Journal of the Minnesota Academy of Science

Volume 53 | Number 1 Article 14

1987

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Introduction

Fundamental discoveries in molecular biology within the past 30 years have initiated a biological revolution, which will have a profound effect on industry, government, and academic institutions. To date, the major industrial focus of this technology has been its use in the development of human healthcare-related products, such as human growth hormone, insulin, interferons, and interleukins, which can now be mass-produced by genetically engineered microorganisms. However, the potential for genetically engineering plant, animal, and microbial cells with desirable structural, functional or chemical properties, offers an exciting new dimension for biotechnological input into the production and processing of foods. This paper will focus on the potential role of biotechnology in altering agriculture and the nature of foods.

Plant Biotechnology

Traditional plant breeding techniques have been used for centuries to improve agronomically important plants. These improved varieties have been responsible for the almost 300% increase in farm productivity within the last five decades (1). The primary limitations to even the most advanced breeding techniques are the limited genetic diversity of available plant varieties, and the time required to develop a desired strain. The application of biotechnology to plants can markedly shorten the time needed for crop improvement, since theoretically, the alteration of genes can be accomplished in the equivalent of one generation. In addition, plant tissue culture techniques provide mechanisms for generating novel genetic variation, which can be transmitted through seed in a predictable manner (2).

Tissue culture techniques have been used for micropropagation of numerous plant species. Clonal propagation provides potential for the large-scale production of genetic carbon copies of superior genetic varieties for commercial use. Examples of crops propagated commercially by tissue culture include disease-resistant asparagus and higher yielding strawberry and oil palm. An area of future technology is the development of artificial seeds through encapsulation of clonally propagated embryos in a biopolymer. Unlike conventional seeds, these embryos offer uniform genetic traits and maturation times (3).

Regeneration of plants from undifferentiated plant cells (callus tissue) allows recovery of mutant plant varieties. This is called somoclonal variation and has been used to select disease-resistant breeding lines of potato, rice, and wheat; herbicide- and insecticide-tolerant tobacco and corn; and more nutritious varieties of corn (3).

Tissue culture technology has also been used to develop fresh market products geared to the consumer. Vegisnax@ snacking vegetables offer the consumer celery without strings and crisper, sweeter carrots, a new alternative to sweet or salty snacks. This technology also offers the potential to custom design raw commodities, such as corn, wheat, tomatoes, or vegetable oils, that possess predetermined functional or processing characteristics. For example, bioengineered varieties of tomatoes with higher than average solids content could significantly reduce overall processings (4). For every 1 percent increase in tomato solids, the tomato processing industry could save $80 million per year in reduced raw product volumes, transportation costs, and processing energy costs (5).

An emerging area of interest to the food industry is the use of plant tissue culture for production of high value additives normally extracted from whole plants (6). In certain cases, undifferentiated callus tissue can be transferred to broth media, where individual plant cells are capable of proliferating and producing secondary metabolites such as flavors and colors. This technology is currently being used for the production of shikonin, a purple pigment used in Japan as a dye and pharmaceutical (7), and thaumatin, a sweetener 2500 times as sweet as sucrose. Production of "natural" flavors such as vanilla, cocoa, strawberry and other berry flavors, pineapple, citrus, and banana by tissue culture would provide an inexpensive alternative to extraction of these components from whole plants. In addition to the desirable "natural" status of these ingredients, the quality, availability, and processing consistency would be controlled by the processor (8).

Animal Biotechnology

Farmers, discouraged by rising farm production costs and decreasing farm income, are turning to biotechnology to improve the profitability of animal agriculture. The ability to extract, split, and implant embryos into surrogate mothers will allow for the amplification of genetically superior animals for meat and milk production. In the future, it will be possible to genetically manipulate embryos to produce animals that are larger, more efficient in converting feed into lean meat, and more resistant to disease.

The gene for bovine somatotropin (growth hormone) has been isolated and cloned into microorganisms, which are capable of producing large quantities of the hormone.

When injected, bovine growth hormone has been shown to increase milk production and feed efficiency, accelerate the growth rate, and alter carcass composition (9). Future studies will involve cloning the gene directly into the germ line so the capability can be stably transmitted to subsequent generations.

Biotechnology is being used to develop safe and effective vaccines to prevent losses due to animal death and disease. A monoclonal antibody vaccine for the treatment of neonatal calf scours is available (10); a subunit vaccine for swine pseudorabies, and a vaccine for foot and mouth disease, are currently being evaluated in clinical trials. Diagnostic kits incorporating DNA probes and monoclonal antibodies are being developed for more than 25 animal diseases and will allow rapid detection and containment of infectious diseases (11). All of these biotechnological applications will have a profound impact on efficiency and profitability in animal agriculture.

