

Microbiology and Technology of Fermented Foods

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Introduction

*“When our souls are happy, they talk about food.”
Charles Simic, poet*

Fermented Foods and Human History

Fermented foods were very likely among the first foods consumed by human beings. This was not because early humans had actually planned on or had intended to make a particular fermented food, but rather because fermentation was simply the inevitable outcome that resulted when raw food materials were left in an otherwise unpreserved state. When, for example, several thousands of years ago, milk was collected from a domesticated cow, goat, or camel, it was either consumed within a few hours or else it would sour and curdle, turning into something we might today call buttermilk. A third possibility, that the milk would become spoiled and putrid, must have also occurred on many occasions. Likewise, the juice of grapes and other fruits would remain sweet for only a few days before it too would be transformed into a pleasant, intoxicating wine-like drink. Undoubtedly, these products provided more than mere sustenance; they were also probably well enjoyed for aesthetic or organoleptic reasons. Importantly, it must have been recognized and appreciated early on that however imperfect the soured milk, cheese, wine, and other fermented foods may have been (at least compared to modern versions), they all were less perishable and were usually (but not always) safer to eat and drink

than the raw materials from which they were made. Despite the “discovery” that fermented foods tasted good and were well preserved, it must have taken many years for humans to figure out how to control or influence conditions to consistently produce fermented food products. It is remarkable that the means for producing so many fermented foods evolved independently on every continent and on an entirely empirical basis. Although there must have been countless failures and disappointments, small “industries,” skilled in the art of making fermented foods, would eventually develop. As long ago as 3000 to 4000 B.C.E., for example, bread and beer were already being mass produced by Egyptian bakeries and Babylonian breweries. Likewise, it is clear from the historical record that the rise of civilizations around the Mediterranean and throughout the Middle East and Europe coincided with the production and consumption of wine and other fermented food and beverage products (Box 1-1). It is noteworthy that the fermented foods consumed in China, Japan, and the Far East were vastly different from those in the Middle East; yet, it is now apparent that the fermentation also evolved and became established around the same time.

Fermentation became an even more widespread practice during the Roman Empire, as

Box 1-1. Where and When Did Fermentations Get Started? Answers from Biomolecular Archaeologists

Although the very first fermentations were certainly inadvertent, it is just as certain that human beings eventually learned how to intentionally produce fermented foods. When, where, and how this discovery occurred have been elusive questions, since written records do not exist. However, other forms of archaeological evidence do indeed exist and have made it possible to not only establish the historical and geographical origins of many of these fermentations, but also to describe some of the techniques likely used to produce these products.

For the most part, investigations into the origins of food fermentations have focused on alcoholic fermentations, namely wine and beer, and have been led primarily by a research group at the University of Pennsylvania Museum of Archaeology and Anthropology's Museum Applied Science Center for Archaeology (<http://masca.museum.upenn.edu>). These "biomolecular archaeologists" depend not so much on written or other traditional types of physical evidence (which are mostly absent), but rather on the chemical and molecular "records" obtained from artifacts discovered around the world (McGovern et al., 2004).

Specifically, they have extracted residues still present in the ancient clay pottery jars and vessels found in excavated archaeological sites (mainly from the Near East and China). Because these vessels are generally porous, any organic material was adsorbed and trapped within the vessel pores. In a dehydrated state, this material was protected against microbial or chemical decomposition. Carbon dating is used to establish the approximate age of these vessels, and then various analytical procedures (including gas chromatography-mass spectroscopy, Fourier transform infrared spectrometry, and other techniques) are used to identify the chemical constituents.

The analyses have revealed the presence of several marker compounds, in particular, tartaric acid, which is present in high concentrations in grapes (but is generally absent elsewhere), and therefore is ordinarily present in wine, as well (Guash-Jané et al., 2004; McGovern, 2003). Based on these studies (and others on "grape archaeology"), it would appear that wine had been produced in the Near East regions around present-day Turkey, Egypt, and Iran as long ago as the Neolithic Period (8500 to 4000 B.C.E.).

Recent molecular archaeological analyses have revealed additional findings. In 2004, it was reported that another organic marker chemical, syringic acid (which is derived from malvidin, a pigment found in red wines), was present in Egyptian pottery vessels. This was not a real surprise, because the vessels were labeled as wine jars and even indicated the year, source, and vintner. What made this finding especially interesting, however, was that one of the vessels had originally been discovered in the tomb of King Tutankhamun (King Tut, the "boy king"). Thus, not only does it now appear that King Tut preferred red wine, but that when he died (at about age 17), he was, by today's standards, not even of drinking age.

new raw materials and technologies were adopted from conquered lands and spread throughout the empire. Fermented foods also were important for distant armies and navies, due to their increased storage stability. Beer and wine, for example, were often preferred over water (no surprise there), because the latter was often polluted with fecal material or other foreign material. During this era, the means to conduct trade had developed, and cheese and wine, as well as wheat for bread-making, became available around the Mediterranean, Europe, and the British Isles.

