The Future of Food and Agricultural Biotechnology

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Summary. The use of food and agricultural biotechnology will play an important role in world affairs as the world population continues to grow, as the quality of the environment becomes a more pressing world issue, and as the expectation of all consumers for better and safer foods continues to grow. Biotechnology will play a major role in providing many of the answers to questions concerning production and safety, since it can provide techniques that will impact on the quality, the productivity, and the processing of crops, and the safety of food products. Biotechnology practices in agriculture will also safeguard our environment by reducing the contamination of our soil, water, and air. Thus the benefits of biotechnology make it an important tool for fulfilling our over-all expectations for a healthier life. This paper will briefly summarize some of the current activities and concepts in the area of agricultural and food biotechnology.

General Benefits of Food and Agricultural Biotechnology

Some of the practices of the new biotechnology will benefit consumers and producers alike and can be summarized as follows:

1. There will be less dependence on the use of agricultural chemicals. Foods will be less contaminated with chemicals and therefore safer for consumption. The use of chemical pesticides will be reduced as crops that are naturally resistant to pests are developed. The use of biodegradable herbicides and herbicide resistant plants will allow a lower level usage of chemical herbicides. This will reduce chemical contamination of water and soil.
2. The quality of crops will be improved for their nutritional value and their products will also be of benefit for dietary reasons. For instance the vitamin content can be increased or the lipid content can be decreased.
3. The improvements in agronomic qualities of plants will improve food production and processing. Crops may produce more products with less

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water and over a shorter growing season. Marginal farm lands will be more productive.

4. New and improved products will be developed which will open up new markets. For instance, plants producing different types of fatty acids and lipids will allow the development of new products with different fat properties.
5. Biotechnology should profit both the consumers and producers. Higher quality foods should result in better nutrition, health, and environment for the consumers. The producers will benefit from cost effective properties of the product, e.g. longer shelf-life of market crops, increased stability of the product prior to processing, controlled ripening.

New Technology Used for Improvement of Agriculture

The progress that is being made involves a number of new techniques developed in the last 10-15 years. These are listed in Table 1. These new technologies are bringing about a revolution in agriculture and food production. These technologies will result in products that will not be perceived by the public as necessarily being a new or novel product, since one cannot distinguish a biotechnology produced tomato or potato from a traditionally derived products. This is particularly true if the tomato is made into a paste or if the potato is eaten in a mashed or fried form. Frost resistant strawberries will not look or taste differently from the ordinary strawberry. Herbicide and pesticide resistant crops will look the same to the consumer. Although there is some controversy about the use of the new biotechnology for production of foods, it is highly likely that this new technology will result in great benefits for

Table 1. New Techniques for Agricultural Improvements.
Tabuľka 1. Nové techniky pre zdokonaľovanie v poľnohospodárstve.

Genetic engineering/recombinant DNA technology
Gene transfer between microbes, plants and animals
Polymerase chain reaction (PCR technology)
Restriction fragment length polymorphism (RFLP)
Anti-sense RNA technology
Animal and plant cell culturing
Plant tissue culturing and regeneration
Animal embryo manipulation and transfer
Monoclonal antibody/hybridoma technology
Protein engineering and bioprocess engineering

the consumers and producers. The number of oversight committees in the USA at the university, state, and federal levels ensures the development of crops that are safe for the American public.

What are some of the techniques being employed for food and agriculture? A brief summary is listed below:

- The *Bacillus thuringiensis* (BT) toxin gene is being incorporated into plants so that they will be resistant to host specific insects.
- Tissue cultures are grown free of viruses and nematodes.
- A non-plant gene is inserted to control ethylene production in plants.
- RFLP screening is used to analyze and compare plant genomes.
- Cells and protoplasts are fused.
- Genes are inserted for herbicide resistance.
- Micropropagation is used.
- Better modulation is obtained for nitrogen fixation.
- Proteins with higher amounts of sulfur obtained by use of Brazil nut gene.
- Gene deletions are used to prevent synthesis of unwanted compounds, e.g. cyanogenic glycosides.
- Rapid propagations of trees by somaclonal variation.
- Anti-freeze gene is inserted for protection against frost and freezing.
- Engineer baculovirus to contain genes that inhibit caterpillar eating and growth.
- Obtain high starch potato by inserting an *E. coli* gene for ADP glucose pyrophophorylase.
- Tomatoes are obtained with high solid or sucrose content.
- New varieties of flowers are obtained by transposons.