Food Processing Biotechnology

Biotechnology is not new to the food industry. Microorganisms have been employed for the production of fermented foods and beverages, such as cheese, yogurt, sausage, bread, wine, and beer, for thousands of years. Genetic engineering is being applied to the bacteria, yeast, and fungi used in food fermentations to "tailor-make" starter cultures for specific purposes. Examples include the development of dairy streptococci that are capable of metabolizing cholesterol, resisting bacteriophage disruption, accelerating the ripening of cheese, and producing natural antibiotics to inhibit spoilage organisms and extend the shelf life of fermented dairy products (12). The brewing industry is currently engineering yeast strains capable of metabolizing more of the malt carbohydrate to ethanol for the production of "lite" (low calorie) beer (13).

Microorganisms are currently employed to produce a host of ingredients, nutritive additives, and processing aids for the food processing industry. These include amino acids, vitamins, nucleotide flavor enhancers (MSG), acidulants, aroma compounds, pigments, noncaloric sweeteners, stabilizers and thickening agents, and enzymes. Because food-grade microorganisms are generally recognized as safe for human consumption by the U.S. Food and Drug Administration, there is a great deal of interest in engineering these organisms to produce additional compounds of interest to the food processing industry, including the sweet-tasting plant protein, thaumatin (14), polysaccharides with unique rheological properties (15), and low-calorie fats and oils (16).

The food processing industry is the largest consumer of industrial enzymes, composing about 40% of the market (17). Microorganisms produce most of the enzymes that are added during food processing to control texture or appearance, enhance nutritive value, and generate desirable flavors and aromas. By introducing changes in the primary structure of an enzyme using site-specific mutagenesis, it is now possible to engineer enzymes that are more stable and active in commercial food processing systems. In addition, the techniques of protein engineering will one day be used for modifying the properties of traditional food proteins to improve the quality, consistency, and functionality of raw agricultural commodities used in processed foods (18).

Food Safety

Ensuring the quality and safety of our food supply is a major concern of the food processing industry and government regulatory agencies. The ability to monitor foods for microbial contamination has become critically important with the demonstration that food products can serve as the vehicle of transmission for a number of emerging pathogens. Detection, identification, and enumeration systems based on monoclonal antibodies and DNA probes have been developed for several emerging pathogens including *Listeria monocytogenes, Salmonella typhimurium, Yersinia enterocolitica, Campylobacter jejuni,* enteropathogenic *Escherichia coli,* and *Clostridium perfringens* (19). Monoclonal antibodies can also be used for the detection of nonmicrobial contaminants of foods, including toxins and pesticide residues. These rapid, sensitive, and selective biosensor systems will provide powerful tools for ensuring the wholesomeness and safety of the food supply.

Waste Management and Value-Added Technology

Environmental concerns and economic issues necessitate better utilization of raw materials and reduction of waste generated by the food processing industry. The food industry must develop innovative methods for using the cellulosic material (skins, peels, leaves, stalk, vines, shells, and pits) from vegetable and fruit processing; the fat, collagen, blood, and bone from meat processing; and the whey generated during cheese manufacture.

In the manufacture of cheddar cheese, for every 10 pounds of milk, the cheesemaker obtains 1 pound of cheese and 9 pounds of whey. In 1983, 4.82 billion pounds of cheese were produced in the United States, and while a number of uses exist for whey, the cost of disposing of greater than 40 billion pounds of whey is staggering. Innovative methods of whey utilization have been developed, and include the use of ultrafiltered whey as feedstock for the production of L-ascorbic acid, a high value food additive. It can also be used for the production of biofuels such as ethanol and methane, and for the production of single-cell protein and baker's yeast (20). In the future it may be possible to use waste streams from the food processing industry for the production of vaccines, therapeutic drugs, and other high value pharmaceutical products (21).

Expanded Use of Surplus Agricultural Products

American agriculture has made remarkable progress in increasing total agricultural production and efficiency. However, the processing and marketing sector of the agricultural system has not experienced a parallel increase in productivity. Decreasing domestic and foreign demand, coupled with increased competition for markets in world trade for raw agricultural commodities, has resulted in large agricultural surpluses. Biotechnology and new techniques in material science offer the potential for new food and nonfood uses of agricultural products. Surplus agricultural commodities could be used for the production of biofuels, specialty chemicals, and unique biomaterials. As fossil fuels and petroleum reserves are depleted, the renewable nature of agricultural materials will become even more significant. A fundamental understanding of the physical, chemical, and biological properties of agricultural products will facilitate their use for a host of new food and nonfood related products.

Conclusion

Biotechnology will have a profound effect on agriculture and the food processing industry. Emerging technologies provide the potential for custom design of agricultural plants and animals with predetermined structural, functional, chemical, and nutritional properties. Emerging technologies create exciting opportunities for the food processing industry in more efficient use of raw materials, new product development and differentiation, cost reduction, and creation of novel processing methods.

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