Although manufacturing guilds for bread had existed even during the Egyptian empire, by the Middle Ages, the manufacture of many fermented foods, including bread, beer, and cheese, had become the province of craftsmen and organized guilds. The guild structure involved apprenticeships and training; once learned, these skills were often passed on to the next generation. For some products, particularly beer, these craftsmen were actually monks operating out of monasteries and churches, a tradition that lasted for hundreds of years. Hence, many of the technologies and

Box 1–1. Where and When Did Fermentations Get Started? Answers from Biomolecular Archaeologists (*Continued*)

As noted above, the origins of wine making in the Near East can be reliably traced to about 5400 B.C.E. The McGovern Molecular Archaeology Lab group has also ventured to China in an effort to establish when fermented beverages were first produced and consumed (McGovern et al., 2004). As described in Chapter 12, Asian wines are made using cereal-derived starch rather than grapes. Rice is the main cereal used. Other components, particularly honey and herbs, were apparently added in ancient times.

As had been done previously, the investigators analyzed material extracted from Neolithic (ca. 7000 B.C.E.) pottery vessels. In this case, the specific biomarkers would not necessarily be the same as for wine made from grapes, but rather would be expected to reflect the different starting materials. Indeed, the analyses revealed the presence of rice, honey, and herbal constituents, but also grapes (tartaric acid). Although domesticated grape vines were not introduced into China until about 200 B.C.E., wild grapes could have been added to the wine (as a source of yeast). Another explanation is that the tartaric acid had been derived from other native fruits and flowers. Additional analyses of “proto-historic” (ca. 1900 to 700 B.C.E.) vessels indicate that these later wines were cereal-based (using rice and millet). Thus, it now appears clear that fermented beverage technology in China began around the same time as in the Near East, and that the very nature of the fermentation evolved over several millennia.

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manufacturing practices employed even today were developed by monks. Eventually, production of these products became more privatized, although often under some form of state control (which allowed for taxation).

From the Neolithic Period to the Middle Ages to the current era, fermented foods have been among the most important foods consumed by humans (Figure 1–1). A good argument can be made that the popularity of fermented foods and the subsequent development of technologies for their production directly contributed to the cultural and social evolution of human history. Consider, after all, how integral fermented foods are to the diets and cuisines of nearly all civilizations or how many fermented foods and beverages are consumed as part of religious customs, rites, and rituals (Box 1–2).

**Fermented Foods:
From Art to Science**

It is difficult for the twenty-first century reader to imagine that fermented foods, whose manufacture relies on the intricate and often subtle participation of microorganisms, could have been produced without even the slightest notion that living organisms were actually involved. The early manufacturers of fermented foods and beverages obviously could not have appreciated the actual science involved in their production, since it was only in the last 150 to 200 years that microorganisms and enzymes were “discovered.” In fact, up until the middle of the nineteenth century, much of the scientific community still believed in the concept of spontaneous generation. The very act of fermentation was a subject for philosophers