These are just a few examples of the types of modifications that are being employed to develop new types of crops.

Crops that are being improved by the new technology.

In California about 250 different crops are produced. They include vegetables, melons, fruits, cereal grain, fiber plants, nuts, oil producing and beverage plants. Thus there is a great diversity of crops and each has to be handled in a specific way or for a specific purpose. Table 2 shows a partial list of plants that are being improved by biotechnology in the USA and the world. The major benefits from biotechnology can be arbitrarily summariyed as follows:

1. Resistance of plants to pathogens and pests including viruses, bacteria, fungi, nematodes, and insects of various sorts.
2. Herbicide tolerance in order to reduce the amount of herbicide used.

Table 2. Crops Being Improved by Biotechnology*.
Tabuľka 2. Zoznam plodín biotechnlogicky zdokonalených*.

Alfalfa	Chicory	Euromelon	Raspberries
Apples	Coffee	Grapes	Soybean
Asparagus	Cabbage	Lettuce	Squash
Banana	Cantaloupe	Mustard	Strawberries
Broccoli	Corn	Palm	Sunflower
Canola Oil	Cottonseed	Peaches	Tomatoes
Carrots/Celery	Cucumber	Potato	Wheat

*Not a complete list. Zoznam nie je úplný.

3. Improvement of food quality:
   - slow ripening, slow softening, extended shelf-life,
   - retain crispiness after harvesting,
   - allow wider shipping radius,
   - control composition of fatty acids, lipids, oils,
   - improved nutrition: higher vitamin content, less caffeine and fats, higher fructans and starch,
   - new varieties: seedless fruits and melons; individual size lettuce,
   - higher sulfur-containing proteins.

4. Other qualities and benefits:
   - higher yields,
   - cold tolerant plants for earlier planting season, use of colder climate farmlands,
   - better use of water and fertilizer,
   - improved production of seeds,
   - higher solids and higher viscosity of products,
   - resistance to post-harvest rot,
   - resistance to frost and freezing,
   - salt tolerant plants,
   - shorter growth seasons resulting in less water usage,
   - reduced costs to producers,
   - more and higher quality products for the consumers at a reasonable cost.

Engineered microorganisms and their products in food biotechnology

Several types of microorganisms have been developed for use in the food industry. A few examples are (a) bacteriophage resistant bacterial strains and more rapid ripening strains for the production of cheese; (b) bacteriocin

producing strains of bacteria that inhibit the growth of spoilage organisms and pathogens and (c) microorganisms with higher levels of maltose permease and maltase for more consistent and improved leavening.

A number of useful enzymes for the food industry have been derived from genetically engineered microorganisms. These enzymes include (a) β-galactosidase to reduce the level of lactose in order to allow lactose-intolerant persons to utilize milk in their diet; (b) α-amylase to produce low calorie „lite" beer; (c) chymosin for the production of cheese; (d) industrial enzymes such as amylases, cellulases, isomerases, lipases, pectinases, and proteases.

Another use of enzymes depends on their substrate specificity and several enzymes are used as biosensors to detect certain compounds in food products. In Table 3 is a list of biosensors and their target compounds.

Table 3. Biosensors for Food Ingredients.
Tabuľka 3. Biosenzory pre potravinárske ingrediencie.

BIOSENSORS [1]	COMPOUNDS DETECTED [2]
Alcohol dehydrogenase	Ethanol
Amino acid dehydrogenase	Amino acids
Aminopeptidase	Peptides
Antibody-enzyme conjugate	Penicillin
L-aspartase or alcohol oxidase	Aspartame
Ascorbate oxidase	Ascorbic acid
β-galactosidase	Lactose
Glucose oxidase	Glucose
L-glutamate oxidase	Glutamate
p-Hydroxybenzoate hydroxylase	Polyhydroxybutyrate
Invertase	Sucrose
Lactate dehydrogenase	Lactate
Sulfite oxidase	Sulfite

1 - biosenzory, 2 - zisťované zložky.

Microbially derived food ingredients play an important part in various types of food and include (a) organic acids such as acetic acid and citric acid; (b) flavour compounds such as diacetyl and monosodium glutamate; (c) amino acids such as glutamic acid, leucine, phenylalanine, lysine and aspartic acid.

