, most notably

*Vernonia stokesia* and *Euphorbia* spp. In *V. stokesia*, the epoxidases responsible for synthesis of vernolic acid (cis-12,13-epoxy-cis-9-octadecenoic acid) from linoleic acid, appear to resemble fatty acid desaturases in some respects and may be structurally related to them (Bafor *et al*, 1993). This suggests that PCR-based strategies may be used to clone epoxidase genes from such species for insertion into oilseed rape in order to produce transgenic oilseed rape varieties capable of accumulating commercially useful epoxy fatty acids. At least one laboratory in Sweden is already working along these lines, and it would be surprising if companies or public laboratories in the USA are not doing the same. Although it is unlikely that such cultivars will be produced in the next five years, the rapid rate of progress in the characterisation of plant desaturases encourages the speculation that epoxy oilseed rape oils could be available by the end of the decade.

## WAX ESTERS

Wax esters are relatively uncommon storage compounds in plants, but do make up the major seed reserve in the desert shrub, jojoba. Jojoba wax consists of a C20 or C22 fatty acid esterified to a fatty alcohol of similar chain length. This liquid wax has numerous industrial uses, such as in lubricants and cosmetics. Very-long-chain fatty alcohols are produced from fatty acids in jojoba by a reductase and then esterified to very-long-chain fatty acids by a ligase. The jojoba reductase gene has been cloned at Calgene and it is understood that the ligase gene has also been cloned very recently. The aim is then to transfer these two genes into high-erucic oilseed rape in order to create a transgenic variety capable of accumulating commercially valuable waxes, rather than triacylglycerols, as its seed reserve. It may be necessary to down-regulate enzymes competing for very-long-chain fatty acids (eg acyltransferases) in order to obtain high levels of 'jojoba wax' in oilseed rape, but an informed guess would rate changes of success in this project quite highly with 'jojoba' oilseed rape cultivars possibly becoming available by the end of the decade.

## POLYHYDROXYBUTYRATE

Polyhydroxybutyrate (PHB) and polyhydroxybutyrate/hydroxyvalerate (PHB/V) are polymers produced commercially via fermentation, using the bacterium *Alcaligenes eutrophus*. The product is marketed by Zeneca plc as BIOPOL and is the only thermoplastic derived from renewable resources that is highly durable and yet completely biodegradable. More economic production of PHB might be achieved if it could be produced in plants. To this end, genes encoding the three enzymes of PHB synthesis have been transferred from the bacterium to oilseed rape (Smith *et al*, 1993). Preliminary experiments suggest that very low levels of PHB formation are possible in transgenic plants. Since PHB synthesis uses the same precursor as oil synthesis (ie acetyl-CoA) the two pathways will compete with each other. This can be resolved by using antisense methods for the partial suppression of oil synthesis from acetyl-CoA, hence allowing higher levels of PHB accumulation (Elborough *et al*, 1994).

The ultimate aim is to produce a novel transgenic oilseed rape variety which contains up to 50% of its seed lipid as PHB, but which still contains sufficient storage oil to allow normal seed germination and growth. Very recent biochemical data indicate that it may be more difficult to antisense the acetyl-CoA carboxylase gene than was previously supposed (S Rawsthorne, pers comm, 1994). However, the antisense-mediated down-regulation of genes encoding components of the fatty acid synthetase (FAS) complex may achieve similar results and such a project is now underway in the UK. While this may delay the Zeneca project, it is unlikely to affect its final chances of success, which are reasonable. Nevertheless, this is largely pioneering biotechnology with high risks and large potential rewards so the final outcome remains uncertain at present.

## MOLECULAR FARMING

Molecular farming involves the engineering of oilseeds to supply products such as pharmaceuticals where the tonnages required may be relatively low, but the value of the end product is extremely high. Recent developments make molecular farming highly relevant in considering future options for the development of novel *Brassica* oilseed crops. It has been recognised for some time that plants and, in particular, seeds could potentially be used as bioreactors to produce relatively large amounts of high-value products, including pharmaceutical peptides and industrial enzymes. The problem has always been that it is both difficult and expensive to extract such peptides from the transgenic seeds (Krebbers *et al*, 1993).

Recent developments in Canada offer an ingenious way to circumvent this problem (Moloney, 1993). The high value peptides or proteins are synthesised as fusion products attached to the oleosin proteins which coat seed oil bodies. This means that the fusion products can be purified away from all other soluble proteins by a simple flotation process. The novel peptides or proteins can then be removed from the oil droplets by a straightforward enzymatic cleavage reaction and recovered in virtually pure form. Much developmental work needs to be done, but oilseed rape molecular farming may offer a genuine alternative to conventional microbial fermentation for the production of pure high-value peptides or proteins for a variety of low-volume, high value end uses, ranging from pharmaceutical peptides, such as hirudin or interleukin, to industrial enzymes, such as cellulases, lipases or proteases.

