chapter 6

The Food Processing Industry

Chapter 6

Tables

Figure

Chapter 6

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Introduction—the industry

The food processing industry comprises those manufacturers that transform or process agricultural products into edible products for market. It is distinguished from the production, or farming and breeding portions of the agricultural industry.

Genetics can be used in the food processing industry in two ways: to design micro-organisms that transform inedible biomass into food for human consumption or for animal feed; and to design organisms that aid in food processing, either by acting directly on the food itseIf or by providing materials that can be added to food.

Eight million to ten million people work in the meat, poultry, dairy, and baking industries; in canned, cured, and frozen food plants; and in moving food from the farm to the dinner table. In 1979, the payroll was over $3.2 billion for the meat and poultry industries, $2.6 billion for baking, and $1.9 billion for food processing.

Traditionally, micro-organisms have been used to stabilize, flavor, and modify various properties of food. More recently, efforts have been made to control microbial spoilage and to ensure that foods are free from micro-organisms that may be hazardous to public health. These are the two major ways in which microbiology has been useful.

Historically, most efforts have been devoted to improving the ability to control the harmful effects of micro-organisms. The industry recognized the extreme heat resistance of bacterial spores in the early 20th century and sponsored or conducted much of the early research on the mechanisms of bacterial spore heat resistance. Efforts to exploit the beneficial characteristics of micro-organisms, on the other hand, have been largely through trial-and-error. Strains that improve the quality or character of food generally have been found, rather than designed.

Single-cell protein

The interest in augmenting the world's supply of protein has focused attention on microbial sources of protein as food for both animals and humans. * Since a large portion of each bacterial or yeast cell consists of proteins (up to 72 percent for some protein-rich cells), large numbers have been grown to supply single-cell protein (SCP) for consumption, The protein can be consumed directly as part of the cell itself or can be extracted and processed into fibers or meat-like items. By now, advanced food processing technologies can combine this protein with meat flavoring and other substances to produce nutritious food that looks, feels, and tastes like meat.

***AS ıı example of {nıı potential significance of the Soviet one o which is one of the largest producers, expects produce veast ır fodder yeast from internally available raw materials to be self-sufficient in animal protein foodstuffs 1990.**

The idea of using SCP as animal feed or human food is not new; yeast has been used as food protein since the beginning of the century. However, in the past 15 years, there has been a dramatic increase in research on SCP and in the construction of large-scale plants for its production, especially for the production of yeast. (See table 20.) Interest in this material is reflected in the numerous national and international conferences on SCP, the increasing number of proceedings and reviews published, and the number of patents issued in recent years. (See table 21.)

The issues addressed have covered topics such as the economic and technological factors influencing SCP processes, nutrition and safety, and SCP applications to human or animal foods. Thus far, commercial use has been limited by

Table 20.-Estimated Annual Yeast Production, 1977
(dry tonnes)

	Baker's yeast	Dried yeast[a]
Europe.	74,000[b]	160,000[b]
North America	73,000	53,000
The Orient.	15,000	25,000
United Kingdom.	15,500	(c)
South America.	7,500	2,000
Africa.	2,700	2,500
Totals	187,700	242,500

includes food and fodder yeasts; data for petroleum-grown Yeasts are not available.
figures for U.S.S.R. not **reported.**
reported.

SOURCE: H. J. Peppier and D. · J. Pepp er anc *Microbial Technology, vol.* 1 (London: Academic Press, 1979), p. 159.

Table 21.—Classification of Yeast-Related U.S. patents (1970 to July 1977)

Category	Number issued
Yeast technology (apparatus, processing)	22
Growth on hydrocarbons. ., ...	28
Growth on alcohols, acids, wastes.	22
Production of chemicals.	14
Use of baking and pasta products	24
Condiments and flavor enhancers	18
Reduced RNA. . . . . ,.	11
Yeast modification of food products	13
Isolated protein	5
Texturized yeast protein	7
Lysates and ruptured cells	7
Animal feed supplements	12
Total. ., ...	183

SOURCE: H. J. Peppier, "Yeast," Peppie , Tea: *on Fermentation Processes,* D. (cd.), vol. 2 (London: Academic Press, 1978), pp. 191-200.

several factors. For each bacterial, yeast, or algal **strain** used, technological problems (from the choice of micro-organisms to the use of corresponding raw material) and logistical problems of construction and location of plants have arisen. But the primary limitation so far has been the cost of production compared with the costs of competing sources of protein. (The comparative price ranges in 1979 for selected microbial, plant, and animal protein products are shown in table 22.)

