B. Innovation related to the production of processed food

Innovation related to the production of processed food has also been influenced to a large extent by biotechnology. Biotechnology related to the production of processed food comprises the use of microorganisms, cell cultures and genetic modification. The food sector's ability to develop new processed food products is widened by biotechnology.[316] First, the use of microorganisms in the production of processed food is described. Next, the completely new fields of functional food and nutraceuticals are explained.[317]

I. Use of microorganisms in the production of processed food

The most important field of innovation in the production of processed food with regard to biotechnology is the use of microorganisms.[318] Improved genetically modified microorganisms, especially bacteria and yeasts, are used for conventional fermentation. Genetically modified microorganisms are applied in processing bread, wine, beer, yoghurt and cheese. Additionally, new fermentation products for food or feed additives have been developed using genetically modified organisms. Such fermentation products contain enzymes, vitamins, amino acids and flavoring agents.[319] The evolving concept of functional food, nutraceuticals and dietetic food raises exciting prospects for future implementation of biotechnology in the field of processed food production.[320]

A wide range of food additives, supplements and processing aids are obtained from microorganisms. These include amino acids, citric acid, vitamins, natural colorings and gums, as well as enzymes.

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316 *Gardner*, The Development of the Functional Food Business in the United States and Europe, in: *Goldberg* (ed.), Functional Foods, Designer Foods, Pharmafoods, Nutraceuticals, London 1994, 468, 476.

317 For a detailed overview of biotechnology in food production and processing see *Reed&Ngodavithana* (eds.), Biotechnology, 2, ed., volume 9: Enzymes, Biomass, Food and Feed, Weinheim 1995. A recent overview is provided in World Health Organisation, Modern Food Biotechnology, Human Health and Development: An Evidence-Based Study, Geneva 2006, 9 s.

318 For an overview see GMO Compass, Additives, Vitamins, Amino Acids, Enzymes - GM Microorganisms Taking the Place of Chemical Factories (2006), available at http://www.gmo-compass.org/eng/grocery_shopping/ingredients_additives/36.gm_microorganisms_taking_place_chemical_factories.html.

319 FAO, Electronic Forum on Biotechnology in Food and Agriculture, Conference 11: Biotechnology Applications in food production: Can Developing Countries Benefit?, June 14–July 15, 2004, available at www.fao.org/biotech/C11doc.htm.

320 *Hardy*, Nutraceuticals and Functional Foods: Introduction and Meaning, 16 Nutrition 688, 689 (2000).

Amino acids are used to enhance flavors and to act as seasonings, nutritional additives and improvers. Microorganisms overproducing specific amino acids are grown in large fermenters. The acids are secreted into the fermentation medium and harvested. For instance, glutaminic acid produced by microorganisms is used as monosodium glutamate, as a flavor enhancer. The amino acids lysine, cysteine, methionine and phenylalanine are used as supplements in animal feed. Furthermore, citric, acetic, lactic and ascorbic acids are produced in large quantities by microbial fermentation.[321]

Gums are used widely in the food sector as thickeners, emulsifiers and fillers. Gum obtained from seed has been transformed into a gum similar to the expensive locust bean gum using α-galactosidase. The gene encoding the enzyme was inserted into baker's yeast. Bacterial polysaccharides provide novel gums with improved and valuable properties.[322] Important applications of such enzymes produced by genetically modified microorganisms in the food sector are shown in table 11.

321 *Madden,* Food Biotechnology - An Introduction, ILSI 1995, 15, available at www.ilsi.org/publications/ilsifobi.pdf. For an overview see also Biotechnology Industry Organization, Food Biotechnology (2006), available at http://www.bio.org/speeches/pubs/er/food.asp. See also *Kleerebezem*, Molecular Advances and Novel Directions in Food Biotechnology Innovation, 17 Current Opinion in Biotechnology 179 (2006).

322 *Madden,* Food Biotechnology - An Introduction, ILSI 1995, 15, available at www.ilsi.org/publications/ilsifobi.pdf. For an overview see also Biotechnology Industry Organization, Food Biotechnology (2006), available at http://www.bio.org/speeches/pubs/er/food.asp. See also *Kleerebezem*, Molecular Advances and Novel Directions in Food Biotechnology Innovation, 17 Current Opinion in Biotechnology 179 (2006).