## CONCLUSIONS

In conclusion, the application of biotechnology to *Brassica* oilseed development will have manifold benefits ranging from the enhancing of the speed and efficiency of conventional programmes to the introduction of genes from unrelated species and the production of novel products, such as industrial oils and pharmaceuticals. The considerable investment in research into the genetics and molecular biology of *Arabidopsis thaliana* will be of almost immediate practical benefit to *Brassica* oilseed improvement. This has already been demonstrated by the cloning of most of the major fatty-acid desaturase genes from *Brassica* species using *Arabidopsis* molecular genetics. The availability of effective *Brassica* hybrid systems, some of which are based on biotechnology, will enable seed companies to protect their often considerable investment in the development of novel cultivars. In the broader agricultural context, the application of biotechnology will lead to new crops for farmers to grow, the production of industrial oils from a renewable resource, cheaper production of high value pharmaceuticals and more environmentally sustainable agricultural systems.

It must be emphasised, however, that much of the biotechnological work is still at the laboratory research stage and even the products available already, such as the Calgene transgenic lauric or stearic oilseed rape varieties, require considerable developmental work before they are suitable for marketing. Experience with other products of agricultural biotechnology, such as the Flavr Savr© tomato, shows that the time and financial investment in development normally far exceeds the scientific research costs. Oilseed rape can be manipulated now via either transgenic or non-transgenic routes to produce a variety of seed oil profiles of potential industrial interest, as shown in Figure AIV.2. However, these novel varieties will probably not be suitable for large-scale farming for at least another 3-5 years. By the early years of the next decade it is likely that several transgenic varieties of non-edible oilseed rape will be available commercially. Whether these are developed and marketed in the UK or overseas will depend on the fostering of the UK academic research base and its links with breeders and seed companies, and most importantly, the industrial end users of the oils.

Novel industrial oilseed rape varieties should be an option that is taken up by UK farmers and end users during the next few years. At present, oilseed rape is the most advanced oil crop with regard to its biotechnological development, but this situation may not last. In the USA, DuPont have recently produced a range of transgenic soya bean varieties with altered seed oils (Kinney, 1994). These are currently aimed at edible markets, but industrial markets are also being considered for the future. Also in the USA, several companies have transformed maize and at least one large multinational is developing transgenic maize with industrial grade oils. This means that we cannot be complacent about the present lead held by oilseed rape biotechnology. It also means that it is unlikely that UK-grown industrial oilseed rape oils will compete in the long-term for global bulk markets - soya bean industrial oils will probably win out, at least in the USA. However, this does not rule out the development of oilseed rape products (not only oils) for UK/European bulk markets (eg petroselinic, erucic or PHB oils) or UK/global niche markets (GLA or pharmaceuticals).

