Cheese and bread are just two of the many food products that are produced by fermentation.

**Objectives**

After studying this chapter, you will be able to:

- describe the types of microbes that impact the food supply.
- list factors that impact the growth of single-celled organisms.
- differentiate among yeast, bacterial, and mold fermentation.
- identify food products that are a result of fermentation.

**Key Terms**

- microbiology
- microorganism
- microbe
- Monera
- Fungi
- bacteria
- micrometer
- cytoplasm
- bacilli
- cocci
- spirilla
- Gram’s stain
- aerobic
- anaerobic
- facultative
- fungus
- hyphae
- mycelium
- spore
- mold
- yeast
- pure culture
- starter
- proteolytic
- lipolytic
- halophilic
- genus
- species
- pasteurization
- fermentation
- by-product
- brine
- curd
Microbiology is the study of living organisms too small to be seen by the unaided human eye. Living organisms that are only visible through a microscope are called microorganisms or microbes. Microbes are all around you. They are in the soil under your feet and on the desk in front of you. They are in the air you breathe, the water you drink, and the food you eat. They multiply rapidly, transfer from one surface to another easily, and blow around in the wind.

You may be unaware that microbes are unavoidable. Perhaps you would rather not think about the fact that microbes live on and in you. However, you can think of many microbes as friends and allies. There are thousands of different microorganisms. Several hundred of these are associated in one way or another with the production of food products. Without microbes, many foods you enjoy would not be possible. Foods produced with the help of microbes include chocolate, coffee, tea, cheese, soy sauce, pickles, sauerkraut, and yeast breads.

This chapter will look at the main kinds of microbes. You will study how they multiply and how they change food into new products. You will also read about how the nutritional value of foods is affected by microbes.

The Types of Single-Celled Organisms

Three categories of microbes can have positive uses in foods. They are bacteria, yeasts, and molds. These microbes have some similarities. Individually, they cannot be seen by the human eye. They reproduce very rapidly when given the right environment. They also depend on outside sources of food to grow and multiply.

Research in the twentieth century changed scientific understanding of microscopic organisms. This led to disagreement on how to classify microbes. Most of the microbes that affect the food supply belong to one of two kingdoms of organisms. Most biologists classify bacteria as members of the Monera kingdom. Yeasts and molds are members of the Fungi kingdom.

Bacteria

Bacteria are extremely small single-celled organisms that multiply through cell division. The head of a pin can hold thousands of bacteria. These microbes must be magnified 1,000 times with a microscope to make them visible. Bacteria are usually one to three micrometers (µm) in length. A micrometer is one-thousandth (0.001) of a millimeter. Suppose you were to lay bacteria that are 1 µm in length end to end. It would take 1,000 of them to equal 1 millimeter. It would take one million of these bacteria to equal 1 meter.

Bacteria cells have rigid walls and no nucleus. The cells are filled with a gelatinous liquid called cytoplasm. The processes of metabolism and reproduction take place within this liquid. Bacteria are classified according to their shape, their cell wall structure, and their oxygen needs.

Bacteria have three basic shapes: rod, spherical, and spiral. Rod-shaped bacteria are called bacilli. Spherical bacteria are called cocci. Spiral bacteria are called spirilla. See 17-1.

Bacteria have two basic types of cell wall structures. The two types of cell walls are identified by their ability to be stained by a crystal violet dye. One of the first steps in identifying a type of bacteria is a staining process called Gram's stain. Hans Christian Gram developed Gram's stain in 1884. He developed the process because bacteria cells are nearly colorless. This makes them difficult to see, even with a microscope. Gram-positive cell walls will turn blue-violet during the staining process. Gram-negative cells will turn red. See 17-2.

Doctors need to be able to tell the two types of bacteria cell wall structures apart. This allows doctors to decide what medicine to prescribe for a bacterial infection. Many antibiotics will kill either gram-negative or gram-positive bacteria but not both. Plant cell walls and animal cell membranes are not made of the same material as bacteria cell walls. This is why antibiotics can kill bacteria without damaging body tissue.

The oxygen needs of bacteria are important to food scientists who work with food-related bacteria. Some bacteria need oxygen to
17-1 The three basic shapes of bacteria are bacilli (rods), cocci (spheres), and spirilla (spirals).

You can get an idea of how aerobic and anaerobic bacteria work from the example of cabbage. Cabbage spoils when aerobic bacteria are present and given time to multiply. Aerobic bacteria must have oxygen present for respiration to occur. In simple terms, respiration is the transfer of electrons to release energy for cellular function. In aerobes, oxygen is the electron receptor. In contrast, the enzymes in anaerobes will not function in the presence of oxygen. They use carbon dioxide or sulfur-or nitrogen-based compounds as electron receptors. If cabbage is submerged in water, where oxygen levels are low, anaerobic bacteria will begin to multiply. Sauerkraut is made by submerging cabbage in salt water. In this environment, the aerobes cannot spoil the cabbage because oxygen is unavailable. However, the anaerobes can grow, and they are responsible for developing the characteristic flavor and texture of sauerkraut.

Bacteria's rate of growth depends on their environment. When temperature, air, pH, and food supply are right, bacteria can reproduce in as little as 20 minutes. Bacteria reproduce by increasing their cell size. The cytoplasm material divides equally in half, and the cells split into two daughter cells. Every time the cells divide, the number of cells doubles.

Fungi

A fungus is a plant that lacks chlorophyll. It also lacks definite roots, stems, and leaves. Unlike bacteria, fungi are not always single-celled, and their cells contain a nucleus. Fungi include mildews, molds, mushrooms, rusts,
Fungi absorb nutrients through their mycelium structure and reproduce through spores. Mycelia tend to grow in a circular pattern. This pattern is created as the hyphae extend outward from a spore or a single cell. When a mycelium becomes large enough, it is visible without magnification.

Of the various types of fungi, molds and yeasts play key roles in food processing. Most yeast and mold cells are three to five times larger than the cells of bacteria. Molds and yeasts vary in length, width, and structure.

Chapter 17  Fermentation: Desirable Effects of Microbes

Smuts, and yeasts. They are widely distributed in nature and play a major role in helping organic matter decay. They break down the complex macromolecules of organic matter into usable nutrients, which they absorb.

Fungi are classified by their structure and reproduction methods. The basic structure of most fungi is made of filaments or tubes called hyphae. Hyphae are elongated cells or chains of cells that absorb nutrients from the environment. As the hyphae lengthen, they intertwine and form a branched network called a mycelium. Part of the mycelium grows down into an energy source to absorb nutrients. The other part remains in the air above the energy source and reproduces through spores.