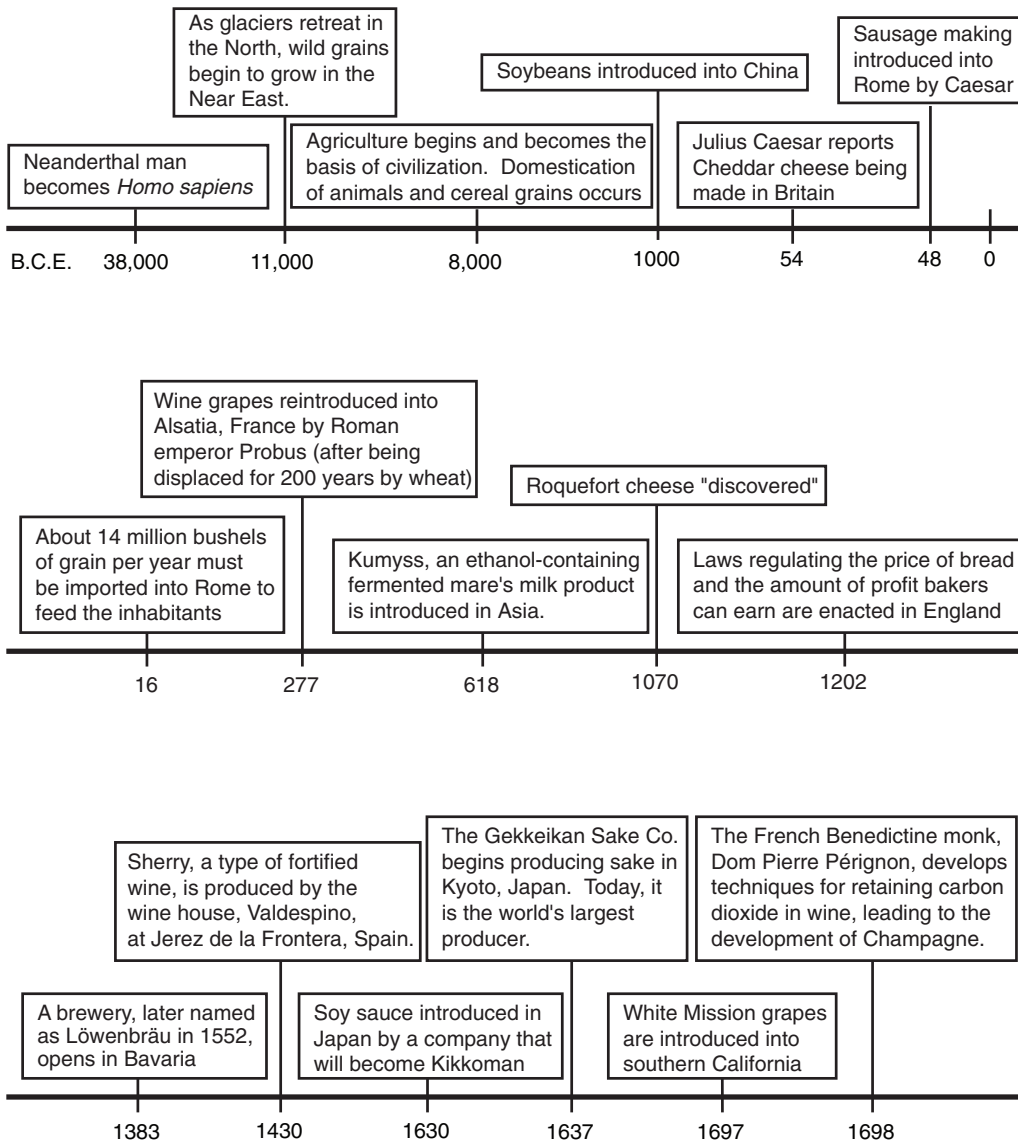


Figure 1-1. Developments in the history of fermented foods. From Trager, J., 1995. *The Food Chronology*. Henry Holt and Co., New York, and other sources.

and alchemists, not biologists. Although the Dutch scientist Antonie van Leeuwenhoek had observed microorganisms in his rather crude microscope in 1675, the connection between Leeuwenhoek’s “animalcules” and their biological or fermentative activities was only slowly realized. It was not until later in the next cen-

tury that scientists began to address the question of how fermentation occurs.

Initially it was chemists who began to study the scientific basis for fermentation. In the late 1700s and early 1800s, the chemists Lavoisier and Gay-Lussac independently described the overall equations for the alcoholic fermenta-