**Figure AIV.1**
**Range of useful fatty acids produced by plants**

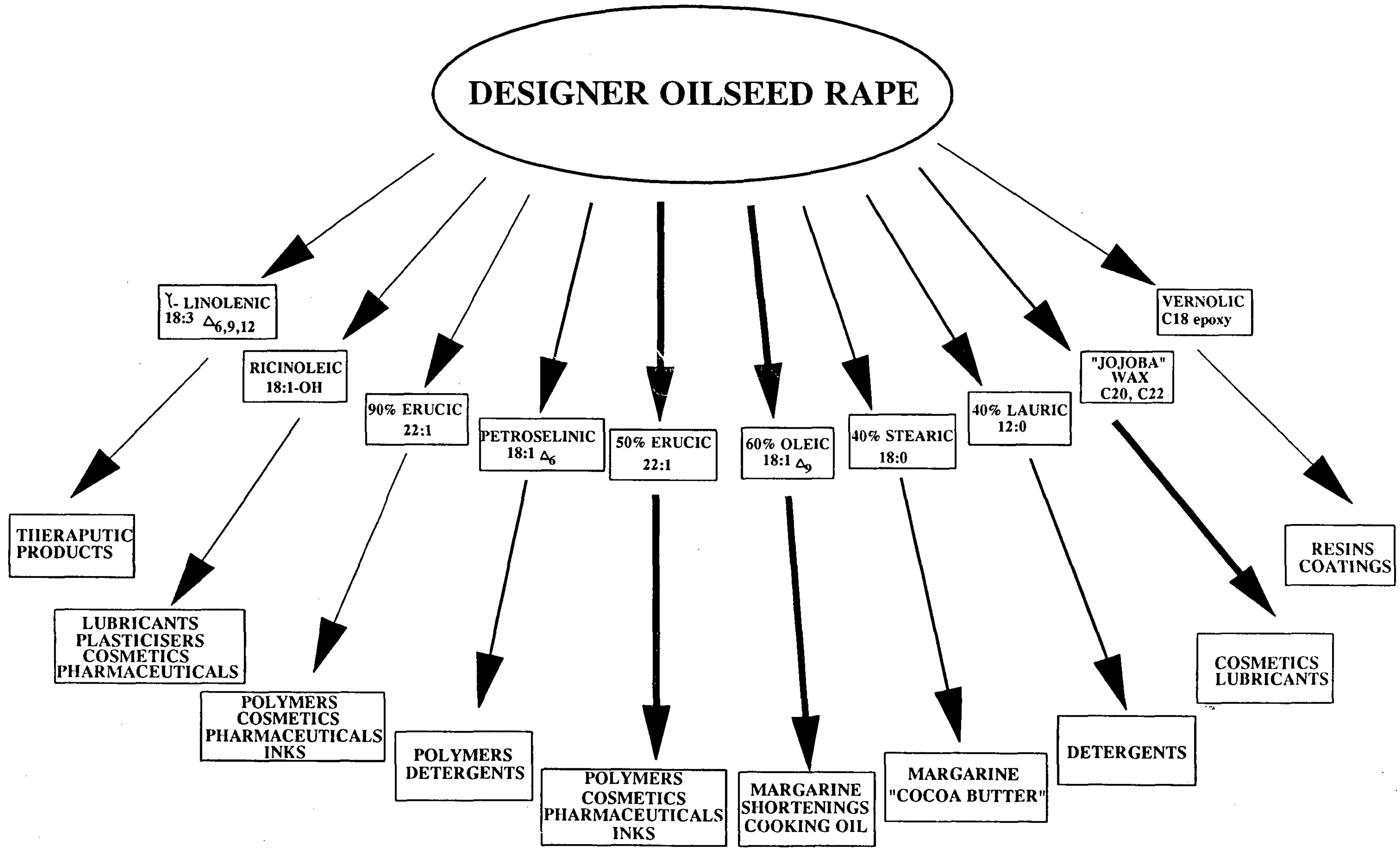
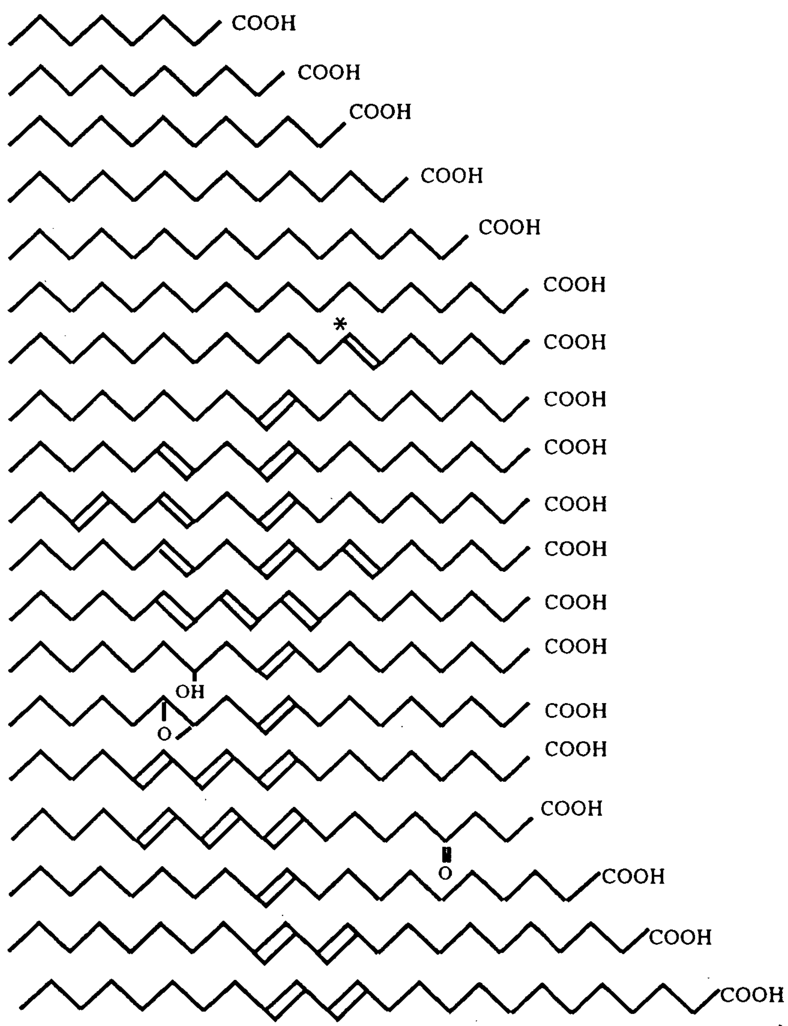


