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The Future of New and Genetically Modified Oil Crops

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Oil crops are one of the most valuable traded agricultural commodities and are probably worth over $100 billion/yr. The current volume of traded vegetable oils is over 70 Mt per year and is predicted to increased to over 100 Mt per year by the year 2010 (Murphy 1996). This is probably a considerable underestimate of the total volume of oil production since, particularly in developing countries, most vegetable oils are consumed locally, rather than entering into trading networks. Despite the large volume of globally traded vegetable oil, only four major crops, soybean, oil palm, rapeseed, and sunflower contribute about 75% of this production. The domination of the oilseed market by the "big four" oil crops is set to continue for the foreseeable future. Indeed, the establishment of new plantations in South East Asia is predicted to double oil palm production in the next 15 years, making it, by then, the most important source of vegetable oils in the world.

The vast majority of vegetable oils are currently used for edible commodities, such as margarines, cooking oils, and processed foods. Only about 15% of production goes towards the manufacture of oleochemicals, i.e. industrial products derived from oil crops. Over the next few decades two important factors will contribute to an expansion in the markets for both edible and industrial oil crops. Firstly, according to current demographic trends, the global human population will at least double before stabilizing at some time in the mid 21st century. This, coupled with rising levels of affluence in many developing countries, will lead to increased demands for both raw and refined edible oil products. Secondly, it is well known that global hydrocarbon reserves are a non-renewable resource. The most recent estimates from six different national and international agencies predict that world oil production from petroleum reserves will peak at some time between the years 2000 and 2020, and will decline thereafter (Kerr 1998). In addition to being an important source of energy, e.g. electricity generation and vehicle fuel, petroleum is also the source of a huge range of petrochemicals. These petrochemicals are the raw materials for products such as plastics, textiles, lubricants, paints, varnishes. Once non-renewable hydrocarbon resources such as petroleum and coal are exhausted, there will be no other source of such products, other than oleochemicals derived from oil crops.

The challenge for researchers in the coming years will be to produce oil crops with higher yields to satisfy increased demands and also to increase the spectrum of useful products, whether for edible or industrial use, that can be derived from these crops. To date, the vast majority of research and development activities has focused on improving existing crops and most notably the "big four" oil crops as above. More recently, there has been considerable interest in using recombinant DNA technology to transfer genes from other oil-producing species into the major oil crops, in order to extend the range of fatty acids produced by such crops. Until now, relatively little effort has gone into the domestication of completely new oil-producing species. Partly, this has been due to the considerable agronomic problems faced in adapting a wild or semi-wild species for large scale agricultural production. Nevertheless, recent advances in plant science, which have been considerably assisted by technical developments related to the biotechnology industry, now make it a realistic option to consider domestication as an alternative to transgenic technology, in order to produce novel oils for future generations (Murphy 1998).

POTENTIAL AND LIMITATIONS OF TRANSGENIC TECHNOLOGY

The manipulation of seed oil content via transgene insertion has been one of the earliest successful applications of modern biotechnology in agriculture. For example, the first transgenic crop with a modified seed composition to be approved for unrestricted commercial cultivation in the US was a lauric oil, rapeseed, grown in 1995 (Murphy 1996). Many of the major agricultural companies have considerable investments in transgene technology, particularly as applied to oil crops. One of the major drivers for such investment was a perception that oil quality is a relatively plastic phenotype and that substantial changes could be effected by the insertion of one or two key genes. In addition, one of the major oil crops, rapeseed, turned out to be particularly amenable to tissue culture and regeneration and could therefore be transformed relatively easily. More recently, soybean transformation has also become relatively routine (at least within companies) albeit much more labor intensive than rapeseed transformation (Krebbers et al. 1997). There were also some significant early successes, mostly notably the achievement of 40% to 60% lauric content in rapeseed oil, which normally accumulates little or no lauric acid (Murphy, 1996). Nevertheless, attempts to achieve high levels of other novel fatty acids in seed oils have met with much less success and there have been several reports that the presence of novel fatty acids in transgenic plants can sometimes lead to the induction of catabolic pathways which break down the novel fatty acid, i.e. the plant recognizes the "strange" fatty acid and, far from tolerating it, may even actively eliminate it from the seed oil (Ecclestone and Ohlrogge 1998; Murphy et al. 1999).

During the past two years there has also been an increasing recognition that the metabolic pathways involved in seed oil biosynthesis are considerably more complex than was first appreciated. For example, several new enzymes have been discovered which may be involved in remodeling oil, even after it has been deposited into storage oil bodies (Stobart et al. 1997; Mancha and Stymne 1997). It has proved extremely difficult to achieve the high levels (70 to 90%) of a particular fatty acid in the seed oil that is often important for its commercial viability. One of the key problems faced in the production of novel fatty acids in transgenic plants is that the major oil crops, such as rapeseed, may lack mechanisms which are able to channel such fatty acids towards storage oil and away from accumulation in membrane lipids. It is likely that the presence of even relatively small amounts of certain unusual fatty acids in membrane lipids could cause serious disruption to important cellular processes. It is possible that such plants seek to avoid these problems by identifying and breaking down novel fatty acids, such as petroselinic acid as has recently been shown in our laboratory (Murphy et al. 1999).