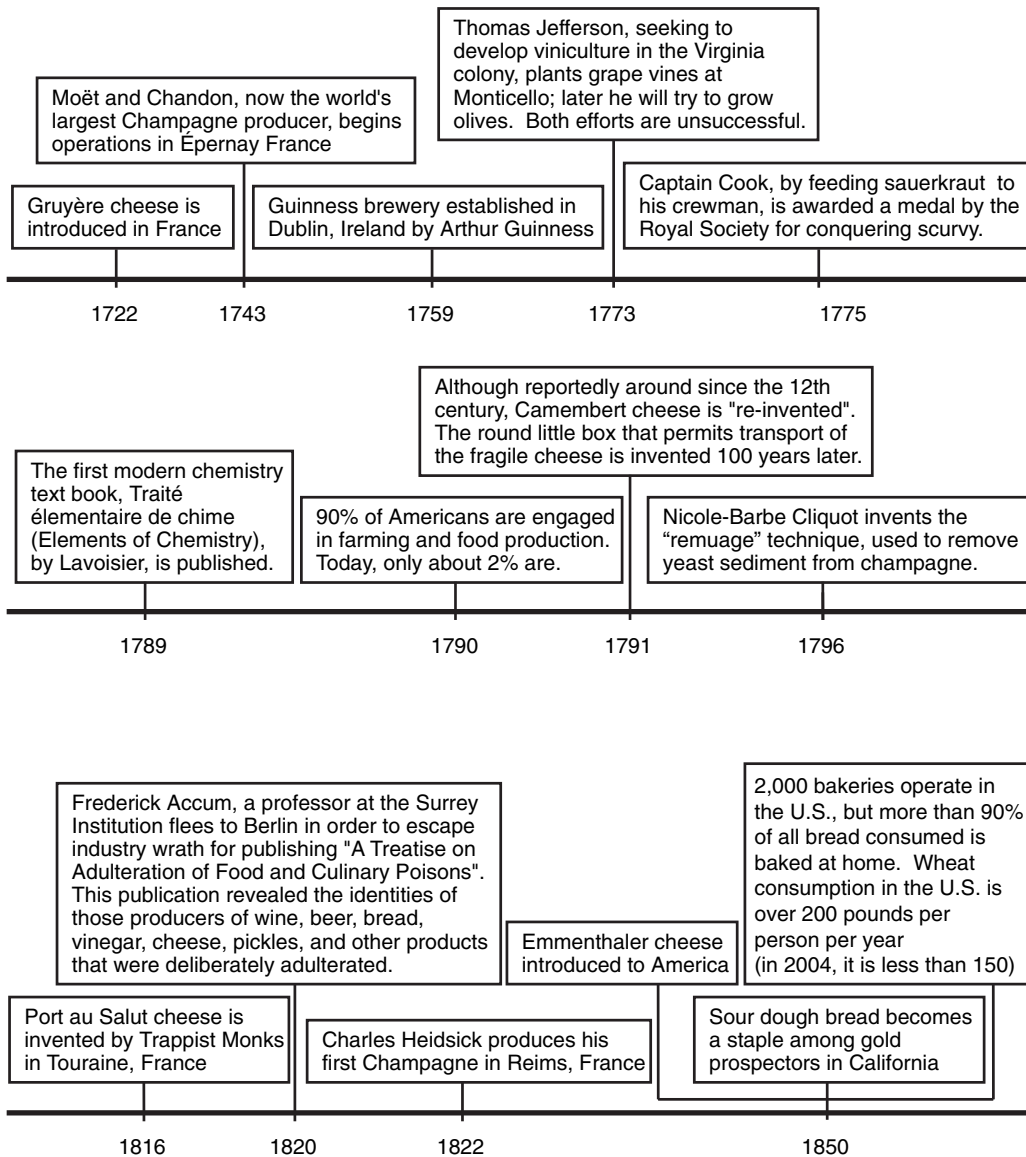


Figure 1-1. (Continued)

tion. Improvements in microscopy led Kützing, Schwann, and others to observe the presence of yeast cells in fermenting liquids, including beer and wine. These observations led Schwann to propose in 1837 (as recounted by Barnett, 2003) that "it is very probable that, by means of the development of the fungus, fermentation is

started." The suggestion that yeasts were actually responsible for fermentation was not widely accepted, however; and instead it was argued by his contemporaries (namely Berzelius, Liebig, and Wöhler) that fermentation was caused by aerobic chemical reactions and that yeasts were inert and had nothing to do with fermentative