Spores could be called the seeds of fungi. Spores usually develop in a sac- or balloonlike structure. This structure explodes when full, sending spores out into the surrounding air. Spores are microscopic, resistant to harsh environments, and easily carried to other surfaces. See 17-3.

Historical Highlight
Food Poisoning in Salem, MA?

In Salem, Massachusetts, in 1692, over 100 people were accused of witchcraft. Twelve were found guilty and hanged. The teenage girls who made the accusations suffered from a number of symptoms. These symptoms were similar to those of people who take hallucinogenic drugs like LSD.

A fungus that grows on rye when the weather is especially cool and wet is called Claviceps purpurea. (Its common name is ergot.) One of the by-products of this fungus is LSD, a powerful hallucinogen. The fungus can cause a foodborne illness known as convulsive ergotism. The symptoms range from mild to severe and can even cause death, especially among the young. The disease causes prickling feeling to severe pain in the joints. There may also be blindness, deafness, hallucinations, fits, and laughing and crying spells.

Outbreaks of ergotism occur throughout the world when rye crops are weakened by cold and damp weather. Historical records indicate these conditions existed in New England from 1690 to 1692. This is one of many possible explanations proposed for the events in Salem.
Molds

*Molds* are fungi that form a mycelium structure with a fuzzy appearance. Visible molds have a wide range of colors. These colors include yellow, rust, red, green, and black. Many molds give off an antibiotic that kills bacteria likely to be growing in the same area.

Like other fungi, molds reproduce through spores. During their reproductive stage, some molds produce a visible spore case. This spore case is called a *basidiocarp*. The basidiocarp has a stem, a cap, and gills. The gills, which contain the spores, are located under the cap. The stem lifts the cap and gills into the air so the wind can disperse the spores. Mushrooms, toadstools, and puffballs are examples of basidiocarps produced by molds, 17-4.

Yeast

*Yeasts* are fungi with a single-celled structure. They reproduce by budding. This means they form buds that swell and separate into a duplicate cell or form a chain of cells. Reactions involving yeast result in the production of alcohol.

A unique feature of some fungi, including some yeasts, is the ability to form both mycelium and single-celled structures. When a spore from one of these fungi lands on soil or plants, it produces a mycelium structure. When these fungi are found in people or animals, they reproduce by budding. See 17-5.

Common Characteristics of Microbes

Both bacteria and fungi grow very rapidly and can be good sources of edible protein. Microbial sources of protein are used in animal feed. Research is underway to develop microbial proteins that are safe for human consumption. Microbes enhance or add to the nutritional value of foods. An example is yeast bread. When yeast dough is held at room temperature for one hour, it will double in volume. The increase in volume is caused by carbon dioxide, which is released as the yeast feed, grow, and multiply. Yeast cells in baked bread add small amounts of protein, vitamins, and minerals. Baking kills the yeast but does not destroy the nutritious value of the yeast.

Bacteria and fungi can also enter a dormant, or inactive, state. This last characteristic allows these microbes to protect themselves. When temperature, pH, moisture level, or the surrounding air becomes harsh, the cells will dehydrate themselves. The dehydrated cells can remain dormant for long periods. As soon as the environment matches a cell’s growth needs, the cell will rehydrate and begin to reproduce again.

The ability of microbes to go into a dormant state helps manufacturers mass-produce them. Manufacturers isolate the desired microbe and create ideal conditions for it to grow. The result is a *pure culture*, which is a large volume of one type of microbe that has purposely been grown in a nutrient medium. After mass-producing a desired microbe, manufacturers create an environment that encourages the microbes to dehydrate themselves. Manufacturers can ship cultures or
dehydrated microbes to food processing plants. At processing plants, large volumes of microbes are used in the development of foods such as cheeses, pickles, and beverages. When a pure culture is mixed with a food source, a starter is made. A starter is a substance containing microorganisms that is added to food to bring about desired flavor, texture, and/or color changes. Once starters are mixed, the microbes come out of the dormant state. Then they can begin to reproduce and change a food product.

**Microbial Enzymes**

Changes in food products are usually a result of enzymes produced by the microbes in the food. Microbes use large organic molecules as a food source. However, most organic molecules are too large to be transported through a microbe's cell wall. To access the energy in these compounds, microbes excrete digestive enzymes. These enzymes break down the large molecules. Then the microbes can absorb the resulting fragments and use them as fuel.

Another way to classify microbes is by the type of organic molecules they use as food sources. The classifications are based on the types of enzymes produced by the microbes. Most microbes rely on sugars and starches for their energy source. These microbes produce a variety of carbohydrases. See 17-6.

A few microbes rely on protein as their food source. Microbes that make enzymes to digest protein are called proteolytic. Proteolytic microbes change proteins to amino acids. Some uses of proteolytic bacteria in food production are tenderizing meat and clotting milk. Proteolytic bacteria also help remove the outside pulp and develop the chocolate flavor of cacao beans.

Lipolytic microbes produce enzymes that digest fats. Some uses include flavor production in cheese and removing egg yolk from egg white. A nonfood use of lipolytic bacteria is to help clean up industrial oil spills. The bacteria digest the oil and change it into a form that is easily removed from the environment.

A few microbes thrive in salty environments. They are found in nature in salt deposits that result from the evaporation of seawater. Microbes that require high salt concentrations to function are called halophilic.