The costs of manufacturing SCP for animal feed in the United States are high, particularly relative to its major competing protein source, soybeans, which can be produced with little fertilizer and minimal processing. The easy availability of this legume severely limits microbial SCP production for animal feed or human food. In fact, according to the U.S. Department of Agriculture (USDA), total domestic and export supply for U.S. soybeans will grow 73 percent by 1985.

Table 22.—Comparison of Selling Price Ranges for Selected Microbial, Plant, and Animal Protein Products

Product, substrate, and quality	Crude protein content	Price range 1979 Us. dollars/kg
Single cell proteins		
Candida utilis, **ethanol, food grade**	52	1.32-1.35
Kluyveromyces tragilis, **cheese**		
whey, food grade.	54	1.32
Saccharomyces ccnaromyc		
Brewer's, debittered, food grade	52	1.00-1.20
Feed grade.	52	0.39-0.50
Plant proteins		
Alfalfa (dehydrated)		0.12-0.13
Soybean meal, defatted.		0.20-0.22
Soy protein concentrate.	70-72	0.90-1.14
Soy protein isolate	90" 92	1.96-2.20
Animal proteins		
Fishmeal (Peruvian)	65	0.41-0.45
Meat and bonemeal	50	0.24-0.25
Dry skim milk.	37	0.88-1.00

SOURCE: Office of Technology Assessment.

Soybeans are primarily consumed as animal feed. But while only 4 percent of their annual production are directly consumed by humans, the market is growing significantly. The introduction of improved textured soy protein in cereals, in meat substitutes and extenders, and in dairy substitutes has increased the use of soy products. Nevertheless, the market does not demand soy products in particular but protein supplements, vegetable oils, feed grain supplements, and meat extenders in general. Other protein and oil sources could replace soybeans if the economics were attractive enough. Fishmeal, dry beans, SCP, and cereals are all potential competitors. As long as a substitute can meet the nutritional, flavor, toxicity, and regulatory standards, competition will be primarily based on price.

The competition between soybeans and SCP illustrates one of the paradoxes of genetic engineering. While significant research is attempting the genetic improvement of soybeans, genetic techniques are also being explored to increase the production of SCP. Consequently, the same tool—genetic engineering—encourages competition between the two commodities.

Genetic engineering and SCP production

Despite the microbial screening studies that have been conducted and the wealth of basic genetic knowledge available about common yeast (a major source of SCP), genetic engineering has had little economic impact on SCP processes until recently. Today, a variety of substances are being considered as raw materials for conversion.

- ***Petroleum-based hydrocarbons.—Until*** recently, the wide availability and low cost of petrochemicals have made the n-alkane hydrocarbons (straight chain molecules of carbon and hydrogen), which are petrochemical byproducts, potential raw materials for SCP production. At British Petroleum, mutants of micro-organisms have been obtained having an increased protein content. Mutants have also been found with other increased nutritive values, e.g., vitamin content.
- ***Methane or methanol-Relatively*** few genetic studies have been directed at investigating the genetic control of the microbial use of methane or methanol. However, one recent application of genetic engineering has been reported by the Imperia] Chemical Industries (ICI) in the United Kingdom, where the genetic makeup of a bacterium ***(Methylophilus methylotrophus)*** has been altered so that the organism can grow more readily on methanol. The increase in growth provides increased protein and has made its production less expensive. The genetic alteration was accomplished by transferring a gene from ***Escherichia coli*** to ***M. methylotrophus.***
- ***Carbohydrates.*** —Many carbohydrate substrates—from starch and cellulose to beets and papermill wastes—have been investigated. Forests are the most abundant source of carbohydrate in the form of cellulose. But before it can be used by micro-organisms, it must be transformed into the carbohydrate, glucose, by chemical or enzymatic pretreatment. Many of the SCP processes that use cellulose employ organisms that produce the enzyme cellulase, which degrades cellulose to glucose.

Most of the significant genetic studies on the production of cellulase by micro-organisms are just beginning to appear in the literature. The most recent experiments have been successful in creating fungal mutants that produce excess amounts.

Commercial production

Of the estimated 2 million tons of SCP produced annually throughout the world, most comes from cane and beet molasses, with about 500,000 tons from hydrolyzed wood wastes, corn trash, and papermill wastes. (See table 23.)