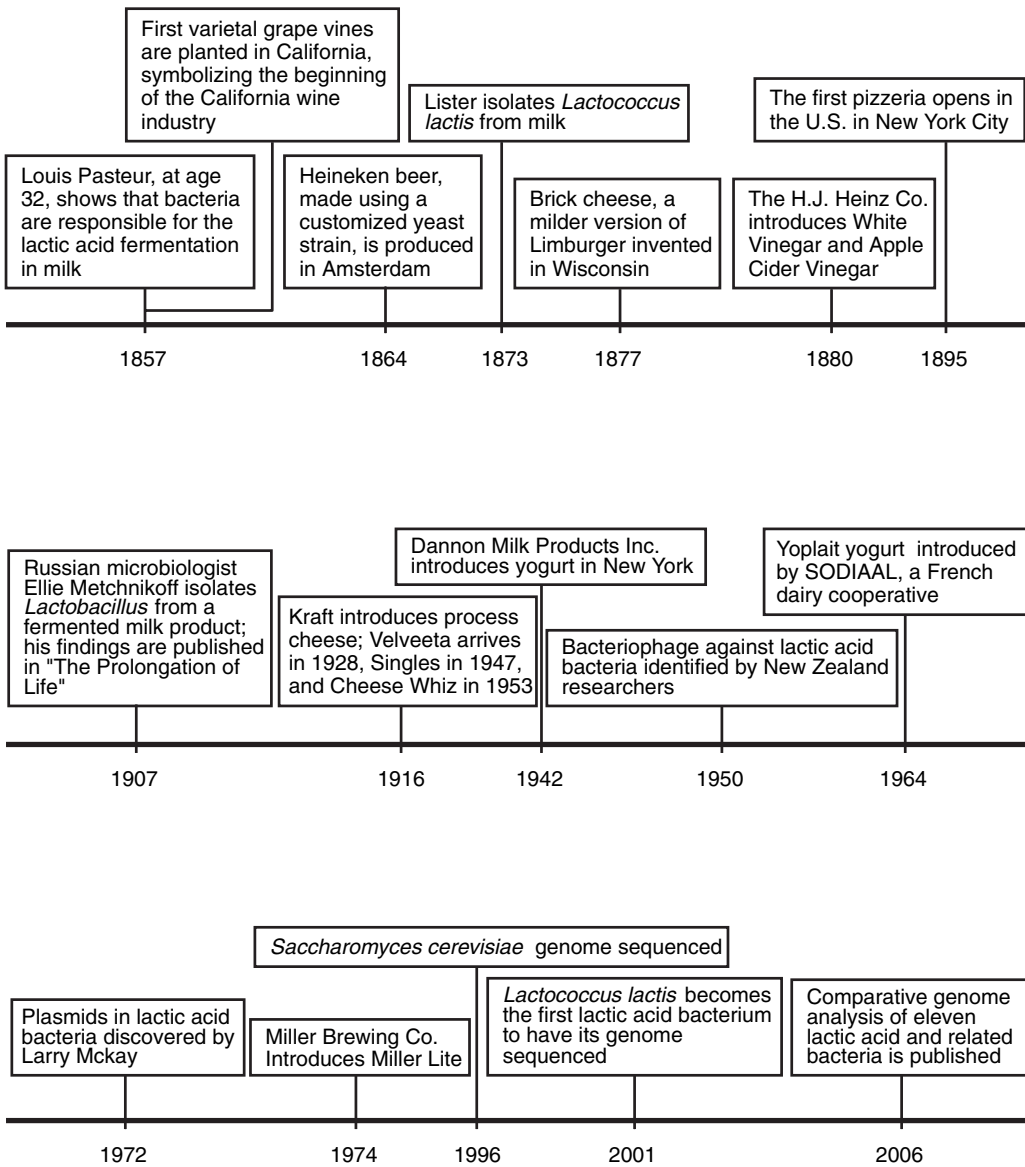


Figure 1-1. (Continued)

processes. The debate over the role of microorganisms in fermentation was brought to an unequivocal conclusion by another chemist, Louis Pasteur, who wrote in 1857 that “fermentation, far from being a lifeless phenomenon, is a living process” which “correlates with the development of . . . cells and plants which I have prepared and studied in an isolated and pure state”

(Schwartz, 2001). In other words, fermentation could only occur when microorganisms were present. The corollary was also true—that when fermentation was observed, growth of the microorganisms occurred.

In a series of now famous publications, Pasteur described details on lactic and ethanolic fermentations, including those relevant to milk

Box 1–2. Fermented foods and the Bible.

The importance of fermented foods and beverages to the cultural history of human societies is evident from many references in early written records. Of course, the Bible (Old and New Testaments) and other religious tracts are replete with such references (see below). Fermented foods, however, also serve a major role in ancient Eastern and Western mythologies.

The writers, who had no scientific explanation for the unique sensory and often intoxicating properties of fermented foods, described them as “gifts of the gods.” In Greek mythology, for example, Dionysus was the god of wine (Bacchus, according to Roman mythology). The Iliad and the Odyssey, classic poems written by the Greek poet Homer in about 1150 B.C.E., also contain numerous references to wine, cheese, and bread. Korean and Japanese mythology also refers to the gods that provided miso and other Asian fermented foods (Chapter 12).

Fermented foods and the Bible

From the Genesis story of Eve and the apple, to the dietary laws described in the books of Exodus and Leviticus, food serves a major metaphoric and thematic role throughout the Old Testament. Fermented foods, in particular, are frequently mentioned in biblical passages, indicating that these foods must have already been well known to those cultures and civilizations that lived during the time at which the bible was written.

In Genesis (9:20), for example, one of the first actions taken by Noah after the flood waters had receded was to plant a vineyard. In the very next line, it is revealed that Noah drank enough wine to become drunk (and naked), leading to the first, but certainly not last, episode in which drunkenness and nakedness occur. Later in Genesis (18:8), Abraham receives three strangers (presumably angels), to whom he offers various refreshments, including “curds.”

Perhaps the most relevant reference to fermentation in the Bible is the Passover story. As described in Exodus (12:39), once Moses had secured the freedom of the Hebrew slaves, they were “thrust out of Egypt, and could not tarry.” Thus, the dough could not rise or become leavened, and was baked instead in its “unleavened” state. This product, called matzoh, is still eaten today by people of the Jewish faith to symbolically commemorate the Hebrew exodus.

Ritual consumption of other fermented foods is also prescribed in Judaism. Every Sabbath, for example, the egg bread, Challah, is to be eaten, and grapes or wine is to be drunk, preceded by appropriate blessings of praise.