**Table AIV.1**
**Diversity of fatty acid composition ($\%^{w}/_{w}$) in various oilseed species**

| FATTY ACID | | *CUPHEA* SPECIES | | | | PALM | COCOA | OLIVE | CORIANDER | CASTOR-BEAN | SUN-FLOWER | VERNONIA | LINSEED | EVENING PRIMROSE | TUNG | MEADOW FOAM | RAPE SEED | CRAMBE | HONESTY |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Cuphea hookerina* | *Cuphea paucipetala* | *Cuphea laminuligera* | *Cuphea viscocissima* | *Elaris guineensis* | *Theobroma cacao* | *Olea Europea* | *Coriandrum sativum* | *Ricinus communis* | *Helianthus annuus* | *Vernonia anthelmintica* | *Linum usitatissimum* | *Oenothera biennis* | *Aleurites fordii* | *Limnanthes alba* | *Brassica napus* | *Crambe abyssinica* | *Lunaria annua* |
| octanoic | 8:0 | **65.0** | 1.2 | - | 0.5 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| capric | 10:0 | 24.0 | **87.4** | 17.1 | 6.7 | - | - | - | - | - | - | - | - | - | - | - | - | - | - |
| lauric | 12:0 | 0.1 | 2.0 | **62.6** | 7.8 | 0.1 | - | - | - | - | - | - | - | - | - | - | - | - | - |
| myristic | 14:0 | tr | 0.8 | 9.5 | **29.5** | 0.9 | 0.1 | - | 0.2 | - | 0.2 | tr | - | - | - | - | - | 0.1 | - |
| palmitic | 16:0 | - | 1.9 | 2.8 | 25.3 | **45.0** | 26.0 | 10.3 | 3.0 | 1.0 | 6.0 | 2.0 | 6.1 | 7.0 | 3.1 | 0.3 | 3.5 | 1.7 | 4.0 |
| stearic | 18:0 | - | - | 0.2 | 1.2 | 4.5 | **34.4** | 2.3 | 0.5 | 1.0 | 5.6 | 1.0 | 3.2 | 2.0 | 2.1 | 0.5 | 1.2 | tr | 2.0 |
| oleic | 18:1 $\Delta_9$ | - | 1.8 | 2.0 | 14.0 | 39.5 | 34.8 | **78.1** | 5.9 | 3.0 | 17.8 | 2.0 | 16.6 | 9.0 | 11.2 | 1.4 | 14.2 | 16.7 | 18.0 |
| petroselinic | 18:1 $\Delta_6$ | - | - | - | - | - | - | - | **75.3** | - | - | - | - | - | - | - | - | - | - |
| ricinoleic | 18:1-OH | - | - | - | - | - | - | - | - | **90.0** | - | - | - | - | - | - | - | - | - |
| linoleic | 18:2 $\Delta_{9,12}$ | - | 4.0 | 3.5 | 14.4 | 9.6 | 3.0 | 7.3 | 13.3 | 4.0 | **68.7** | 9.0 | 14.2 | 72.0 | 14.6 | 2.9 | 13.8 | 7.8 | 2.0 |
| vernoleic | 18:2 $\Delta_{12,13}$ | - | - | - | - | - | - | - | - | - | - | **79.5** | - | - | - | - | - | - | - |
| α-linolenic | 18:3 $\Delta_{9,12,15}$ | - | - | - | 0.7 | 0.1 | 0.2 | 0.6 | - | tr | 0.2 | 0.5 | **59.8** | - | - | - | 9.1 | 6.9 | - |
| γ-linolenic | 18:3 $\Delta_{6,9,12}$ | - | - | - | - | - | - | - | - | - | - | - | - | **10.0** | - | - | - | - | - |
| α-eleostearic | 18:3 $\Delta_{9,11,13}$ | - | - | - | - | - | - | - | - | - | - | - | - | - | **69.0** | - | - | - | - |
| $\Delta_5$eicosenoic | 20:1 $\Delta_5$ | - | - | - | - | - | - | - | - | - | - | - | - | - | - | **66.6** | - | - | - |
| gondoic | 20:1 $\Delta_{11}$ | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | **10.9** | 2.9 | |
| erucic | 22:1 $\Delta_{13}$ | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 10.2 | 46.9 | **55.7** | 48.0 |
| nervonic | 24:1 $\Delta_{15}$ | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | - | 2.9 | **24.0** |

