pH and Fermentation

TAKE any science class, and before long you will undoubtedly hear about the pH scale. But what is this scale exactly, and how will learning about it help you in your understanding of food science? What role does pH play in the fermentation of food products?

Objective:

Define the pH scale and explain how it relates to the process of fermentation.

Key Terms:

aerobic
alcoholic fermentation
anaerobic
autotrophs
bacteria
buffer
byproduct
cellular respiration
fermentation
gluten
glycolysis
heterotrophs
lactic acid fermentation
molds
photosynthesis
pH scale
yeasts

The pH Scale

The **pH scale** is a measurement of the total acidity or alkalinity of a substance. Every substance has a pH that can be measured with a variety of methods. The pH scale measures from 0 to 14.0, with 7.0 being neutral. Any substance that has a pH of less than 7.0 (meaning 0 to 6.9) is considered acidic and will display characteristics of an acid. On the other hand, any substance that has a pH of more than 7.0 (meaning 7.1 to 14.0) is considered alkaline, or basic, and will display characteristics of a base.

The number used on the pH scale is calculated by measuring the hydrogen ions present in the substance. The greater the hydrogen ion (H^+) concentration, the more acidic the substance will be, and the lower its number on the pH scale. In return, the lower the hydrogen ion concentration, the more alkaline the substance will be, and the higher its number on the pH scale. A very strong acid with a large hydrogen ion concentration may have a pH of 2.0, while a very strong base with a small hydrogen ion concentration may have a pH of 12.0.

When reading values on the pH scale, it is important to remember that each numerical division on the scale represents a tenfold difference in the hydrogen ions present. For example, a substance that has a pH of 6.0 would be 10 times as acidic as a substance measuring 7.0. A substance that has a pH of 5.0 would be 10 times as acidic as a substance measuring 6.0 and 100 times as acidic as a substance measuring 7.0!

Many people have the misconception that only acids are dangerous and that basic substances are harmless. The fact is that strong bases can be as harmful as strong acids. Soaps, ammonia solutions, bleach, and oven cleaners are all examples of substances with strong alkaline properties. Tomato juice, citrus juices, and stomach acid are examples of substances with strong acidic properties.

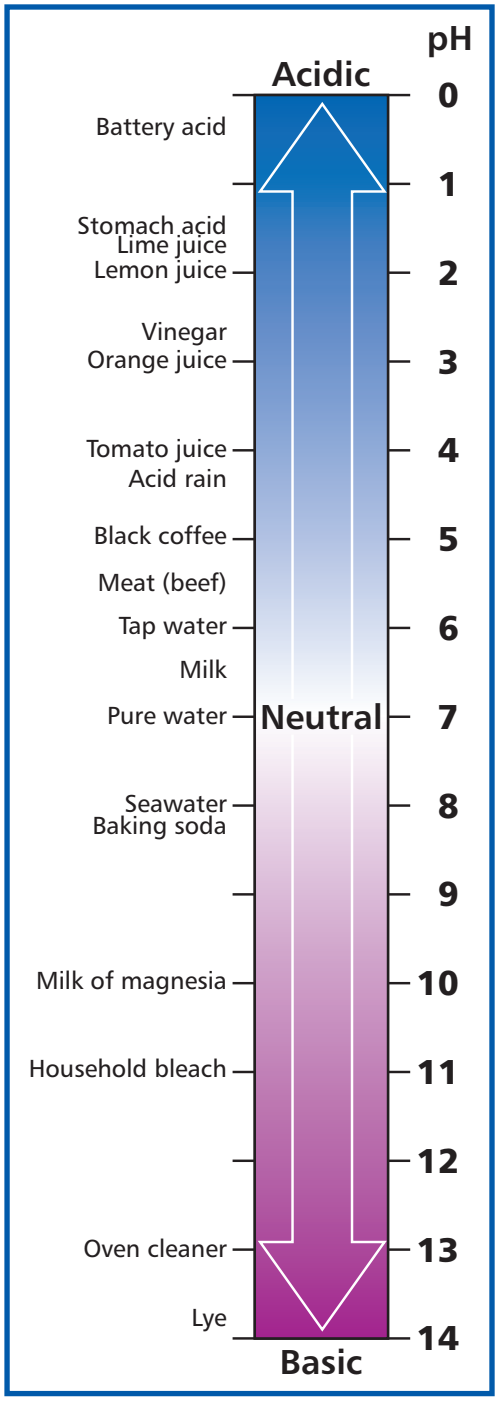

FIGURE 1. A pH scale measures the acidity or alkalinity of a substance.