Fermented foods are also featured prominently in the New Testament. At the wedding in Cana (John 2:1–11), Jesus’ first miracle is to turn water into wine. Later (John 6:1–14), another miracle is performed when five loaves of bread (and two fish) are able to feed 5,000 men. The Sacrament of Holy Communion (described by Jesus during the Last Supper) is represented by bread and wine.

fermentations, beer, and wine. He also identified the organism that causes the acetic acid (i.e., vinegar) fermentation and that was responsible for wine spoilage. The behavior of yeasts during aerobic and anaerobic growth also led to important discoveries in microbial physiology (e.g., the aptly named Pasteur effect, which accounts for the inhibitory effect of oxygen on glycolytic metabolism). Ultimately, the recognition that fermentation (and spoilage) was caused by microorganisms led Pasteur to begin working on other microbial problems, in particular, infec-

tious diseases. Future studies on fermentations would be left to other scientists who had embraced this new field of microbiology.

Once the scientific basis of fermentation was established, efforts soon began to identify and cultivate microorganisms capable of performing specific fermentations. Breweries such as the Carlsberg Brewery in Copenhagen and the Anheuser-Busch brewery in St. Louis were among the first to begin using pure yeast strains, based on the techniques and recommendations of Pasteur, Lister, and others. By the

early 1900s, cultures for butter and other dairy products had also become available. The dairy industry was soon to become the largest user of commercial cultures, and many specialized culture supply “houses” began selling not only cultures, but also enzymes, colors, and other products necessary for the manufacture of cheese and cultured milk products (Chapter 3). Although many cheese factories continued to propagate their own cultures throughout the first half of the century, as factory size and product throughput increased, the use of dairy starter cultures eventually became commonplace. Likewise, cultures for bread, wine, beer, and fermented meats have also become the norm for industries producing those products.

The Modern Fermented Foods Industry

The fermented foods industry, like all other segments of the food processing industry, has changed dramatically in the past fifty years. Certainly, the average size of a typical production facility has increased several-fold, as has the rate at which raw materials are converted to finished product (i.e., throughput). Although small, traditional-style facilities still exist, as is evident by the many microbreweries, small wineries, and artisanal-style bakery and cheese manufacturing operations, the fermented foods industry is dominated by producers with large production capacity.

Not only has the size of the industry changed, but so has the fundamental manner

in which fermented foods are produced (Table 1-1). For example, up until the past forty or so years, most cheese manufacturers used raw, manufacturing (or Grade B) milk, whereas pasteurized Grade A milk, meeting higher quality standards, is now more commonly used. Manufacturing tanks or vats are now usually enclosed and are constructed from stainless steel or other materials that facilitate cleaning and even sterilization treatments. In fact, modern facilities are designed from the outset with an emphasis on sanitation requirements, so that exposure to air-borne microorganisms and cross-contamination is minimized.

Many of the unit operations are mechanized and automated, and, other than requiring a few keystrokes from a control panel, the manufacture of fermented foods involves minimal human contact. Fermented food production is now, more than ever before, subject to time and scheduling demands. In the so-called “old days,” if the fermentation was slow or sluggish, it simply meant that the workers (who were probably family members) would be late for supper, and little else. In a modern production operation, a slow fermentation may mean that the workers have to stay beyond their shift (requiring that they be paid overtime), and in many cases, it could also affect the entire production schedule, since the production vat could not be turned over and refilled as quickly as needed. Although traditional manufacturing practices may not have always yielded consistent products, lot sizes were small and economic losses due to an occasional misstep were not likely to be too se-

Table 1.1. Fermented foods industry: past and present

Traditional	Modern
Small scale (craft industry)	Large scale (in factories)
Non-sterile medium	Pasteurized or heat-treated medium
Septic	Aseptic
Open	Contained
Manual	Automated
Insensitive to time	Time-sensitive
Significant exposure to contaminants	Minimal exposure to contaminants
Varying quality	Consistent quality
Safety a minor concern	Safety a major concern

rious. Besides, for every inferior cask of wine or wheel of cheese, there may have been an equally superior lot that compensated for the one that turned out badly. Even the absolute worst case scenario—a food poisoning outbreak as a result of an improperly manufactured product—would have been limited in scope due to the small production volume and narrow distribution range.

Such an attitude, today, however, is simply beyond consideration. A day's worth of product may well be worth tens, if not hundreds of thousands of dollars, and there is no way a producer could tolerate such losses, even on a sporadic basis. Food safety, in particular, has become an international priority, and there is generally zero tolerance for pathogens or other hazards in fermented foods. Quality assurance programs now exist throughout the industry, which strive to produce safe and consistent products. In essence, the fermented foods industry has evolved from a mostly art- or craft-based practice to one that relies on modern science and technology. Obviously, the issues discussed above—safety, sanitation, quality, and consistency—apply to all processed foods, and not just fermented foods. However, the fermented foods industry is unique in one major respect—it is the only food processing industry in which product success depends on the growth and activity of microorganisms. The implications of this are highly significant.