In addition to the technical problems associated with producing novel oils in transgenic crops, it has recently been pointed out that there are considerable challenges involved in the management of such crops (Murphy 1999). For example, at present there are at least 10 to 20 different transgenic cultivars of rapeseed at various stages of development, both in the laboratory and in field trials. All of these cultivars appear identical and the only differences are in their seed oil compositions. It is these different seed oil profiles that determines that one cultivar may be used for detergent manufacture, while other cultivars may be used for margarines, cosmetics, therapeutic agents, or lubricants. Clearly, the segregation and identity preservation of such mutually incompatible commodity streams raises formidable challenges at all levels of production, ranging from sowing, harvesting, storage, crushing, and processing. The expensive and sophisticated analytical equipment required to differentiate between the different transgenic cultivars will not be available to all growers, crushers or processors and therefore there is serious potential for mixing and cross-contamination of different seed lots.

In many countries, particularly in Europe, there is also a considerable consumer resistance to the cultivation of genetically modified crops for food use. For example, France has already imposed a three year moratorium on the release of genetically modified crops and the UK is considering a similar moratorium at present. Although this situation may well change with better public education about genetic research and with more thorough risk assessment programs, consumer resistance is likely to be an important factor which may limit the application of transgene technology in the near future.

A final argument against an ever increasing reliance on a very small number of major crops is the concern that such large scale monocultures may be more prone to opportunistic infection by pests and diseases, as well as reducing biodiversity at the farm level. It is official policy of the European Union to encourage greater crop diversity and therefore to favor the introduction of new crops rather than the continued increase in cultivation of existing major crop species.

DOMESTICATION OF NEW CROP SPECIES

All of our existing major crop species have been through a continual process of domestication and improvement since the beginnings of agriculture more than ten thousand years ago. However, research aimed at the domestication of new species rarely finds favor with the agribusiness industry or with Government funding agencies. The process of domestication is perceived to be extremely slow. It is also obviously limited by the climatic range of the candidate crop. For example, some potential novel oil crops are found in tropical regions and therefore are unlikely ever to be domesticated for cultivation in temperate regions. Nevertheless, given the extraordinary diversity of seed oil contents found in the natural world, it is likely that a species producing useful quantities of a particular seed oil can be found in several different climatic zones. Another problem is that the novel crops may have a different growth habit to existing crops and may therefore not be suitable for harvesting using existing equipment. These problems are added to the, often serious, agronomic difficulties exhibited by many candidate oilseed plants. Nevertheless, we should not be discouraged by such challenges. The application of modern biotechnological methods such as genome mapping and molecular marker assisted selection, now make it feasible to consider domestication of such species within one or two decades (Martin 1998; Murphy 1998). This time horizon is well within the normal development lifetime of most new pharmaceutical products or large civil engineering projects.

There are many agronomic problems faced by new oil crops. Among the most common of these are asynchronous flowering, premature pod shattering, allogamy, low seed oil content, poor germination rates, and low seed yield. Until recently, the solution to such problems was to look for natural variation, e.g. reduced pod shattering or increased oil yield and to attempt to produce reasonably defined lines in which these characters were well expressed. The production of more uniform inbred lines has been assisted by techniques such as double haploids and by the development molecular maps for at least some of the major species. In the future, new kinds of molecular markers, such as microsatellites, promise to make the process of producing a detailed genetic map for any species much more rapid and much less expensive than in the past.

The recent advances in genomics and in gene function studies has allowed us to understand the detailed genetic basis of many complex traits, such as flowering time, height, and disease resistance (Murphy 1998). Many of these complex traits had been regarded as being controlled by large numbers of genes, which made them difficult to manipulate by simple Mendelian genetics. However, there are now several striking examples where the vast majority of the variation underlying such complex characters has been mapped to only a very small number of quantitative trait loci (QTL) (Doebley 1993; Martin 1998). Once such genes have been mapped in a model species such as *Arabidopsis*, techniques such as positional cloning can be used to isolate the gene of interest and to verify its function in the laboratory. Within the next few years, more and more important agronomic traits will be explicable in terms of a relatively small number of key genes which account for most of the observed variation. Such information can then be used for the selection of plants expressing such genes. For example, in our own laboratories we are currently studying genes regulating characters such as pod shattering, oil yield, oil quality, flowering and canopy architecture. Such research has the potential to provide tools for the much more rapid domestication of new oil crops within the next few years.

CONCLUSIONS

It is likely that, in the future, transgenic oil crops and newly domesticated oil crops will both be developed in order to provide the increased amount and diversity of oils which will be required for both edible and industrial use. It is important that we recognize that both approaches have both positive and negative points. It will be a combination of these two strategies that is most likely to supply the increasing demands for plant oils in the 21st century and beyond.

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