If tomato and citrus juices are such strong acids, how can we drink them without damaging our stomachs? The answer lies in a substance known as a buffer. A **buffer** is a weak acid or base that works in opposition to a strong acid or base to equalize the substance and bring the pH closer to neutral (7.0). The human body is constantly striving to achieve homeostasis, or a

state of stability within the body. When a strong acid, such as citrus juice, is ingested, the body uses homemade buffers to counteract the acid and keep the body pH near 7.0.

If buffers were not in use in the digestive system, strong acids in foods would interfere with normal chemical reactions in the body, and serious health conditions could develop.

FIGURE 2. Common acidic and alkaline substances.

Fermentation

All living things, including humans, require energy to carry out the basic functions of daily life. Just as there must be energy to begin these functions, there will be some sort of byproduct as a result of these functions. A **byproduct** is anything created in the course of producing another substance. For humans, most byproducts of other living things are simply waste materials and not extremely useful. Fermentation, however, is a reaction that has numerous benefits for human beings. **Fermentation** is a chemical reaction in which a microorganism uses carbohydrate as an energy source and, as a result, changes the chemical environment of a food.

Before we discuss fermentation, we must understand how organisms obtain energy. All organisms receive their energy to live in one of two forms—by creating it themselves or by consuming another substance.

Autotrophs are organisms that are able to use the energy from the sun to create their own energy, or food supply. The ability to create food is possible through the process of **photosynthesis**—taking sunlight, carbon dioxide, and water and creating glucose and oxygen. The chemical formula for photosynthesis is:

$$\underset{\text{carbon dioxide}}{6CO_2} + \underset{\text{water}}{12H_2O} \xrightarrow[\text{Chlorophyll}]{\text{Light}} \underset{\text{glucose or fructose}}{C_6H_{12}O_6} + \underset{\text{oxygen}}{6O_2} + \underset{\text{water}}{6H_2O}$$

In other words, 6 molecules of carbon dioxide plus 12 molecules of water combine using energy from the sun to produce 1 molecule of glucose or fructose, 6 molecules of oxygen, and 6 molecules of water. The water is released into the atmosphere.

Heterotrophs have a slightly more difficult task when it comes to obtaining energy. **Heterotrophs** are organisms that rely on the consumption of other living organisms for energy. Animals, including humans, do not have the ability to make their own food and are,

therefore, heterotrophic by nature. Although animals do not rely directly on the sun for food, without the autotrophic plants growing and creating energy, our food chain would quickly halt, and our food supply would be exhausted.

FIGURE 3. The plants seen in this picture are autotrophic, while the animal consuming a plant is heterotrophic. (Courtesy, USDA)

Once plants have created their energy supply, glucose, they must find a way to benefit from it. **Cellular respiration** is the process by which molecules of food are broken down into usable energy. It may sound confusing, but once a plant has produced glucose, it uses oxygen to break the glucose molecule back down into carbon dioxide, water, and energy. The glucose molecule acts as a sort of short-term storage device within the plant until it is needed for energy. Imagine a candy bar sitting on the store shelf. The candy bar was made from relatively simple substances (sugars, carbohydrates, and proteins) and is now a source of energy waiting to be consumed. The bar itself can do nothing, but when you eat it and your body breaks the candy back down into simple substances, you can gain energy through this process.

Glycolysis is the first in a series of reactions that break down a glucose molecule into pyruvic acid. Once glycolysis has occurred, fermentation can begin to release energy from molecules for use in metabolic functions. Fermentation is a unique reaction that can be **aerobic** (taking place in the presence of oxygen) or **anaerobic** (taking place in the absence of oxygen).

There are two main types of fermentation that provide the results that humans find beneficial: alcoholic fermentation and lactic acid fermentation. **Alcoholic fermentation** is a reaction caused by many microorganisms, including yeast, that produces alcohol and carbon dioxide. **Lactic acid fermentation** is a process that occurs as pyruvic acid is changed into lactic acid. Lactic acid fermentation occurs in our own muscle cells and has probably been felt by most people at times of intense exercise. As the oxygen in our muscle cells is consumed through exercise, pyruvic acid

FIGURE 4. These athletes are experiencing lactic acid fermentation inside the cells of their muscles.