### Uses for Sugar- and Starch-Digesting Microbes

<table>
<thead>
<tr>
<th>Enzymes Produced</th>
<th>Microbial Sources</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amylases</td>
<td>Aspergillus</td>
<td>Convert starch to sugar for baking, brewing, and syrup production</td>
</tr>
<tr>
<td></td>
<td>Rhizopus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bacillus</td>
<td></td>
</tr>
<tr>
<td>Cellulases</td>
<td>Aspergillus</td>
<td>Change cellulose to fermentable products</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Clarify fruit juices</td>
</tr>
<tr>
<td>Sucrases</td>
<td>Saccharomyces</td>
<td>Convert maltose to glucose in brewing</td>
</tr>
<tr>
<td></td>
<td>Streptomyces</td>
<td>Convert glucose to fructose in corn syrup</td>
</tr>
<tr>
<td></td>
<td>Aspergillus</td>
<td>Convert glucose to gluconic acid in liquid eggs</td>
</tr>
<tr>
<td></td>
<td>Penicillium</td>
<td></td>
</tr>
<tr>
<td>Invertases</td>
<td>S. cerevisiae</td>
<td>Convert sucrose to glucose and fructose</td>
</tr>
<tr>
<td></td>
<td>Candida utilis</td>
<td>Prevent crystallization in soft-centered candies</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Aid in production of artificial honey</td>
</tr>
<tr>
<td>Pectinases</td>
<td>Aspergillus</td>
<td>Clarify wine and fruit juice</td>
</tr>
<tr>
<td></td>
<td>Rhizopus</td>
<td>Release juice from fruit for increased yields</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Remove pectin for the production of concentrated fruit juices</td>
</tr>
</tbody>
</table>

17-6 Microbes that produce carbohydrate-digesting enzymes are used for a variety of food processing functions.
Such microbes are used in Asia to make several fish- and soybean-based products, including Chinese cheese and bean cake.

Bacteria have varying tolerances for salt. The addition of salt to cabbage helps slow the growth of spoilage bacteria, which have a low tolerance to salt. The bacteria that develop the characteristic flavor and texture of sauerkraut tolerate higher levels of salt.

Scientific Names for Microbes

Microbes are classified by two Latin names. The first is the name of their genus. A genus is a group of living organisms that have similar characteristics. You could say that the genus is a family name like your last name. The name of the genus is always capitalized.

The second Latin name used to classify microbes is the name of the species. Species is the basic category of the classification of living organisms. It identifies the type of microbe within the family and is never capitalized.

An example of a microbe name is Lactobacillus acidophilus. This is the name of a bacterium used in the processing of fruits, vegetables, meats, and dairy products. Lacto refers to milk. It is the same root used in the term lactose, which is milk sugar. The -bacillus ending on the first name indicates the bacteria cells have a rod shape. The endings -bacter, -monas, and -ella also indicate rod-shaped bacteria. The -coccus ending is used if the genus of bacteria has a spherical shape. (None of the spiral-shaped bacteria are used in food production.) The species name acidophilus indicates the bacteria give off an acid. Therefore, the name Lactobacillus acidophilus tells you this bacterium probably lives in or feeds on milk. From the name, you can also tell the bacterium has a rod shape and produces an acid.

Scientists often abbreviate these long Latin names when referring to particular microbes. Scientists typically use only the initial of the genus name. For example, Lactobacillus acidophilus is shortened to L. acidophilus. In this book, the first time a bacterium is discussed, the full name will be written. After that, the name will be abbreviated.

Factors Affecting Microbe Growth

A number of factors are known to affect the growth of microbes. These are food supply, water availability, pH, and temperature. However, the specific conditions that best support growth differ for each type of microbe. Each microbe has a preferred range within each factor. Therefore, there is no one set of guidelines that can be followed for every bacterium, mold, and yeast.

Food Supply

Microbes are composed of complex molecules made from carbon, oxygen, nitrogen, and hydrogen. Therefore, microbes need a food supply that provides these four chemical building blocks. Most microbes use organic compounds (carbohydrates, lipids, or proteins) as a main source for these chemicals.

Some microbes need protein for their food supply. Other microbes need lipids, and others need starches. Some microbes can feed off several types of macromolecules. The food supply needed by a microbe depends on the enzyme systems the organism can make. If a bacterium can only produce proteolytic enzymes, then it will only be able to digest proteins. A proteolytic bacterium could be surrounded by sugar and never reproduce. This is not because there is no source of energy. It is because the energy is in a form the bacterium cannot use.

Microbes need small amounts of minerals to enhance enzyme activity. Microbes need vitamins, too. Many vitamins act as coenzymes. Therefore, a microbe's need for vitamins varies according to the enzyme reactions the microbe performs. The microbe must absorb directly from its food supply any vitamin it cannot produce.

Water

Like all living organisms, microbes need water to function. Some microbes are able to remain alive in a dried condition. These microbes survive but cannot grow or reproduce.
Microbiologists have found a group of bacteria called *carboxydothobacteria*. These bacteria use carbon monoxide from automobile exhaust as their energy source. They reproduce rapidly in an environment of 50% air and 50% exhaust. The bacteria cells contain 65% crude protein. There are about 350 million cars in the world. Experts estimate these bacteria could produce 500,000 tons of protein per year from all the exhaust.

In the future, scientists could develop a method for producing this protein from carboxydothobacteria. Then they can mass-produce carboxydothobacteria to turn poisonous car exhaust into nutritious protein. Food scientists may have a new source of protein to use in producing tasty foods.

Food scientists measure water needs in terms of water activity, $a_w$. (See Chapter 7.) Pure water has an $a_w$ of 1.0. A saturated salt solution has an $a_w$ of 0.75. See 17-7.

Determining water needs of microbes can be difficult. This is because factors such as temperature and pH also impact whether a microbe will grow. Freezing temperatures make water unavailable to microbes. High water temperatures can kill microbes. For example, yeast dies when the water used in bread dough is too hot. The pH level also affects which type of microbe can grow at a given $a_w$ level. For example, the $a_w$ of most fruits is around 0.97. Bacteria should multiply rapidly in such an environment. However, the reason bacteria do not spoil many fruits has to do with the fruits' acidic pH. The low pH kills bacteria. This allows molds that usually prefer a lower $a_w$ to grow.

### Preferred $a_w$ Ranges for Microbes

<table>
<thead>
<tr>
<th>Microbe</th>
<th>Preferred $a_w$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria</td>
<td>0.83–0.96</td>
</tr>
<tr>
<td>most spoilage bacteria</td>
<td>0.90–0.91</td>
</tr>
<tr>
<td>Most yeasts</td>
<td>0.87–0.94</td>
</tr>
<tr>
<td>Most molds</td>
<td>0.70–0.80</td>
</tr>
</tbody>
</table>

A safe $a_w$ for most food storage is considered to be 0.70 or lower. There are three main ways to lower water activity level. These are removing water, adding solutes to the solution, and freezing. Removing water from the environment causes microbes to dehydrate. Adding solutes, such as sugar or salt, creates an imbalance that pulls water out of the microbe cells. Freezing locks water molecules into a crystalline structure and limits access to the water.