Integrated systems can be designed to couple the production of a product or food with SCP production from wastes. E.g., the waste sawdust from the lumber industry could become a source of cellulose for micro-organisms. ICI's successful genetic engineering of a micro-organism to increase the usefulness of one raw material (methanol) should encourage similar attempts for other raw materials.

But while SCP can be obtained from a wide variety of micro-organisms and raw materials, the nutritional value and the safety of each micro-organism vary widely, as do the costs of competing protein sources in regional markets. Consequently, accurate predictions cannot be made about the likelihood that SCP will displace traditional protein products, overall. Displacements have and will continue to occur on a case-by-case basis.

Table 23.-Raw Materials Already Tested on a Laboratory or Small Plant Scale

Agave juices	Pulpmill wastes
Barley straw	Sawdust
Citrus wastes	Sunflower seed husks (treated)
Date carbohydrates	Wastes from chemical production of maleic anhydride
Meatpacking wastes	Waste polyethylene (treated)
Mesquite wood	
Peat (treated)	

SOURCE: Office of Technology Assessment.

Genetics in baking, brewing, and winemaking

The micro-organism of greatest significance in the baking, brewing, and winemaking industries is common yeast. Because of its importance, yeast was one of the first micro-organisms to be used in genetic research. Nevertheless, the surge in studies in yeast genetics has not been accompanied by an increase in its practical application, for three reasons:

- industries already have the desired efficient strains, mainly as a result of trial-and-error studies;
- new genetic strains are not easily bred; they are incompatible for mating and the genetic characteristics are poorly understood; and
- many of the important characteristics of industrial microbes are complex; several genes being responsible for each.

Changing technologies in the brewing industry and increased sophistication in the molecular genetics of yeast have made it possible for researchers to achieve novel goals in yeast breeding. one strain that has already been constructed can produce a low-carbohydraate beer suitable for diabetics. (See figure 26.)

The baking industry is also undergoing technological revolution, and yeasts with new properties are now needed for the faster fermentation of dough. New strains with improved biological activity, storage stability, and yield would allow improvements in the baking process.

In the past, most genetic applications have come in the formation of hybrid yeasts. The newel* genetic approaches, which use cell fusion now open up the possibility of hybrids developed from strains of yeast that carry useful genes but cannot mate normally,

Classical genetic research has also been carried out with wine yeasts. Interestingly, within the past 10 years, scientists have isolated induced mutants of wine yeasts that have: ı) an increased alcohol tolerance and the capacity to completely ferment grape extracts of unusually high sugar content; 2) improved sedimentation properties, improving or facilitating separation of yeasts from the wine; and 3) improved performance in the production of certain types of wines. Hybridization studies of wine yeasts have been actively pursued only recently.

Progress in developing strains of yeast with novel properties is limited by the lack of enough suitable approved systems for using recombinant DNA (rDNA) technology. Eventual approval by the Recombinant DNA Advisory Committee is expected to boost applied research for the brewing, baking, and winemaking industries.

Figure 26.—The Use of Hybridization To Obtain a Yeast Strain for the Production of Low-Carbohydrate Beer

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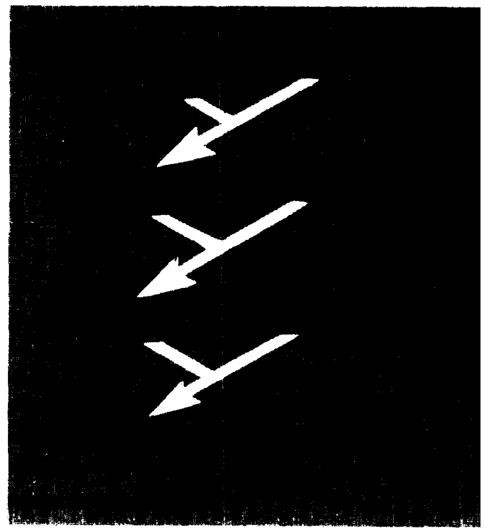

SOURCE: Office of Technology Assessment.

Microbial polysaccharides

The food processing industry uses polysaccharides (polymeric sugars) to alter or control the physical properties of foods. Many are incorporated into foods as thickeners, gelling agents, and agents to control ice crystal formation in frozen foods. They are used in instant foods, salad dressings, sauces, whips, toppings, processed cheeses, and dairy products. New uses are constantly appearing. The annual market in the United States is reported to be over 36,000 tons, not including starches and derivatives of cellulose.