Table 11:
Uses of enzymes in the production of processed food.[323]

Enzyme	Product	Use
α-Amylase	Sweeteners Beer Bread, cakes and biscuits	Liquefaction of starch Removal of starch haze Flour supplementation
Amyloglucosidase	Sweeteners Low-carbohydrate beer Wine and fruit juice Bread manufacture	Saccharification Saccharification Starch removal Improved crust color
β- Galactosidase (lactase)	Whey syrup Lactose-reduced milk and dairy products Ice cream	Greater sweetness Removal of lactose for those who are lactose intolerant Prevention of "sandy" texture caused by lactose crystals
Glucose oxidase	Fruit juices	Removal of oxygen
Invertase	Soft-centered sweets	Liquefaction of sucrose Sugar syrups
Lipases	Cheese Flavorings	Flavor development Accelerated ripening Ester synthesis
Papain	Beer	Removal of protein
Pectinases	Wine and fruit juice Coffee	Increased yield, clarification Extraction of the bean
Proteases[324] (various)	Dairy products Caviar Bread, cakes and cookies Meat	Modification of milk proteins Viscosity reduction of "stickwater" Gluten weakening Tenderization

323 *Madden,* Food Biotechnology - An Introduction, ILSI 1995, 17, available at www.ilsi.org/publications/ilsifobi.pdf. For an overview see also Biotechnology Industry Organization, Food Biotechnology (2006), available at http://www.bio.org/speeches/pubs/er/food.asp.
See also *Kleerebezem*, Molecular Advances and Novel Directions in Food Biotechnology Innovation, 17 Current Opinion in Biotechnology 179 (2006).

324 A recent review on the application of proteases in food production is provided by *Sumantha et al.*, Microbiology and Industrial Biotechnology of Food-Grade Proteases: A Perspective, 44 Food Technology & Biotechnology 211 (2006).

Biotechnology is applied in milk processing to a large extent.[325] Chymosin and *Lactococcus lactis* are examples of this application of biotechnology.[326] Milk is coagulated by the enzyme chymosin. Originally, this coagulation in cheese production was induced by calf rennet. Chymosin is nowadays produced by genetically modified microorganisms, e.g. *Escherichia coli, Kluyveromyces lactis* or *Aspergillus niger*. Today, at least 50% of cheese is made with chymosin from genetically modified microorganisms. Lipases are added in cheese production to accelerate the ripening process. Whey from cheese processing is treated with the enzyme betagalactosidase in order to form a protein-rich syrup with a range of applications in the confectionery segment.[327] *Lactococcus lactis* is the best studied food microorganism. It is used in the dairy segment for fermentation. Phages pose a significant problem in industrial fermentation.[328] Strains with plasmid-encoded phage-resistance mechanisms successfully counter phage proliferation.[329]

Biotechnology has also improved the production process of fruit juice.[330] Biotechnology helps to overcome the problems posed by the fruit wall constituent pectin in fruit juice processing. The pectin is altered by enzymes during fruit ripening. As a result, the pectin becomes more soluble. Dissolved pectin makes juice more viscous and difficult to press from the fruit. Pectin also helps to retain important compounds of color and flavor within the fruit, so juice pressed from it is of inferior quality. Juice is difficult to purify and to filter because of suspended pectin particles. In the fruit juice segment, pectinases obtained from microorganisms are used to overcome all of these problems. Enzymes extract, clarify and modify juices from such fruits as juice berries, stone and citrus fruits, grapes, apples, pears and even vegetables.[331]

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325 GMO Compass, Processed Foods – Dairy Products and Eggs (2006), available at http://www.gmo-compass.org/eng/grocery_shopping/processed_foods/29.dairy_products_eggs_genetic_engineering.html.

326 For more information on the use of biotechnology for industrial strain development of *lactococcus lactis* see *Vlieg et al.,* Natural Diversity and Adaptive Responses of *Lactococcus lactis*, 17 Current Opinion in Biotechnology 183 (2006).

327 *Madden,* Food Biotechnology - An Introduction, ILSI 1995, 26, available at www.ilsi.org/publications/ilsifobi.pdf.

328 A larger yoghurt factory can process up to 500,000 l of milk, while in the production of cheese, factories may process up to 1,000,000 l daily. Partial phage attacks cause a reduction in the speed of acidification, texture quality, and unpredictable variation in quality.

329 *Garvey et al.,* Molecular Genetics of Bacteriophage and Natural Phage Defence Systems in the Genus *Lactococcus*, 5 International Dairy Journal 905 (1995).

330 GMO Compass, Beverages – Juice, Soft Drinks, Wine, and Beer (2006), available at ww.gmo-compass.org/eng/grocery_shopping/processed_foods/30.beverages_genetic_engineering.html.

331 *Madden,* Food Biotechnology - An Introduction, ILSI 1995, 27, available at www.ilsi.org/publications/ilsifobi.pdf.