**Figure AIV.2**
**Seed oil profiles from 'designer' oilseed rape**

STRUCTURE




| NAME | LENGTH (No. Carbon Atoms) | PRESENT SOURCE | MAJOR USES |
|---|---|---|---|
| octanoic acid | 8 | *Cuphea hookerina* | Fuel, detergents |
| capric acid | 10 | *Cuphea paucipetala* | Fuel, detergents |
| lauric acid | 12 | California bay | Detergents |
| myristic acid | 14 | Nutmeg, Coconut | Detergents, soaps, food |
| palmitic acid | 16 | Oil palm | Food |
| stearic acid | 18 | Cocoa | Food |
| petroselinic acid | 18 | Coriander, carrot | Plastics, detergents |
| oleic acid | 18 | Olive, rapeseed | Food, resins, adhesives |
| linoleic acid | 18 | Sunflower, maize | Food, paints |
| α-linolenic acid | 18 | Linseed | Paints, varnishes, linoleum |
| γ-linolenic acid | 18 | Evening primrose | Pharmaceuticals |
| calendic acid | 18 | *Calendula officinalis* | Perfumes, lubricants, nylons |
| ricinoleic acid | 18 | Castor bean | Dyes, greases |
| vernolic acid | 18 | *Vernonia anthelmintica* | Epoxy resins |
| α-eleostearic acid | 18 | Tung | Enamels, varnishes |
| α-licanic acid | 18 | Octicica | Paints, inks, enamels |
| $\Delta_5$ eicosenoic acid | 20 | Meadowfoam | Lubricants |
| erucic acid | 22 | Mustard | Lubricants, perfumes cosmetics, nylons |
| nervonic acid | 24 | Honesty | Lubricants |

*Note that all double bonds are cis conformers, although they have been drawn as trans in order to save space.

# Appendix V: Persons and organisations consulted

D A Boreham, Plant Variety Rights Office and Seeds Division, MAFF, Cambridge
Dr C Boyce, Technical Director, British Society of Plant Breeders, Ely
Dr J Casey, Unilever Research, Colworth Laboratory, Biosciences Division, Sharnbrook
Dr P A Fentem, Zeneca Plant Science, Jealotts Hill Research Station, Bracknell
Professor F D Gunstone, Lipid Chemistry Unit, School of Chemistry, University of St Andrews
Dr B R T Keene, Mid-Kent College of Higher and Further Education, Chatham
S P J Kightley, National Institute of Agricultural Botany
R C Lowson, Head of Agricultural Inputs, Plant Protection and Emergencies Group, MAFF, London
Dr S Rawsthorne, Department of Brassica and Oilseeds Research, John Innes Centre
Dr K C Walker, Scottish Agricultural College (SAC), Aberdeen

ADAS, Wolverhampton
Allbright & Wilson Ltd, Oldbury
British Coatings Federation, London
British Lubricants Federation,
Cambridge Plant Breeders Ltd, Royston
Coates Lorilleux Ltd, St Mary Cray
EI Research, Newcastle
Henkel KGaA, Dusseldorf
ICI Paints, Slough
Interagro Ltd, Bishop's Stortford
John K King & Sons, Coggeshall
Lubrizol International Laboratories, Belper
Lubrizol Ltd, Richmond-upon-Thames
Maribo UK Ltd, Lincoln
Microcide Ltd, Bury St Edmonds
Ministry of Agriculture, Fisheries and Food, Agricultural Inputs, Plant Protection and Emergencies Group, London
Nickersons Biocem Centre, Cambridge
Nickerson Seeds Ltd, Joseph Nickerson Research Centre, Lincoln
PIRA International, Leatherhead
PBI Cambridge, Cambridge
Procter & Gamble, Newcastle
John L Seaton & Co Ltd, Hull
Seed Crushers & Oil Processors Association, London
Semundo Ltd, Cambridge
Shakel Edwards & Co, Leatherhead
Shell Chemicals UK Ltd, Chester
Silkolene Lubricants Plc, Belper
Smallman Lubricants Ltd, Dudley
Societe Robbe, Compiegne

Sun Chemicals Ltd, Slough
Unilever Research, Colworth Laboratory, Sharnbrook
Unilever Research, Port Sunlight Laboratory, Wirral
United Oilseeds Marketing Ltd, Devizes
Vitafoods Ltd, Birkenhead
Zeneca Seeds, Jealott's Hill Research Station, Bracknell
Zeneca Seeds, Kings Lynn