Since many of the polymeric sugars now used in food processing are derived from plant sources, microbial polysaccharides have had limited use. To compete economically, a microbial polysaccharide must offer new properties, meet all safety requirements, and be readily available. Very few have reached the level of commercial applications; the only one in large-scale commercial production is xanthan gum. *

● The history of the development of xanthan gum indicates that the commercially significant organisms resulted from an extensive screening program for gum producers stored in the Northern Uti-
h and Research and ivision of USDA's large mi-collection. Xanthan gum roduced by produced nas [. B-1459 was foun B-1459 was aract to stics hat rendered it as a promising as a commercial product. in Merc division fr Merck ie (:0., inc., carried out bili- su studies, con substantial commercial production in of the much d the as been carr ed out w h from one partic from one , there is ncreasing ev is dence tl suggest als be could ed for produced from rains.

A wide variety of polysaccharides could theoretically be produced for use in food processing, Applied genetics may increase their production, modify those that are produced, eliminate the degradative enzymes that break them down, or change the microbes that produce them. However, as with other microbial processes, the application of genetics depends on an understanding of both the biochemical pathway for synthesis of a given polysaccharide and the systems that control microbial production. For many microbial polysaccharides, this information does not yet exist; furthermore, little is known about the enzymes that may be used to modify poly-saccharides to more useful forms. Progress will only be able to occur when these information gaps are filled.

Enzymes

Enzymes are produced for industrial, medical, and laboratory use both by fermentation processes that employ bacteria, molds, and yeasts and by extraction from natural tissues. The present world market for industrial enzymes is estimated to be $150 million to $174 million; the technical (laboratory) market adds another $20 million to $40 million. Fewer than so microbial enzymes are of industrial importance today, but patents have been granted for more than a thousand. This reflects the increasing interest in developing new enzyme products; it also shows that it is easier to discover a new enzyme than to create a profitable application for it. *

Most industrial enzymes are used in the detergent industry and the food processing in-

● The enzyme literature is extensive wel comprises well over 10,00(papers per year. Although less t of 5(1 e of these publications are concerned with nes and n enzymes are found to have no industrial interest, few s per per year are of potential interest for the opment o development of enzymes. Less than 100 papers dealing with industrial processes appear every year, and few ses of gr processes nic sig- economic significance.

dustry, particularly for starch processing. Enzymes began to be used in quantity only 20 years ago. In the early **1960's,** glucoamylase enzyme treatment began to replace traditional acid treatment in processing starch; around 1965, a stable protease (an enzyme) was introduced into detergent preparations to help break down certain stains; and in the 1970's, glucose isomerase was used to convert glucose to fructose, practically creating the high-fructose corn syrup industry.

Genetic engineering and enzymes in the food processing industry

Biotechnology applied to fermentation processes will make available larger quantities of existing enzymes as well as new ones. (See ch. 5.) The role of genetic engineering in opening commercial possibilities in the food processing industry is illustrated by the enzyme, pullulanase. This enzyme degrades pullulan, a polysaccharide, to the maltose or high-maltose syrups that give jams and jellies improved color and brilliance. They reduce off-color development produced by heat in candies and prevent sandiness in ice cream by inhibiting sugar crystallization. Mahose has several unique and favorable characteristics. It is the least water-absorbent of the maltose sugars and, although it is not as sweet as glucose, it has a more acceptable taste. It is also fermentable, nonviscous, and easily soluble. It does not readily crystallize and gives desirable browning reactions.

Pullulanase can also break down another carbohydrate, amylopectin, to produce high amy - lose starches. These starches are used in industry as quick-setting, structurally stable gels, as binders for strong transparent films, and as coatings. Their acetate derivatives are added to textile finishes, sizing, adhesives, and binders. In food, amylose starches thicken and give texture to gumdrop candies and sauces, reduce fat and grease in fried foods, and stabilize the protein, nutrients, colors, and flavors in reconstituted products like meat analogs.

In view of the current shortages of petroleum-derived plastics and the need for a biodegradable replacement, amylose's ability to form plastic-like **wraps may** provide its largest industrial market, although that market has not yet been developed.

[f applications for the products made by pullulanase can be developed, genetic engineering can be used to **insert this enzyme into industrially useful organisms and to increase its production. However, the food processing industry is permitted to use only** enzymes that are obtained from sources approved **for** food use. Since the chief source of pullulanase is a pathogenic bacterium, KlebsiellaII **aerogenes, no** significant efforts have been made to apply genetics to improve its production or quauality. Molecular genetics could ultimately transfer the pullulanase trait from ***K. aerogenes*** to a micro-organism approved for food use, if approved micro-organisms that manufacture pullulanase cannot be found.