UNDER INVESTIGATION...

LAB CONNECTION: pH and Fermentation

Fermentation is an ancient process that has been used to improve the taste, texture, color, and sometimes storage capability of food products. Today, the process is much more refined, but it is still the same in principle. Microorganisms, such as bacteria, yeast, and mold, break down the sugars found in a food product into energy sources for the microorganisms' use. In this process, byproducts are produced that can change the taste, digestibility, and even the alcoholic content of the food source. Fermentation can sometimes produce negative results as well. For example, unchecked fermentation can lead to a destruction of the original food, making it unfit for consumption.

Fermentation also has many applications outside of human food production. It can be used to make a variety of products, ranging from medicines and antibiotics to garden compost and livestock feed. Scientists are constantly studying fermentation and developing new ways for this age-old process to be used.

In a laboratory experiment, observe how well fermentation of yeast occurs in solutions with different pH levels. Pour 200 ml of vinegar, ammonia, and distilled water into separate flasks or jars. Add corn syrup and yeast to each flask. Pour 50 ml of limewater into three beakers. Using modeling clay, form a stopper for each flask, and use a straw to make a conduit from each flask to a beaker of limewater. A milky precipitate in the limewater indicates the production of CO_2, a product of fermentation.

Knowledge of chemistry is important in understanding how fermentation is used to produce many of our favorite food products.

is converted to lactic acid and begins to build up inside our muscle cells. This collection of lactic acid can produce a burning or painful feeling in our muscles. Normally, with the continued intake of oxygen and time for our muscles to rest, the sensation will fade away as the lactic acid is removed.

MICROORGANISMS AND FERMENTATION

Many microorganisms use the process of fermentation to provide themselves with the necessary energy to carry out their daily metabolic functions. Three of the most common microorganisms are bacteria, yeasts, and molds.

Bacteria are usually single-celled organisms that can multiply by simple division and can be seen only with the use of a microscope. Bacteria are present to some extent on nearly every surface, including food. Most bacteria are harmless to humans, but some can cause illness, food spoilage, and serious health problems.

Another type of microorganism commonly used in fermentation is yeast. **Yeasts** are various single-celled fungi that do not develop mycelia, or filaments, like other fungi. Yeasts are capable of reproducing by budding, a form of asexual reproduction in which the cells bulge and eventually split off the original cell. Moisture is needed for yeasts to become active; therefore, packets containing dry yeast granules can be sealed and stored for long periods.

Molds are a form of fungi that grow in large tangled masses of filaments containing cells. Although molds may appear somewhat plantlike, they are not autotrophic and therefore obtain their energy from the food source upon which they grow. A mold is eukaryotic, meaning it contains a cell membrane, another difference from a plant. A mold can break down its food supply outside its body and then consume the simplified substance for energy.

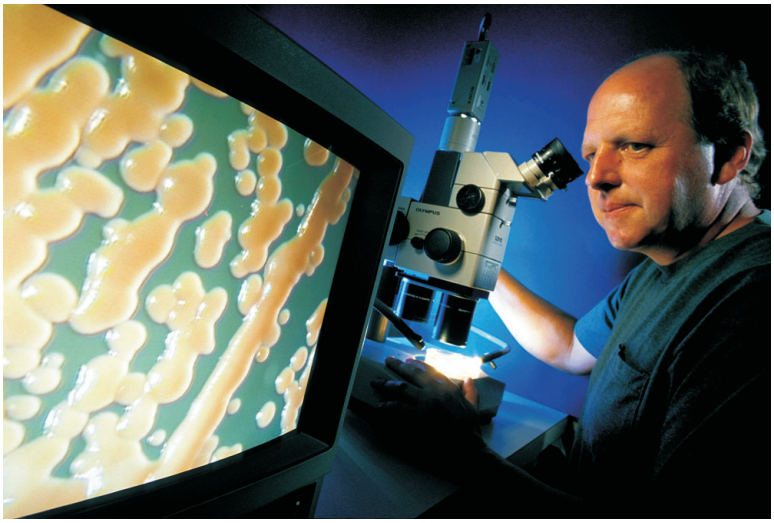

FIGURE 5. Yeasts are commonly used in fermentation. (Courtesy, Agricultural Research Service, USDA)

FOODS AND FERMENTATION

So far, our discussion of fermentation has included molds, bacteria, acids, glucose, and yeasts—not exactly appetizing descriptions! The truth is that without fermentation, we would not be able to enjoy countless food products that humans eat every day. A few common foods that undergo fermentation at some point in their production are cheese, yogurt, wine, cider, beer, bread, sauerkraut, flavorings, candy, and fruit juice. Fermentation is also important to livestock producers, as silage, a product of chopped corn, undergoes fermentation before being fed to cattle.