Microorganisms used to initiate fermentations are, unlike other “ingredients,” not easily standardized, since their biochemical activity and even their concentration (number of cells per unit volume) may fluctuate from lot to lot. Although custom-made starter cultures that are indeed standardized for cell number and activity are readily available, many industrial fermentations still rely, by necessity, on the presence of naturally-occurring microflora, whose composition and biological activities are often subject to considerable variation. In addition, microorganisms are often exposed to a variety of inhibitory chemical and biological agents in the food or environment that can compromise their viability and activity. Finally, the culture

organisms are often the main means by which spoilage and pathogenic microorganisms are controlled in fermented foods. If they fail to perform in an effective and timely manner, the finished product will then be subject to spoilage or worse. Thus, the challenge confronting the fermented foods industry is to manufacture products whose very production is subject to inherent variability yet satisfy the modern era demands of consistency, quality, line-speed, and safety.

Properties of Fermented Foods

As noted in the previous discussion, fermented foods were among the first “processed” foods produced and consumed by humans. Their popularity more than 5,000 years ago was due to many of the same reasons why they continue to be popular today (Table 1-2).

Preservation

The preservation aspect of fermented foods was obviously important thousands of years ago, when few other preservation techniques existed. A raw food material such as milk or meat had to be eaten immediately or it would soon spoil. Although salting or smoking could be used for some products, fermentation must have been an attractive alternative, due to other desirable features. Preservation was undoubtedly one of the main reasons why fermented foods became such an integral part of human diet. However, even today, preservation, or to use modern parlance, shelf-life (or extended shelf-life), is still an important feature of fermented foods. For example, specialized cultures that contain organisms that produce

Table 1.2. Properties of fermented foods

Enhanced preservation
Enhanced nutritional value
Enhanced functionality
Enhanced organoleptic properties
Uniqueness
Increased economic value

specific antimicrobial agents in the food are now available, providing an extra margin of safety and longer shelf-life in those foods.

Nutrition

The nutritional value of fermented foods has long been recognized, even though the scientific bases for many of the nutritional claims have only recently been studied. Strong evidence that fermentation enhances nutritional value now exists for several fermented products, especially yogurt and wine. Fluid milk is not regularly consumed in most of the world because most people are unable to produce the enzyme β -galactosidase, which is necessary for digestion of lactose, the sugar found naturally in milk. Individuals deficient in β -galactosidase production are said to be lactose intolerant, and when they consume milk, mild-to-severe intestinal distress may occur. This condition is most common among Asian and African populations, although many adult Caucasians may also be lactose intolerant.

Many studies have revealed, however, that lactose-intolerant subjects can consume yogurt without any untoward symptoms and can therefore obtain the nutritional benefits (e.g., calcium, high quality protein, and B vitamins) contained in milk. In addition, it has been suggested that there may be health benefits of yogurt consumption that extend beyond these macronutrients. Specifically, the microorganisms that perform the actual yogurt fermentation, or that are added as dietary adjuncts, are now thought to contribute to gastrointestinal health, and perhaps even broader overall well-being (Chapter 4).

Similarly, there is now compelling evidence that wine also contains components that contribute to enhanced health (Chapter 10). Specific chemicals, including several different types of phenolic compounds, have been identified and shown to have anti-oxidant activities that may reduce the risk of heart disease and cancer. That wine (and other fermented foods) are widely consumed in Mediterranean countries where mortality rates are low has led to

the suggestion that a “Mediterranean diet” may be good for human health.

Functionality

Most fermented foods are quite different, in terms of their functionality, from the raw, starting materials. Cheese, for example, is obviously functionally different from milk. However, functional enhancement is perhaps nowhere more evident than in bread and beer. When humans first collected wheat flour some 10,000 years ago, there was little they could do with it, other than to make simple flat breads. However, once people learned how to achieve a leavened dough via fermentation, the functionality of wheat flour became limitless. Likewise, barley was another grain that was widespread and had use in breadmaking, but which also had limited functionality prior to the advent of fermentation. Given that barley is the main ingredient (other than water) in beer manufacture, could there be a better example of enhanced functionality due to fermentation?

Organoleptic

Simply stated, fermented foods taste dramatically different than the starting materials. Individuals that do not particularly care for Limburger cheese or fermented fish sauce might argue that those differences are for the worse, but there is little argument that fermented foods have aroma, flavor, and appearance attributes that are quite unlike the raw materials from which they were made. And for those individuals who partake of and appreciate Limburger cheese, the sensory characteristics between the cheese and the milk make all the difference in the world.