**pH**

Each type of microbe has a different preferred pH range. Many fruits have a pH of less
than 4. Most bacteria are killed if the pH is below 4.6. Molds, on the other hand, can survive with a pH as low as 1.5. This explains why molds are more likely than bacteria to spoil fruits. However, as molds grow on fruit, they release substances that can cause the pH of the fruit to rise. The pH of the fruit can become high enough for bacteria to begin to grow. This is especially true of bacteria that give off lactic or acetic acid. These bacteria will usually tolerate a lower pH than proteolytic bacteria, which produce ammonia. See 17-8.

**Temperature**

The last factor that affects microbe growth is temperature. You have already studied how freezing can slow enzyme activity and cell reproduction. Extreme cold generally does not kill microbes. It slows them down or causes them to enter a dormant or resting state. On the other hand, heating can kill microbes. The temperatures that support microbe growth are between the freezing and boiling points of water. The temperature at which microorganisms die is usually 5°C to 12°C (9°F to 22°F) above the temperature at which maximum growth occurs.

Food processors often use high temperatures to kill harmful microbes. Processors must think about how heating foods will affect quality and production costs as well as microbes. For example, pasteurization is a process in which a liquid is heated until pathogens and some spoilage bacteria have been destroyed. This process is used to help prevent disease that can be caused by harmful bacteria. It also helps lengthen the shelf life of milk. However, it can affect the flavor of milk. At a low pasteurization temperature of 63°C (145°F), it takes 30 minutes to kill the bacteria. This affects milk flavor to a more noticeable degree. Using a high pasteurization temperature of 72°C (161°F) for 15 seconds reduces the damage to the milk flavor. See 17-9.

Food scientists can successfully grow cultures of microbes for use in food processing. A culture can be a specific microbe or a mixture of select microbes. To produce the desired culture, scientists must create the right growing conditions. They need to know the microbe's preferred food supply, water activity level, pH, and temperature. Trained technicians are needed to keep track of these factors at each step in the growth process.

Ideal conditions for growing microbes are created in large vats or tanks. Producers mix the necessary food supply with a small amount of the desired microbe. The vats holding the food-microbe mix are kept within the

<table>
<thead>
<tr>
<th>Microbe</th>
<th>Minimum</th>
<th>Preferred</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bacteria (most)</td>
<td>2.9–6.0</td>
<td>6.5–7.5</td>
<td>8.0–10.0</td>
</tr>
<tr>
<td>Yeasts</td>
<td>1.5–3.5</td>
<td>4.0–6.5</td>
<td>8.0–8.5</td>
</tr>
<tr>
<td>Molds</td>
<td>1.5–3.5</td>
<td>4.0–6.8</td>
<td>8.5–10.5</td>
</tr>
</tbody>
</table>

17-8 The pH level of a food product affects what types of microbes can live in the product.

<table>
<thead>
<tr>
<th>Process</th>
<th>Temperature</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vat processing</td>
<td>67.2°C (153.0°F)</td>
<td>30 min.</td>
</tr>
<tr>
<td>High temperature-short time pasteurization</td>
<td>71.7°C (161.1°F)</td>
<td>15 sec.</td>
</tr>
<tr>
<td>Ultrapasteurization</td>
<td>138.0°C (280.4°F)</td>
<td>2 sec.</td>
</tr>
</tbody>
</table>

17-9 By increasing pasteurization temperatures, food processors can reduce the amount of time a product must be exposed to heat.
preferred temperature and pH levels to maximize microbe growth. The cultures are then shipped to manufacturers for use in various food products.

**Fermentation**

Food manufacturers often add microbes to foods to bring about fermentation. *Fermentation* is an enzymatically controlled change in a food product brought on by the action of microorganisms. Some desired changes in food products occur as microbes release digestive enzymes. These enzymes break down components in the food product. Other changes are caused by the release of by-products. A by-product is a substance that is produced in addition to the main product of a reaction. The primary product of a microbial reaction is energy. In producing energy, microbes also produce by-products such as carbon dioxide, acetic and lactic acids, and ethanol. Such by-products can change the color, texture, flavor, aroma, and pH of a food.

Fermentation is an anaerobic process. It relies on microorganisms that use organic compounds for their food supply. These microbes release enzymes to break down proteins, carbohydrates, and lipids that are nearby. After the enzymes break down these large molecules, the microbes absorb the smaller molecules through their cell walls. The microbes use these nutrients for growth and energy. Fermentation is the part of the process in which the nutrients are converted to energy.

Glucose is the energy source for most living organisms. It is converted into two pyruvate molecules. The next step is where fermentation occurs. Pyruvate is broken down into either an acid or alcohol and carbon dioxide. Many organisms can also break protein and lipids down into pyruvate for energy. Energy is released as by-products are formed from pyruvate.

Fermentation varies in terms of the by-products that are created. Microbes are grouped as to the by-products they give off as a result of fermentation. You will study the fermentation process, the types of by-products, and foods produced by yeasts, bacteria, and molds.

**Yeast Fermentation**

Foods fermented by yeast have been used since the dawn of recorded history. Babylonians used yeast to make beer as early as 6000 B.C. Egyptian tomb reliefs show the apparent commercial production of leavened bread, wine, and beer around 2400 B.C.

All yeast breads, alcoholic beverages, and vinegar require yeast in the production process. The most commonly used yeast is *Saccharomyces cerevisiae*. *S. cerevisiae* grows best in a warm, moist environment where sugars and/or starches are available. See 17-10. It is the main yeast in brewer’s yeast and is also used for breads.

*Saccharomyces* means sugar fungus. The *S. cerevisiae* family of yeasts relies on sugar as its main energy source. It can also feed on honey (high in fructose), molasses, or corn syrup. However, high levels of sugar in bread dough will slow yeast growth. This is because high sugar levels lower the $a_w$. When the $a_w$ drops too low, microbes cannot reproduce.

Although some types of yeast can hydrolyze starch, *S. cerevisiae* cannot. Some breads, such as Italian and French breads, do not contain an added sweetener. Therefore, these breads rely on added enzymes or amylases naturally found in the flour to break down the starch.

Some breads are prepared with quick-rising yeast. This is a commercially produced hybrid product made from two yeast strains.
The result is a yeast that releases both amylases and sucrases. This speeds the production of carbon dioxide as a by-product.

Before the commercial production of yeast, starters were the main source of yeast for baking. A yeast starter is a mixture of equal parts of flour and water that has natural yeast growing in it. Natural yeast is present in the air in small amounts. This yeast would settle onto the flour and water mixture. The yeast would use the mixture as a food source to grow and multiply. Bakers learned that adding the mixture to bread dough created a light, airy product when baked. The bakers discovered how to add some of the starter to the bread and save some for later. The saved portion would have equal amounts of flour and water added. It would be stirred and covered daily until the yeast had multiplied and it was time to bake bread again.