Bread, a food staple for nearly every culture, is actually a product of alcoholic fermentation. Yeast cells consume glucose in the bread-dough mixture, initially fueled by the presence of oxygen. As the oxygen in the dough is used up, the yeast begins alcoholic fermentation, producing alcohol and carbon dioxide. The carbon dioxide from this fermentation plays an important role in the production of bread. As flour is added to the bread mixture and kneaded, the gluten helps create an elastic dough structure. **Gluten** is a protein found in wheat. Carbon dioxide, released during fermentation, is trapped by the elastic dough in small pockets, causing

the bread to "rise." This rising does not happen immediately, usually taking one to two hours before the bread can be baked.

Sometimes, during alcoholic fermentation, the producer wants the alcohol to remain after the fermentation process ends. Grapes are used to make wine. Wine production is a $21 billion industry in the United States alone. To produce alcohol, yeast is used to consume the sugars naturally found in grapes. Wine can be fermented for great lengths of time before the yeasts are removed and the liquid is allowed to age. Beer is alcoholic beverage resulting from the fermentation of rice, corn, wheat, barley, hops, and other grains. Champagne is another product of the fermentation of grapes. It is fermented twice, with the second fermentation sometimes lasting up to one year.

The next time you have pickles on your hamburger, remember that they are actually fermented cucumbers. The sauerkraut on your bratwurst is fermented cabbage, and the soy sauce on your stir-fry is fermented soybeans.

Liquids can also be fermented without producing an alcoholic result. Bacteria can ferment alcohol to produce vinegar and can also ferment the lactose in milk to produce cheese and yogurt.

FIGURE 6. A variety of food items are the result of fermentation. (Courtesy, Agricultural Research Service, USDA)

Several nonfood items also rely on fermentation to create the final products. Antibiotics, insulin, laundry detergents, and growth hormones are all commonly used and are results of fermentation. Compost, a garden fertilizer, is the result of the decomposition and fermentation of dead leaves, grass clippings, and other plant material.

BENEFITS OF FERMENTATION

The fermentation of food products has several advantages other than just the production of great tasting food. During fermentation, lactic acid bacteria in dairy products, such as cottage cheese, buttermilk, and sour cream, produce the compound diacetyl, which is responsible for the buttery aroma normally found in these products. Fermentation can also affect the texture, color, and appearance of some food items.

Fermentation can actually increase the shelf life of food by inhibiting natural enzymes that would begin to deteriorate and spoil the product over time. Food safety also benefits from fermentation, as the fermented environment usually prevents the growth of microorganisms in the food product. Pickles, sauerkraut, and vinegar are three examples of food products that have long shelf lives as a result of fermentation.

The health benefits of some foods can also be improved by fermentation. Vitamin content can be increased while the toxicity of some foods may be decreased. Some research scientists believe that various types of fermented dairy products may actually help some digestive disorders and lower the number of harmful bacteria in the digestive tract.

Just as there are advantages to fermentation, there are disadvantages also. Remember that fermentation produces some harmful byproducts, such as carbon dioxide, alcohol, and lactic and other acids. In large enough quantities, these byproducts can create an environment that is unfavorable for microorganisms and a product that is unfit for human consumption! If the environment for fermentation becomes too hostile because of the buildup of these byproducts, the microorganisms driving fermentation are destroyed, and fermentation itself will halt. For example, when the alcohol content of a solution reaches around 12 percent, the yeast cells are killed due to the presence of the alcohol, and the fermentation process stops.

FIGURE 7. This machine carries out fermentation on a larger, commercial scale. (Courtesy, Agricultural Research Service, USDA)

FACTORS AFFECTING FERMENTATION

Fermentation is a complex process, with the interaction of several compounds, microorganisms, and conditions to produce the desired outcome. Any change in the environment where fermentation is taking place could have a large impact on the results. Several factors can affect the working environment for the microorganisms and the entire process of fermentation.

