Biotechnology and the Fats and Oils Industry - An Overview

JAMES B. M. RATTRAY, Department of Chemistry and Biochemistry, University of Guelph, Guelph, Ontario, Canada N1G 2W1

ABSTRACT

Biotechnology is the application of single or multicellular organisms and of associated or derived enzyme systems to the production of desirable products. Particular discussion has been made of the derivation of fats and oils from animals, plants and microorganisms. General consideration has been given to methods, primarily plant breeding and agronomic practices for the improvement of the quantity and quality of oil produced by soybean, rapeseed, palm and sunflower. The possible importance of yeasts, fungi and algae as sources of single cell oil has been examined. A particular role of these systems in the production of specialty oils has been suggested. Enzyme systems, either associated with the intact cell or in isolation, can be used to varying degrees of success in either a free or immobilized form. Particular reference has been made to application of these systems to reactions including specific hydrolysis of triacylglycerols, acylation of glycerol, interesterification of triacylglycerols, wax ester formation and steroid transformations. Consideration has been given to particular plants and microorganisms as sources of new fats and oils. The major impact of biotechnology on the industry is believed to be associated with the production of high value specialty products including cocoa butter substitutes, biosurfactants, waxes and various prostaglandin derivatives. General consideration has been given to the possible relative importance of plant and microbial systems, engineering and scale-up problems, and overall economics of present biotechnological procedures.

INTRODUCTION

Definitions and concepts of biotechnology are many and varied, and reflect the particular view of the specialist. Thus biotechnology has been considered to be "the integrated use of biochemistry, microbiology and chemical engineering in order to achieve the technological application of the capacities of microbes and cultured tissue cells." Such a definition consequently excludes agriculture and medical technology, and emphasizes the application of microorganisms (1). A broader concept of biotechnology is based upon the unique characteristics of biological materials such as microbial, plant or animal cells and enzymes, and is the utilization of them or their components to provide goods or services (2). Although biotechnology is generally considered to be a new technology, many of its practices are based upon old technology. The modern biotechnologist simply builds on the old technology with newer ideas and techniques. The impact of the new biotechnology on the production of a wide variety of consumer goods - foods, pharmaceuticals, renewable fuel sources, chemical feedstocks, etc. - has yet to be fully realized. Potential applications of the new biotechnology in the area of fats, oils and derivatives are summarized in Figure 1.

Different fats and oils have been used by man since earliest times for a variety of purposes. The need for greater and better production initially required improvements in animal husbandry, agronomic practices and fermentation procedures. These changes mainly evolved without any profound scientific consideration until more recent times. Considered improvements in these general areas of old technology are continuing and are necessary adjuncts to the newer practices of modern biotechnology. The old technology generally employs the whole organism, whether animal, plant or microorganism. Applications of single cells from animals and plants, as well as microorganisms, and the use of isolated enzyme systems, are associated with the new technology (see Fig. 2). Particular advances in biotechnology involving specific cell selection, growth practices, genetic engineering and enzyme applications can be anticipated. Thus biotechnology in the forms of old and new technologies is now available. Its particular relevance to the fats and oils industry is the timely topic for consideration.

PARTICULAR FATS AND OILS

Animal Fats

Dairy fats, and generally inedible lard, tallow and animal greases, are projected to constitute a smaller proportion of the total annual production of oils and fats at the beginning of the 21st century (3). Nonetheless, the actual needs have been projected to increase by approximately 40% above current production. Increased dairy fat can be predicted from selected cattle breeding and improved animal husbandry. It has been suggested that the increased demands for tallow could be met from growing genetically obese rats on (low cost) garbage (4). Fish oils, either for human nutrition or industrial purposes, will continue to be obtained by
TABLE I
The Oil Content and Areas of Desired Improvement for Four Major Oil-Bearing Plants

<table>
<thead>
<tr>
<th>Crop</th>
<th>Oil content b (wt, %)</th>
<th>Areas of desired improvement</th>
<th>Plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soybean</td>
<td>18-20</td>
<td>Increased productivity, b Decrease in linolenic acid, d</td>
<td>Local adapted varieties.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Regulation of oleic acid desaturation and triacylglycerol synthesis.</td>
<td>Photo-period, high-yielding cultivars.</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>40-45</td>
<td>Decrease in linolenic acid. c Increase in linoleic acid. c</td>
<td>Winter varieties. Disease and triazine resistance.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Increase in erucic acid. d Decrease in chlorophyll and glucosinolate contamination.</td>
<td></td>
</tr>
</tbody>
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aReference 6. bNot to be obtained at the expense of decrease in protein. cLEAR. dHEAR.

conventional methods. The practice of aquaculture, however, may assume greater significance and will involve selective fish breeding. It is possible that certain fish may be specifically reared for their oil content. A market has not yet been established for the significant quantity of oil by-product obtained during the processing of farm-raised catfish (5).

**Plant Fats and Oils**

The bulk of fats and oils, whether for human consumption or industrial usage, presently is derived from plant sources (6). Nonetheless, definite requirements exist for greater yields, better qualities and products of highly specialized chemical composition. Thus improvements are being made, not only with conventional crops, but also with selected plant species which have an ability to produce unique, desirable fats and oils (7). Some areas of desired upgrading of 4 major oil-producing plants are given in Table I.

Improvements in the quantity and quality of plant seed oils have been associated primarily with agronomic practices and plant breeding programs. Development of improved varieties was based initially on trial and error, but more recently on crossing, polyploidy or mutations (8). Application of the newer technology of tissue culture has tremendous potential for crop improvement and the development of unique germplasm (9). Methods for in vitro selection of such agriculturally valuable traits as disease resistance and stress tolerance have been found useful but limited in their applicability to certain species (10).

Manipulation of crop plants by genetic engineering so far has been limited (11,12). Use of the general procedures of genetic transformation and somatic hybridization shows promise (13), but will complement rather than replace conventional breeding procedures. Protoplast fusion methods can permit gene transfer between plants which cannot be crossed sexually (14). Thus, more effective resistance of plants to disease may be achieved. Despite the high potential of genetic engineering to crop improvement, the desired result frequently may be complicated by a variety of responses of plants to different environmental stresses (15).

Biotransformations by plant cell cultures have been considered for the production of secondary metabolites including steroids and terpenoids (16). Isolated suspension cultures or callus cultures of many plant species have proved useful in basic and applied research particularly on fats, oils and allied compounds (17). Further developments in the applications of immobilized plant cells can be fully anticipated (18-20). Large-scale production of shikonin in Japan and biotransformation of low value digitoxin to the important high value cardiacian digoxin are now industrial realities (21).

Consideration has been given to the problems, both economic and engineering, associated with industrial scale-up of plant culture systems (22,23).

**Soybean oil.** Soybean oil continues to be the major edible oil used in the U.S. and throughout the world (3,6). The mature soybean has approximately 20% oil (24). In addition to improved yields, problems still exist with the oil quality (24). A particular factor is the relatively high content of linolenic acid (5-18% of the total fatty acid component), which has been associated with the oil's poor flavor stability and the generation of room odors. Several biotechnological approaches have been made in an attempt to solve this problem without having to resort to the cost-intensive industrial practice of hydrogenation of the linolenic acid. Application of recurrent selection methodology has resulted in new soybean genotypes which possess reduced contents of both linolenic and linoleic acids (25). Variations in the polyunsaturated fatty acid component, however, depend on the period (25) and ambient temperature (26) of seed development. Increased oil production with lower linolenic acid content occurs under warmer conditions (26). A com-