**Cooking Tip**

You can make a yeast starter by combining 250 mL (1 cup) water, 250 mL (1 cup) flour, and 1 package of yeast. The container used to store the starter should be no more than half full. This allows room for the starter to expand as the yeast feeds on the flour.

**Bread**

Yeast fermentation changes heavy, dense yeast dough into light, porous bread. Yeast is affected by several important steps in the bread-making process. The first step is mixing. Most yeast bread recipes call for warming liquids, which activates the yeast. Mixing the flour, liquid, and other ingredients distributes the yeast evenly throughout the dough. The dough is kneaded, or worked with the hands, to develop gluten. Gluten is an elastic protein substance formed when flour is combined with liquid and manipulated.

The second step in the bread-making process that affects yeast is proofing. Proofing means allowing the dough to sit in a warm environment. During the proofing time, the yeast releases enzymes so it can feed, grow, and multiply. These enzymes break down sugars in the dough, releasing alcohol (ethanol) and carbon dioxide as by-products. The carbon dioxide becomes trapped in small pockets throughout the dense dough. The pressure of the increasing volume of this trapped gas causes the gluten to stretch. This is what makes the dough rise.

Baking is the final step in bread making that affects yeast. During baking, the alcohol produced during proofing quickly evaporates and the yeast cells are killed. The remains of the yeast stay in the dough, providing some flavor and nutritional value. The yeast bread will continue to rise in the oven until a crust forms and the protein structure is set. This is because the carbon dioxide expands as it is heated. The result is a moist, light product.

If guidelines are not followed when making bread, the product may be unsatisfactory. For instance, yeast is killed by relatively low temperatures. The ideal temperature for yeast fermentation is 30°C to 35°C (86°F to 95°F). If the *S. cerevisiae* is hotter than 40°C (104°F), it will begin to die. If the yeast is killed before the dough is proofed, the bread will be heavy and flat. Bread recipes recommend heating the liquids to 41°C to 46°C (105°F to 115°F). This is because the addition of yeast cools the mixture to the ideal fermentation temperature range.

Two things happen if the dough is proofed too long. Keep in mind that the longer the dough sets, the more by-products are produced. When too much carbon dioxide is produced, the dough will be stretched too far. This will cause it either to collapse or develop a coarse, dry texture during baking. When too much alcohol is produced, the bread will have an undesirable flavor.

All bread products have the following ingredients in common: flour, yeast, salt, and water. Additional ingredients that are often used in yeast breads are eggs, milk, sugar, honey, molasses, spices, and seeds. These ingredients change the flavor, nutritive value, and/or texture of the finished bread.

**Wine**

Wine is the fermented juice of plant products. Honey, dandelions, and various fruits are used to produce wine. However, classical wines are made from fermented grape juice.

The quality of wine depends partly on which microbes are present. Therefore, many wine makers treat the crushed grapes to kill...
all wild yeasts, bacteria, and fungi that may be present. Sulfur dioxide (SO₂) or potassium metabisulfite is added to inhibit the growth of unwanted organisms. These sulfites also stabilize the wine color. The crushed grapes then have commercially produced yeasts (S. cerevisiae and S. ellipsoideus) added.

The yeast feeds on sugars naturally found in the fruit juice, releasing alcohol and carbon dioxide as by-products. The fermentation requires anaerobic conditions for one to four weeks. The fermenting juices are held in small oak barrels or large stainless steel tanks, 17-11. The fermentation process is complete when bubbling from carbon dioxide production stops. The wine is then put in barrels or vats for aging. Chemical interactions within the new wine slowly develop the characteristic flavors.

The original sweetness of wine is determined by the degree of fermentation and sugar content of the fruit. In sweeter wines, the fermentation process is stopped before the yeast breaks down all the sugar. These wines have an alcohol content of 8% to 9%. Less sweet, or dry, wines are allowed to ferment until the yeast has broken down all the sugar. These wines contain 12% to 14% alcohol. However, the sweetness and alcohol content of finished wines is sometimes adjusted by the addition of unfermented juice, sugar, and/or alcohol.

During wine production, the carbon dioxide produced as a by-product may be allowed to escape. It may also be collected, compressed, and sold for commercial uses. Sparkling wines, such as champagne, are made by retaining some of the carbon dioxide as a gas solute.

**Other Alcoholic Beverages**

In processes similar to wine making, yeast is used in the fermentation of other alcoholic beverages. The flavors and names of these beverages are determined by the food source used to feed the yeast. Beers are usually made from fermented, malted (germinated) barley. Sake is a Japanese beverage made from fermented rice.

After the fermenting process, whiskey is made by distilling the fermented mixture to concentrate the flavor and alcohol content. Irish whiskey is made from a variety of grains. Scotch whiskey is made mainly from barley.
The amount of contact grape juice has with the grape skins determines the color and flavor of wine. If the skins are removed one to two days after fermentation begins, the wine will be a rosé wine. This is a wine with a pink color. If the skins stay in the fermentation tanks for 5 to 10 days, the wine will be red. White grapes produce white wine.

However, red grapes can also be turned into white wine. This requires the skins to be removed before adding the yeast. Notice the next time you eat a red grape that only the skin has color.

Bourbon is a whiskey that originated in Kentucky. It is made from corn.

Fermented ingredients are distilled to make a number of other alcoholic beverages. Rum is made from sugar cane or molasses. Brandy is distilled wine or fermented fruit juice. Liqueurs and cordials usually have a brandy base with sugar and flavorings added. Popular liqueurs are crème de menthe, which is flavored with mint and curaçao, which is made from bitter oranges.

Bacterial Fermentation

Foods are fermented by microbes other than yeast. A number of types of bacteria are used to ferment food products. There are three main classes of bacterial fermentation. These are lactic acid, proteolytic, and acetic acid fermentation. Some foods require two separate fermenting agents.

Bacterial fermentation often causes texture changes and a unique sour flavor in foods. For instance, the thick texture and sour flavor of yogurt result when bacteria ferment milk. The sour taste is caused by acids that are released as by-products. The acids also act as preserving agents.