Enzymatic treatments are a major way of producing sweeteners.[332] Sweeteners comprise syrups as well as low-caloric sweeteners. Syrups derive from sucrose or starch.[333] High-fructose syrup from corn starch has now eclipsed sucrose as the major sweetener used in the food sector. The production and use of high-fructose syrup in the EU has been limited by quotas intended to protect European sugar beet growers. Nevertheless, more than 8 million tons of high-fructose syrup are processed annually. High-fructose syrup is an alternative to sucrose or invert sugar. It is used in many products, including soft drinks, jam, ice cream, cakes, canned fruit, pickles and sauces. Unlike sucrose, high-fructose syrup remains stable in chilled, frozen and acidic food without forming crystals or undergoing conversion to other sugars.

High-fructose syrup is made from low-cost raw material starch. The starch is converted into syrup by several enzymes. These enzymes are used in distinct stages comprising α-amylase, an enzyme from the bacterium *Bacillus spec.,* to dissolve the starch and to break down the starch into dextrins. Various fungal enzymes are then used to break down the dextrins to glucose. Finally, glucose isomerase converts glucose to fructose, as glucose is about half as sweet as fructose.

332 *Tornare&Kochhar*, Production of Oligosaccharides Using Engineered Bacteria: Engineering of Exopolysaccharides from Lactic Acid Bacteria, in: *Wang&Ichikawa*, Synthesis of Carbohydrates Through Biotechnology, American Chemical Society Symposium Series 873, 139 (2004).

333 GMO Compass, Ingredients and Additives - Corn Syrup, Fructose, and Glucose – All are Products of Starch (2006),
available at http://www.gmo-compass.org/eng/grocery_shopping/ingredients_additives/37.products _ starch_corn_syrup_fructose_glucose.html.

II. Functional food

Another important field of innovation in the production of processed food is functional food.[334] Functional food results from biotechnology as well as from the new developments in traditional food technology like fortification and extraction. "Functional food"[335] describes nutrients or nutrient-enriched food that is designed to prevent diseases. Functional food[336] is "any food or ingredient that has a positive impact on an individual's health, physical performance, or state of mind, in addition to its nutritive value."[337] Functional food is rather a concept than a well-defined food. Functional food addresses various components affecting body functions and belongs to nutrition and not to pharmacology, as it does not comprise pharmaceuticals with therapeutic effects. The borderline between functional food and pharmaceuticals becomes more and more fluent with progress in nutrition science.[338] Table 12 shows areas of human physiology addressed by functional food.[339]

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334 Dietetic food is intended for individuals with a specific disease or condition. While functional food improves or maintains health for consumers, dietetic food aims at physicians or health professionals. Dietetic food must fulfill the requirements set out by the EU: "A particular nutritional use must fulfill the particular nutritional requirements: of certain categories of persons whose digestive processes or metabolism are disturbed; or of certain categories of persons who are in a special physiological condition and who are therefore able to obtain special benefit from controlled consumption of certain substances in foodstuffs." Art. 2(1), Art. 1(2)(b)(i)(ii) of the EU Directive 89/398/EEC.

335 Functional food is also described by "nutraceuticals" and has to be distinguished from the so called "medical food", which the U.S. Food and Drug Administration (FDA) defines as "formulated to be consumed or administered entirally under the supervision of a physician and which is intended for the specific dietary management of a disease or condition for which distinctive nutritional requirements, on the basis of recognized scientific principles, are established by medical evaluation.", 21 U.S.C. 360ee(b)(3). For more details see *DellaPenna*, Nutritional Genomics: Manipulating Plant Micronutrients to Improve Human Health, 285 Science 375 (1999), *Mazut, Krebbers&Tingey*, Gene Discovery and Product Development for Grain Quality Traits, 285 Science 372 (1999), *Pridmore et al.*, Genomics, Molecular Genetics and the Food Industry, 78 Journal of Biotechnology 251 (2000).

336 The European Commission's Concerted Action on Functional Food Science in Europe (FUFOSE = Functional Food Science in Europe) involving about 100 European experts in nutrition and medicine developed a parallel definition of the term functional food: "A food can be regarded as functional if it is satisfactorily demonstrated to affect beneficially one or more target functions in the body, beyond adequate nutritional effects, in a way that is relevant to either improved stage of health and well-being and/or reduction of risk of disease. A functional food must remain food and it must demonstrate its effects in amounts that can normally be expected to be consumed in the diet: it is not a pill or a capsule, but part of the normal food pattern." *Diplock et al.* (eds.), Scientific Concepts of Functional Foods in Europe: Consensus Document, 81 British Journal of Nutrition S1 (1999).

337 *Goldberg*, Functional Foods, Designer Foods, Pharmafoods, Nutraceuticals, London 1994, 3.

338 A European Consensus of Scientific Concepts of Functional Foods, 16 Nutrition 689 (2000).

339 For an overview see *Kotilainen et al.*, Health Enhancing Foods – Opportunities for Strengthening the Sector in Developing Countries, World Bank Agriculture and Rural Development Discussion Paper 20, Washington 2006.