Similar to most processes, over time fermentation will slow down due to the consumption of the sugars present in the food material. Although fermentation will never stop under favorable conditions, the process may become extremely slow and require special facilities to allow the food to ferment for long periods. The yeast cells used in fermentation can tolerate a pH of 4.0 to 8.5 but work best when the pH is between 4.0 and 6.0. This means that yeast cells require a slightly acidic environment to do their best fermenting. In the example of bread dough, as the dough begins to rise and fermentation is taking place, the pH begins to fall and the dough becomes more acidic. Without the use of flour, milk, and calcium carbonate (baking soda) as pH buffers, the pH of the dough may become acidic enough to halt the fermentation process.

Although air is a necessity for humans, anaerobic fermentation can be ruined by its presence. Our air is full of microorganisms just waiting to find the perfect place to live and grow.

Fermenting food products provide the environment and energy source necessary. In some fermented food products, the absence of air is the most critical factor in the fermentation process.

Along with air, water also affects the fermentation process. Microorganisms such as yeast and bacteria require water to become active. If there is not enough water in the food source, the process will be greatly decreased.

FIGURE 8. These wine barrels are sealed to prevent air from affecting the fermentation process.

Temperature can also be a limiting factor in fermentation. For yeast, fermentation will begin at 75° to 85°F (23.9° to 29.4°C) but will increase 3 to 5 percent for each one degree rise in temperature. Increasing the temperature may seem like the answer to speeding up fermentation, but flavor and color of the food product can suffer as a result. Extremely high temperatures will also kill the yeast cells and halt fermentation completely.

Salts and sugars can also have an effect on the process. Salts, used commonly for the preservation of food, will withdraw water from the product and inhibit the growth of microorganisms. High-salt conditions also favor the growth of lactic microorganisms, which undergo lactic, not alcoholic, fermentation. Lactic fermentation does not produce many of the food products we enjoy. Sugar is the source of energy for the microorganisms in fermentation, but too much of a good thing can also be bad. As the sugar concentration rises, the microorganisms, particularly yeast, have trouble breaking down the sugar compounds, and fermentation begins to slow down.

Summary:

The pH scale is a measurement of the total acidity or alkalinity of a substance. It measures from 0 to 14.0, with 7.0 being neutral. Any substance that has a pH of less than 7.0 is considered acidic. Any substance that has a pH of more than 7.0 is considered alkaline, or basic.

Fermentation is the consumption of a sugar compound in a food product by a microorganism to produce a result that will change the flavor or texture of the food. The fermentation process relies on pH, among many other factors. pH is the concentration of hydrogen ions in a compound or solution. As pH rises or falls, the environment for microorganisms in a food product changes. Fermentation can be either aerobic (with oxygen) or anaerobic (without oxygen). Two main types of fer-

mentation are lactic acid fermentation, which ferments dairy products such as yogurt and cheese, and alcoholic fermentation, which ferments grains and vegetables.

Bacteria, yeast, and mold are the three main microorganisms responsible for most of our fermented food products today. Great care is taken to provide the proper environment for fermentation to occur and then to remove the environment when fermentation should be ended. Fermentation can help improve the texture, color, and flavor of foods, as well as increase the shelf life of store food products. Increased vitamin content and better digestibility are two other benefits of controlled fermentation. Other factors besides pH that will affect the fermentation process include time, air, temperature, salts, sugars, and water.

Checking Your Knowledge:

1. What is the range on the pH scale for substances considered acidic? For substances considered alkaline, or basic? Where on the scale are substances considered neutral?
2. Name four qualities of foods that may be improved by fermentation.
3. List the two main types of fermentation and give two examples of foods related to each type.

Expanding Your Knowledge:

Visit a local business involved with fermentation. Observe the steps and equipment used in the fermentation process. Prepare a short written report on your observations and present it to your class.

Web Links:

North Carolina State Extension—Food Safety

http://www.ces.ncsu.edu/depts/foodsci/ext/pubs/formulatingdressings.PDF

Wikipedia—Food Science

http://en.wikipedia.org/wiki/Food_science

Agricultural Career Profiles

http://www.mycaert.com/career-profiles