Value added products from biotechnological treatment of agricultural wastes

Another way that biotechnology will help in agriculture is to turn agricultural wastes into value added products. Examples of agricultural wastes that could be converted by biotechnology to useful products are as follows:

- Whey proteins from cheese manufacturing; amino acids and peptides.
- Blood, bone, collagen from meat processing; amino acids and peptides.
- Feathers from poultry processing; conversion to amino acids and peptides for feed.
- Shells from egg and nut processing.
- Starch from potato processing.
- Cellulosic wastes from fruit and vegetable processing; conversion to more readily utilizable energy sources.
- Enzymes and other compounds from chicken eggs.
- Conversion of animal and plant wastes to utilizable energy compounds, e.g. ethanol and methane.

Food and Agricultural Biotechnology in the Future

Many of the techniques that are currently being applied to crops are still in experimental stages, but it is likely that in the next 10 years, there will be an explosion of new crops. The US Department of Agriculture has reported that there are currently 220 permits issued for field testing of transgenic plants and there have been 1,583 notifications for field releases.

Some areas for future investigations in food and agricultural biotechnology include agronomic properties of plants, food processing traits, nutritional value of plants, use of plants to obtain chemicals and polymers, biofertilization, bioremediation, plant factories, photosynthetic systems, and crop morphology.

Some examples for study include the use of modified fern-blue green algae to fertilize fields; the accumulation of selenium by clover to detoxify soil and water; the production of important precursor compounds, peptides, and proteins for chemical and medicinal use; the alteration of morphology to produce dwarf plants, to facilitate harvesting, and to produce one-portion crops (e.g. a small lettuce head); to improve photosynthetic processes; to obtain value added products from agricultural products, e.g. there are some 20 different high value proteins that can be isolated from a chicken egg.

A most important aspect of the future of food and agricultural biotechnology is to improve the public perception of food and agricultural biotechnology. This will include the education of the public at all levels by providing factual information concerning the new technology. The public in all its

wisdom hopefully will make the proper choices if all the facts are provided in an objective and unemotional manner. Furthermore a good consumer and market analysis should be undertaken prior to the development of any new crops to ensure good public acceptance.

Since food and agricultural crops now compete in the world market, it is critical that biotechnology be used to improve yields and quality. This makes it imperative that sound biotechnology processes be taught at academic institutions and employed in the production areas.

The future of biotechnology in agriculture appears bright and promising and should develop rapidly in the next 10 years.

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References

1. BECK, C.I. - ULRICH, T.: Biotechnology in the food industry. Bio/Technology, *11*, 1993, p. 895-902.
2. HARLANDER, S.: Engineering the foods of the futute. Cereal Food World, *35*, p. 1106-1109.
3. US Department of Agriculture, Biotechnology Notes, *8*, 1995, p. 8.

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Budúcnosť biotechnológií v potravinárstve a poľnohospodárstve

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Súhrn. Biotechnológie zohrávajú významnú úlohu pri riešení problémov vznikajúcich rastom obyvateľstva, najmä potravinových zdrojov, ekologických problémov a problematiky surovín. Zohrajú svoju úlohu aj pri zvyšovaní bezpečnosti potravín, vzniku nových odrôd rastlín a skvalitňovaní a zvyšovaní úrody a zefektívnení technológií. V konečnom dôsledku ich vplyv pozitívne ovplyvní tak výrobcov, ako aj spotrebiteľa: zvýši sa úrodnosť, zníži kontaminácia

rastlín, potravín, zeme a vodných zdrojov. Nové surovinové zdroje pozitívne ovplyvnia potravinársku výrobu a obchod. Tieto skutočnosti sa zabezpečia novými biotechnologickými technikami. Tieto sú už aplikované. V potravinárskych technológiách sa čím ďalej, tým viac uplatnia mikroorganizmy so želateľnými vlastnosťami, napr. rezistentné kmene k bakteriofágom, bakteriocín produkujúce kmene a kmene s cielenými vlastnosťami enzýmu, enzýmy so špecifickou substrátovou aktivitou sa uplatnia v analytike ako biosenzory. Biokonverziou odpadov z potravinárskeho priemyslu je možné získať cenné komponenty pre humánne a veterinárne účely. Aplikácia biotechnológií v poľnohospodárstve a potravinárstve sa bude v priebehu desaťročia rýchlo rozvíjať.