Lactic Acid Fermentation

Many of the foods produced through bacterial fermentation are fermented by bacteria whose major by-product is lactic acid. Some lactic acid bacteria also produce other by-products. These include acetic acid, formic acid, and carbon dioxide. Lactic acid bacteria are found in the genera (plural of genus) of Streptococcus, Pediococcus, Leuconostoc, and Lactobacillus. Lactic acid bacteria are used to ferment vegetables, meats, and dairy products. See 17-12.

Sauerkraut

Sauerkraut means acid cabbage. Sauerkraut is the result of lactic acid fermentation of cabbage submerged in a vat of brine. Brine is a mixture of salt and water. In this case, a 2% to 3% salt solution is used. The salt helps discourage the growth of unwanted bacteria and fungi by controlling water activity level. The salt also pulls water with dissolved
Chapter 17  Fermentation: Desirable Effects of Microbes

17-12 Lactic acid fermentation changes cucumbers into pickles and cabbage into sauerkraut.

Sugar and nutrients to the surface of the cabbage. This provides the water and food source needed for the bacteria to grow. If there is too little salt, the sauerkraut will be soft with a poor flavor. If there is too much salt, the lactic acid bacteria are slowed. The sauerkraut will be darkened, and yeast may begin to grow.

Three types of lactic acid bacteria that prefer the slightly salty environment work in succession over a three-week period. The bacteria feed on the sugar present in the cabbage. The cabbage is shredded to expose more surface area on which the bacteria can feed. The bacteria release mainly carbon dioxide and lactic acid into the brine. The result is a creamy white, shredded product with a soft but firm texture.

Air must be kept from the fermentation process to control the growth of yeasts and molds. The cabbage is weighted down below the surface of the brine. Sheets of plastic are laid over the vat to keep out dirt and air. This creates the necessary salty, anaerobic environment needed to make sauerkraut.

Pickles

Cucumbers can be turned into pickles by three basic methods. They may be heated in a spiced vinegar solution. They can be refrigerated in an acid brine. However, the oldest method is by fermentation with lactic acid bacteria. These processes are used to pickle foods other than cucumbers. Such foods include watermelon rinds, beets, cauliflower, okra, and onions.

When cucumbers are pickled, they are packed in a salt brine for the same reasons as cabbage. It is important that all carbohydrates used during the pickling process be fermentable. This is because bacteria, molds, and yeasts are found on cucumbers. If extra salt is not added during fermentation and simple carbohydrates remain, yeasts can begin to multiply. The yeast can feed off the lactic acid produced by the bacteria. This raises the pH and allows spoilage bacteria to contaminate the pickles.

Commercial pickling starts by washing the cucumbers in a chlorine solution. This removes unwanted yeasts and molds. If these microorganisms are not removed, they can cause softening and bloating. (Bloating is the formation of a large air pocket in the center of the pickle.)

After the cucumbers are washed, they are placed in brine and a pure culture of Lactobacillus is added. The bacteria feed on natural sugars from the cucumbers and release lactic acid into the brine. This lowers the pH and gives pickles their crisp texture and sour taste.

Some picklers choose to make pickles by a natural process. For this process, cucumbers are placed in a brine of the same salt concentration used in the commercial process. Then salt is gradually added to the brine during the fermentation period. The salt level is more than doubled by the end of the process. The additional salt is not needed in the commercial process. This is because the chlorine washing process has already removed the undesirable microbes the salt is used to control.

The commercial process has two advantages. First, it requires less salt, which is important for low-salt diets. Second, it helps picklers meet Environmental Protection Agency (EPA) standards regarding the dumping of brine into streams.

Olives

Olives are fermented by the same types of lactic acid bacteria as cucumbers. However, fermenting olives calls for an added preparation step that is not required in making pickles. Olives are washed in a lye solution to remove bitter flavor compounds. The lye can remove needed microbes, and rinsing removes nutrients as well as the lye. To overcome these problems, lactic acid is added to neutralize any lye remaining after the olives are rinsed. This reduces the amount of washing needed.
Sugar is added, and lactic acid bacteria start the fermentation process.

Fermenting olives also requires a higher salt concentration than making pickles. The salt solution in which olives are fermented needs to be kept between 5% and 15%. This range is ideal for lactic acid bacteria to grow and multiply but is too salty for most spoilage bacteria. As the olives ferment, sugar is pulled out of the olives and salt is pulled into them. This lowers the salt concentration of the brine. Salt must be added anytime the brine drops below the 5% level. Fermentation of olives can take two weeks to several months.

Green or Spanish olives are picked when they have reached full size but before they have ripened. They are then cured and often pitted and stuffed, most commonly with pimento. Black or ripe olives are picked at a riper stage. They have a deep green color when picked. The lye curing process and oxygenation turns them black. Olives that are tree ripened have a dark brown to black color. Most tree-ripened olives are pressed for their oil.

**Meats**

Meats are fermented with lactic acid bacteria to make semidry and dry sausages. The fermentation process increases the acid level. This tenderizes the meat and adds a tart flavor. Fermentation, along with smoking and drying, lowers the a_w level to prevent spoilage.

Fermented sausages are made by mixing chopped meat with sugar, spices, and salt. The sugar provides food for the lactic acid bacteria. The spices and salt add desired flavor. Sodium nitrate, sodium nitrite, or a combination of these is mixed into the meat. These additives prevent the growth of spoilage bacteria. Lactic acid bacteria are added to ensure proper color and flavor of the sausage.

**Cultured Dairy Products**

Cultured dairy products include sour cream, yogurt, and buttermilk, 17-13. These products are made with the help of lactic acid bacteria. The strains of bacteria used vary depending on the desired end product. Several kinds of Streptococci are used because they are the fastest lactic acid producers. They enable the milk base to acidify quickly. This reduces preparation time and the risk of contamination. _Leuconostoc_ and _Lactobacilli_ strains are added to produce the desired flavors.

Fresh milk contains microorganisms that would cause it to spoil. Therefore, milk being used for cultured dairy products is pasteurized. Pasteurization ensures that unwanted microbes are destroyed. This helps produce a consistent, high-quality product.

After pasteurization, starter cultures of bacteria are added to the milk. The bacteria feed off the lactose in the milk. They release carbon dioxide, lactic acid, and a number of flavor compounds. The acid denatures the proteins and causes them to coagulate. The degree of coagulation is determined by the combination of bacteria. Temperature, pH, fermentation time, and added enzymes also affect the texture of the product.