Uniqueness

With few exceptions (see below), there is no way to make fermented foods without fermentation. Beer, wine, aged cheese, salami, and sauerkraut simply cannot be produced any other way. For many fermented products, the

very procedures used for their manufacture are unique and require strict adherence. For example, Parmesan cheese must be made in a defined region of Italy, according to traditional and established procedures, and then aged under specified conditions. Any deviation results in forfeiture of the name Parmesan. For those “fermented” foods made without fermentation (which includes certain fresh cheeses, sausages, and even soy sauce), their manufacture generally involves direct addition of acids and/or enzymes to simulate the activities normally performed by fermentative microorganisms. These products (which the purist might be inclined to dismiss from further discussion) lack the flavor and overall organoleptic properties of their traditional fermented counterparts.

Economic value

Fermented foods were the original members of the value-added category. Milk is milk, but add some culture and manipulate the mixture just right, age it for a time, and the result may be a fine cheese that fetches a price well above the combined costs of the raw materials, labor, and other expenses. Grapes are grapes, but if grown, harvested, and crushed in a particular environment and at under precise conditions, and the juice is allowed to ferment and mature in an optimized manner, some professor may well pay up to \$6 or \$7 (or more!) for a bottle of the finished product. Truly, the economic value of fermented foods, especially fermented grapes, can reach extraordinary heights (apart from the professor market). As noted in Chapter 10, some wines have been sold for more than \$20,000 per bottle. Even some specialty vinegars (Chapter 11) sell for more than \$1,000 per liter. It should be noted that not all fermented foods command such a high dollar value. In truth, the fermented foods market is just as competitive and manufacturers are under the same market pressures as other segments of the food industry. Fermented foods are generally made from inexpensive commodities (e.g., wheat, milk, meat, etc.) and most products have very modest profit margins (some products, such as “current” or un-

aged cheese, are sold on commodity markets, with very tight margins). There is a well-known joke about the wine business that applies to other products as well, and that summarizes the challenge in making fermented foods: “How do you make a million dollars in the wine business? Easy, first you start with two million dollars.” Finally, on an industry-wide basis, fermented foods may have a significant economic impact on a region, state or country. In California, for example, the wine industry was reported to contribute more than \$40 billion to the economy in 2004 (according to a Wine Institute report; www.wineinstitute.org). A similar analysis of the U.S. beer industry (www.beerinstitute.org) reported an overall annual impact of more than \$140 billion to the U.S. economy.

Fermented Foods in the Twenty-first Century

For 10,000 years, humans have consumed fermented foods. As noted above, originally and throughout human history, fermentation provided a means for producing safe and well-preserved foods. Even today, fermented foods are still among the most popular type of food consumed. No wonder that about one-third of all foods consumed are fermented. In the United States, beer is the most widely consumed fermented food product, followed by bread, cheese, wine, and yogurt (Table 1-3). Global statistics are not available, but it can be estimated that alcoholic products head the list of most popular fermented foods in most of the world. In Asia, soy sauce production and consumption ranks at or near the top. Collectively, sales of fermented foods on a global basis exceeds a trillion dollars, with an even greater overall economic impact.

Although fermented foods have been part of the human diet for thousands of years, as the world becomes more multicultural and cuisines and cultures continue to mix, it is likely that fermented foods will assume an even more important dietary and nutritional role. Foods such as kimchi (from Korea), miso (from Japan), and kefir (from Eastern Europe) are fast becoming part

Table 1.3. U.S. production and consumption of selected fermented foods^a

Food	Production	Consumption ^b
Wine	2.3×10^9 L	9 L
Beer	23×10^9 L	100 L
Cheese	4×10^9 Kg	14 Kg
Yogurt	1.2×10^9 Kg	3.4 Kg
Fermented meats	na ^c	0.3 Kg
Bread	7×10^9 Kg	25 Kg
Fermented vegetables	0.8×10^9 Kg	2.8 Kg

^aSources: 2001–2004 data from USDA, WHO, and industry organizations^bPer person, per year^cNot available

of the Western cuisine. Certainly, the desirable flavor and sensory attributes of traditional, as well as new-generation fermented foods, will drive much of the interest in these foods.

Consumption of these products also will likely be increased as the potential beneficial effects of fermented foods on human health become better established, scientifically and clinically. As noted above, compelling evidence now exists to indicate that red wine may reduce the risk of heart disease and that live bacteria present in cultured milk products may positively influence gastrointestinal health. Armed now with extensive genetic information on the microorganisms involved in food fermentations that has only become available in the last century, it is now possible for researchers to custom-produce fermented foods with not only specific

flavor and other functional characteristics, but that also impart nutritional properties that benefit consumers.

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