Sweeteners, flavors, and fragrances

Biotechnology has already had a marked impact on the sweetener industry. The availability of the enzymes glucose isomerase, invertase, and amylase has made the production of high-fructose corn sweeteners (HFCS) profitable. **Pro**duction of HFCS in the United States has increased from virtually nothing in 1970 to 10 percent of the entire production of caloric sweeteners in 1980 (11 lb per capita). The price advantage of HFCS is expected to cause its continued growth, particularly in the beverage industry. In fact, the Coca Cola Co. announced in ***1980*** that fructose will soon constitute as much as ***50*** percent of the sweetener used in its name brand beverage.

Biotechnology can be used to produce other sweeteners as well. While it is unlikely that sucrose will ever be made by micro-organisms (although improvements in sugarcane and sugar beet yields may result from agricultural genetic studies, see ch. ***8.),*** the microbial production of low-caloric sweeteners is a distinct possibility. Three new experimental sweeteners—aspartame, monellin, and thaumatin—are candidates.

Aspartame is synthesized chemically from the amino acids, aspartic acid and phenylalanine, which can themselves be made by fermen-

tation. The possibility of using microbes to cou-ple the two amino acids is being investigated in at least one biotechnology research firm. Chemical production of aspartame is expensive and benefits from biotechnology **are possible.**

Monellin and thaumatin are natural substances—proteins obtained from West African plants. Both are intensely sweet–up to 100,000 times sweeter than table sugar—and the sensation of sweetness can last for hours. Their microbial production may be competitive with their extraction from plants. Since the physical and biological properties of thaumatin are known, it might also be produced through genetic engineering. Such an approach would not only increase the available supply, but would offer new molecules for investigating the physiology of taste.

Other flavors and fragrances show less promise at present. Although the chemistry of several flavors and aromas has **been identified, too little research into their use has been conducted. ***

* ork on the formation by micro-organisms of flavor ... chemicals known as lactones and terpenoids has been ... s Lactones occur as flavor-contributing components in ... fermentation products, where they are formed by micro... Different pathways exist for their ... heir formation ... ma-butyrolactone, which is formed during yeast fermentation, found in sherry wine, and beer. As early as 1930, an or... was isolated that had a peach-like odor ... thought to be Sporobolomyces roseus. resew. The 4-... le and cis-dodecen-4-olide were found to be re... nsi...

Overview

The application of genetic engineering will affect the food processing industry in piecemeal fashion. Isolated successes can be expected for certain food additives, such as aspartame (not yet approved by the Food and Drug Administration (FDA) for sale in the United States) and fructose, and for improvements in SCP production. But an industrywide impact is not expected in the near future because of several conflicting forces:

- The basic genetic knowledge of characteristics that could improve food has not been adequately developed.
- The food processing industry is conservative in its research and development expenditures for improved processes, generally allocating less than half as much as **more technologically sophisticated industries.**
- **Products made by new microbial sources must satisfy** FDA safety regulations, which include undergoing tests to prove lack of harmful effects. * It may be possible to reduce the amount of required testing by transferring the desired gene into microorganisms that already meet FDA standards.

Nevertheless, the application of new genetic technologies will probably accelerate. Technologically sophisticated companies are being drawn into the business. Traditionally capital-intensive companies such as Union Carbide, ITT, General Electric, Corning Glass, and McDonnell-Douglas can be expected to introduce automation and more sophisticated engineering to food processing, modernizing the industry's technology. As **has been noted by one** industry observer: [1]

> You don't **work on a better way to preserve fish. You try to change the system so that you no longer catch fish; you "manufacture" them and, if possible, do it right on top of your market so that you don't have to preserve them at all.**

"Food additives and micro-organisms used in food **used in** ... must be ... **must** ... as generally regarded **regarded**

[1] ... L. "The Coming Food Industry," April **April** 215-217. **215-217.**

You don't worry about processing bacon without nitrites, you engineer a synthetic bacon with designed-in shelf life.

You don't try to educate people to eat a "balanced diet;" you create a "whole" food with the proper balance of nutrients and supplements, and you make it taste like something people already like to eat.

Genetic engineering can be expected to aid in the creation of novel food preparations through effects on both the food itself and the additives used for texturizing, flavoring, and preserving.