Most cultured dairy products are made by similar processes. The products are heated, cooled, mixed with a culture, and fermented. The fermentation process is stopped by cooling. The products are then ready for packaging.

Cultured dairy products are often suggested for people with lactose intolerance. This is because the bacteria use the lactose as their energy supply. The result is low-lactose products that are easier to digest.

People with lactose intolerance can also use lactose-free milk products. These products are made by adding _L. acidophilus_. The
L. acidophilus releases an enzyme that breaks lactose down into glucose and galactose. The products that result are sweeter than milk because glucose tastes sweeter than lactose. People with lactose intolerance can add commercially produced lactase drops or tablets to dairy products, too.

**Health Tip**

Antibiotics will often destroy helpful microbes in the intestines as well as disease-causing bacteria. Eating yogurt that contains “active cultures” can help replenish intestinal microbes after the use of antibiotics.

Cheeses

Like making cultured dairy products, making cheese starts with pasteurizing the milk. The proteolytic enzyme rennin and a culture of lactic acid bacteria are then added to help form the curds. **Curds** are clumps of coagulated protein. In this case, the protein is casein. The lactic acid bacteria lower the pH so the proteolytic enzymes in rennin will coagulate the casein more effectively.

The curds are cut into small cubes. The mixture is then heated to 38°C to 40°C (100°F to 104°F) for about 45 minutes. The cutting and cooking process helps the whey separate from the curds. **Whey** is a liquid high in soluble whey proteins. The whey is drained off and collected to be used as an additive in processed foods such as baked goods, mixes, and margarine. The curds are then salted to add flavor and reduce the risk of spoilage.

At this point, the cheese making process varies according to the type of cheese being made. Curds being used to make cottage cheese are mixed with cream that has had cultured skim milk added. Curds for aged cheeses, such as Cheddar, Edam, Swiss, brick, and blue, are put in presses. The presses squeeze out excess moisture.

Most cheeses need a ripening period. Bacteria remaining in the curds will ripen some cheeses. For other cheeses, microorganisms such as mold are added to the salted curds to do the ripening. During ripening, the cheeses are wrapped or covered with wax and placed in curing rooms. The curing rooms have controlled humidity and temperature levels. These conditions are designed to match the growth needs of the microorganisms doing the ripening.

Specific types of fermenting bacteria and/or molds are used to give each type of cheese its characteristic flavor. Propionic acid bacteria are added to Swiss cheese. These bacteria develop the carbon dioxide that forms the characteristic eyes, or holes, in Swiss cheese, 17-14. Molds are used to make cheeses such as Limburger and blue cheeses. Limburger uses a mold at the beginning of the ripening process. This mold lowers the acidity so proteolytic bacteria can develop the cheese’s characteristic flavor, texture, and aroma. Blue cheeses, such as Roquefort, have a blue-green mold added. This mold needs oxygen to grow. Therefore, the surfaces of blue cheeses are pierced with needles to allow oxygen to reach the mold within the cheese.

The sharpness of cheese refers to the strength of its flavor and aroma. Sharpness is caused by acids and a variety of aroma compounds. These compounds are formed as bacteria and enzymes in cheese continue to ferment lactose and other organic compounds during a curing process. Therefore, the sharpness of cheese depends on the length of time the cheese is cured. For instance, mild Cheddar cheese is cured for four months. Sharp Cheddar is cured for about a year. Extra sharp Cheddar is cured for up to two years. Tasting samples of mild, sharp, and extra sharp Cheddar cheese will illustrate...
these flavor differences. You will also note texture differences. Cheeses that are cured longer tend to have firmer textures, are more crumbly, and melt into sauces more readily.

Mold Fermentation

Some fermented foods are produced by the action of molds. Molds create a wide range of by-products. These by-products include antibiotics, flavor compounds, and enzymes.

Soy Sauce

Soy sauce, an important flavoring ingredient in Asian cooking, is a fermented mix of soybeans and wheat. The fermenting agent is a mixture of cooked rice and several strains of mold from the Aspergillus family. When added to the soy-wheat mixture, the molds produce enzymes. These enzymes hydrolyze the proteins and carbohydrates in the soybeans and wheat. Once mold covers the soy-wheat mixture, a brine is added. The brine stops the growth of unwanted microbes. Lactic acid bacteria can then multiply, causing the pH of the mixture to drop. Toward the end of the fermentation period, yeasts are added. They ferment the sugars remaining from the hydrolysis of the carbohydrates. The fermented mixture is filtered, pasteurized, and bottled.

Tempeh

Another soy product produced through mold fermentation is tempeh. Tempeh is an Asian soybean cake. The soybeans are cooked, mashed, and formed into cakes. The cakes are inoculated with Rhizopus molds. The cakes are then wrapped in banana leaves and fermented for one to two days.

Two-Step Fermentation

Many fermented foods are made with two or more fermentation steps. Each step may require a different kind of microbes. Some two-step fermentation processes involve lactic acid bacteria plus other microbes. Acetic acid fermentation is an example of a two-step process. It requires yeast as well as bacteria.

Lactic Acid Plus Other Microbes

Two-step fermentation often involves lactic acid bacteria in one step and other microbes in a second step. The aged cheeses you read about earlier are examples of this type of fermentation. Lactic acid fermentation is used to make the cheese. Then other microbes are used to develop the characteristic flavors and textures.

Sourdough bread is another example of a food product made with a two-step fermentation process involving lactic acid bacteria. The first step of the process requires lactic acid bacteria to ferment the yeast starter. This step is what gives sourdough bread its characteristic sour flavor. See 17-15. The second step of the process is the same yeast fermentation used to make other yeast breads.

The strain of bacteria used in sourdough starter is Lactobacillus sanfrancisco. This bacterium is indigenous, or native, to the San Francisco bay area. During the Alaskan gold rush, many prospectors would keep jars of yeast starter in their parkas. This would keep the starter warm. The prospectors would use part of the starter to make bread, biscuits, or pancakes. Then the prospectors would add more flour and water to feed the base starter for the next day. Many of these prospectors would sail from San Francisco or return to the bay area for the winter. The bacteria would get into their starter when they were in San Francisco.

Acetic Acid Fermentation

The first step of acetic acid fermentation is yeast fermentation. Yeasts are added to a food product under anaerobic conditions. The yeasts use sugars in the food product for their
food supply. The yeasts release alcohol as a by-product as they break down the sugars. After the yeast fermentation is complete, the second step of acetic acid fermentation can begin.

For the second step, *Acetobacter* bacteria are added to the food product. These bacteria are aerobic. They use the alcohol produced by the yeast as their food supply. They release acetic acid as a by-product as they break down the alcohol. The chemical changes caused by *Acetobacter* are shown by the following chemical formula:

\[
\text{C}_2\text{H}_5\text{OH} + \text{O}_2 \xrightarrow{\text{acetic acid bacteria}} \text{CH}_3\text{COOH} + \text{H}_2\text{O}
\]

Vinegar is one of the foods produced as a result of acetic acid fermentation. Acetic acid is what gives vinegar its sour taste. Acetic acid bacteria will produce different types of vinegar depending on the food on which it feeds. When acetic acid bacteria are present in red wine, red wine vinegar is produced. A mixture of water and wheat will produce white vinegar. Apple juice with acetic acid bacteria will yield apple cider vinegar. The FDA requires that vinegar contain at least 4 mL of acetic acid per 100 mL of water. This means vinegar is a 4% solution.

Other foods that require acetic acid fermentation are cacao beans and candied citron. This two-step process helps turn cacao beans into chocolate. Candied citron is a fermented product of citron lemons used in baked goods such as fruitcake.

**Benefits of Fermentation**

Fermenting food products has a couple of key advantages. First, microbes help preserve some foods. Milk will keep for about a week in the refrigerator. Cheese can keep for

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**Historical Highlight**

**Louis Pasteur: One of the World’s Greatest Scientists**

During his lifetime, Louis Pasteur (1822-1895) made major contributions to science, medicine, and the food industry. His science contributions began with his work in chemistry with the structure of crystals. He then turned to studying microbes. He was the first to prove the theory of *spontaneous generation* was false. This theory stated that living things (microbes) could come from nonliving material, such as dirt.

Pasteur made several contributions in the areas of human and animal medicine. He helped prove that microorganisms are the source of infectious disease. He worked to prevent the death of silkworms. He also focused on the development of immunity to disease through vaccination. He developed vaccines to protect sheep from anthrax and chickens from cholera. He also developed the vaccine for rabies.

Pasteur made an impact on the food industry in his day. In 1857, he wrote in his journals that alcoholic fermentation was caused by yeast. He noted that lactic acid fermentation was caused by round organisms (now known as lactic acid bacteria). In 1861, he identified rod-shaped organisms as the source of butyric acid fermentation. He also noted these bacteria were anaerobic. In 1864, Pasteur began researching the cause of bitter flavors in wine. He found that microbes were the cause. He developed the pasteurization process to protect wine from these microbes. He applied this method to the preservation of milk and beer as well as wine.
months when properly stored. Cucumbers will spoil in a week or so in the refrigerator. Pickles will keep in unopened jars on the shelf for a year or more.

A second benefit of fermentation is variety. Fermented products have added a wider range of food options to diets around the world.

**Nutritional Changes in Fermented Products**

The nutritional value of fermented foods often differs from the value of their unfermented counterparts. The types of microbes added and the energy sources they consume affect the nutrient content. For instance, cheeses are higher in fat than milk. This is because portions of the casein molecules that form the curds are attracted to fat. When the water-soluble whey is drained off, the fat concentration is increased. Calcium is also concentrated in cheese. One ounce of Cheddar or Monterey Jack cheese contains as much calcium as six ounces of milk. The iron in one cup of raw cabbage is 0.4 mg. One cup of sauerkraut contains 3.47 mg of iron.

Other ingredients added during processing also affect the nutritional quality of fermented foods. For instance, all pickles have more sodium than cucumbers. This is because of the salty brine used during fermentation. Soybeans contain 1 mg of sodium per cup. "Light" soy sauce contains as much as 530 mg of sodium per tablespoon. See 17-16.

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**What Microbes Do to Food Value**

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<tr>
<th>Food</th>
<th>Serving</th>
<th>Cal</th>
<th>Protein</th>
<th>Carb</th>
<th>Fat</th>
<th>Sodium</th>
<th>Calcium</th>
<th>Iron</th>
<th>Vit A (RE)</th>
<th>Vit C (mg)</th>
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<tbody>
<tr>
<td>Cucumbers</td>
<td>15 slices</td>
<td>11</td>
<td>&lt;1</td>
<td>3</td>
<td>&lt;1</td>
<td>3</td>
<td>11</td>
<td>0.22</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Pickle, dill</td>
<td>1 med</td>
<td>12</td>
<td>&lt;1</td>
<td>3</td>
<td>&lt;1</td>
<td>833</td>
<td>6</td>
<td>0.34</td>
<td>21</td>
<td>1</td>
</tr>
<tr>
<td>Grape juice</td>
<td>4 oz</td>
<td>78</td>
<td>&lt;1</td>
<td>19</td>
<td>&lt;1</td>
<td>4</td>
<td>11</td>
<td>0.31</td>
<td>1</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Red wine</td>
<td>3.5 oz</td>
<td>74</td>
<td>&lt;1</td>
<td>2</td>
<td>0</td>
<td>8</td>
<td>8</td>
<td>0.22</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Vinegar</td>
<td>4 oz</td>
<td>8</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>60</td>
<td>4</td>
<td>0.36</td>
<td>0</td>
<td>0</td>
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<td>75</td>
<td>7</td>
<td>4</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>43</td>
<td>2.21</td>
<td>&lt;1</td>
<td>1</td>
</tr>
<tr>
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<td>36</td>
<td>4</td>
<td>8</td>
<td>&lt;1</td>
<td>4116</td>
<td>12</td>
<td>1.44</td>
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<tr>
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<td>8</td>
<td>20</td>
<td>4</td>
<td>2516</td>
<td>46</td>
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<tr>
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<td>16</td>
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<td>4</td>
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<td>0.4</td>
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<tr>
<td>Sauerkraut</td>
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<td>2</td>
<td>10</td>
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<td>1561</td>
<td>72</td>
<td>3.47</td>
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<td>Milk</td>
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<td>11</td>
<td>8</td>
<td>120</td>
<td>291</td>
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<tr>
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<td>9</td>
<td>850</td>
<td>126</td>
<td>0.30</td>
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<tr>
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<td>455</td>
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<td>1</td>
<td>37</td>
<td>701</td>
<td>815</td>
<td>0.77</td>
<td>342</td>
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*Alcohol provides 7 calories per gram.

17-16 The nutritional profile of a fermented food differs from its unfermented equivalent due to added ingredients and microbial activity.