CHAPTER 2
MICROORGANISMS AND FOODS

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CHAPTER 2

MICROORGANISMS AND FOODS

2.1 INTRODUCTION

Notes

Microorganisms (microbes) are all around us, in water, air, soil, and in much of the food we eat. While some microbes cause disease, most are harmless to humans and many perform useful functions. They aid our digestion, they are essential in recycling of organic material in the environment, and they preserve certain foods by fermentation (e.g., pickles, sauerkraut, cheese, beer, and wine). Because of their small size, however, microbes were unknown to us until the 1800s, when it was shown by Louis Pasteur and others that microbes are responsible for both desirable (fermentation to produce wine, beer, etc.) and undesirable (food spoilage, disease) changes in foods and beverages. The procedure called pasteurization was so-named in honor of Pasteur.

The food processing industry has advanced significantly over the past century, due largely to a better understanding of how to prevent or control the growth of microbes. Food regulations are based largely on this knowledge. The purpose of this chapter is to introduce you to the microbial world in order that you may better help your company comply with regulations and produce foods that are safe for consumption.

2.2 GENERAL MICROBIOLOGY

2.2.1 What are Microorganisms?

Micro means very small, so we are talking about very small organisms. All the microbes of primary concern to food processors are much too small to be seen as individuals with the unaided eye. However, included in the biological definition are certain seaweeds which are over 100 feet long. What is different? Microorganisms do not have specialized tissues such as leaves, stems, roots, hearts, lungs, kidneys, etc. Bacteria, algae, fungi, and protozoa are small microorganisms. Fortunately, food processors are primarily concerned with only a few groups of bacteria and fungi (yeasts and molds).

2.2.2 Bacteria

Notes

The bacteria vary greatly in their shape and organization. However, the common ones are single cells which are either spheres (cocci; singular, coccus) or rodlets (bacilli; singular, bacillus). The cocci may occur either singly, in pairs, tetrads, short to long chains, or clusters (Fig. 2.1). The bacilli vary primarily in the size of the cells. Most all reproduce by fission, i.e., one cell divides into two equal cells. These are the smallest organisms we will discuss. The common cocci may vary from about 0.5 to 1.5 μm (1 μm = 1/1,000,000 meters = 1/25,400 inches) in diameter and the bacilli from 1 to 3 μm long. It takes about 500 thousand billion cells of an average bacterium to weigh 1 pound. When bacteria grow in a clear liquid containing suitable nutrients, they have to reach a population of about 10 million per ml (1 ml = 1/1000 liter = 1/946 quart) or about 5 billion cells per pint before the liquid shows any visible turbidity.

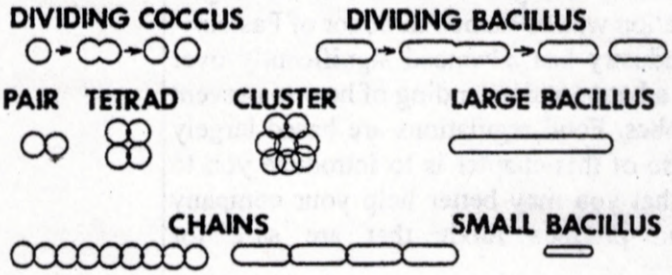

Fig. 2.1 Shapes and organization of common bacteria.

While bacteria have to reach large populations before they become visible, it does not take very long for them to do this under favorable conditions. They increase in numbers by simply dividing (called fission). This division occurs most rapidly under ideal growth conditions for the particular bacterium. They reach such high numbers that microbiologists condense the numbers by expressing them exponentially or logarithmically. Thus, one billion (1,000,000,000) cells is expressed exponentially as 10^9, or logarithmically as simply 9. The numbers on the left side of Figure 2.2 are expressed as the actual numbers and the logarithm (log) of that number.

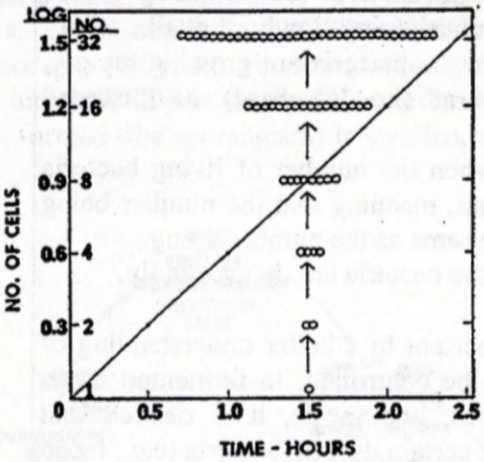

Fig. 2.2 Multiplication of bacteria during maximum growth rate. The circles (o) represent individual bacterial cells. Starting with a single bacterium, dividing every half hour, there would be 32 cells in 2½ hours and 1 million cells in 10 hours.

A further discussion of big and small numbers appears later in Chapter 3. The rate of cell division depends not only on the organism, but on the environment, and the actual time per division (i.e., generation time) may vary from 20 minutes to several hours. Starting with only one cell in a pint jar of liquid dividing every 20 minutes, a clear medium would start to become turbid within one-half day (over 50 billion cells). If the cells could continue dividing at this rate, the cell mass at the end of two days would be greater than that of the Earth. In fact, this cannot happen because the growth of bacteria is limited by the availability of nutrients. Also, they produce waste products which limit their growth or kill them. A typical growth curve for bacteria is given in Figure 2.3. The growth curve can be divided into four stages, as Figure 2.3 illustrates.

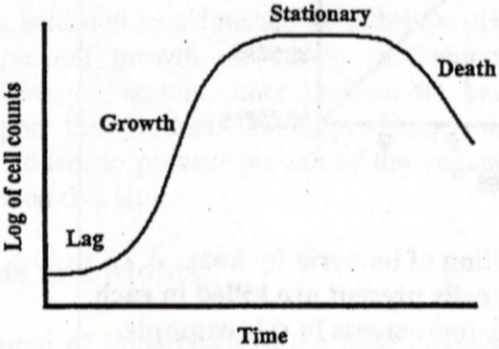

Fig. 2.3 Typical growth curve for bacteria.

Notes

(1) Lag phase – when the bacteria are adjusting to the environment and are multiplying slowly, if at all.

(2) Growth phase – when the bacteria are growing rapidly, doubling at a constant rate (i.e., lag phase) , as illustrated also in Figure 2.2.

(3) Stationary phase – when the number of living bacteria remains about constant, meaning that the number being produced is about the same as the number dying.

(4) Death phase – when the bacteria are dying rapidly.

Each of these phases is important to a better understanding of how bacterial growth in foods can be controlled. In fermented foods such as pickles, sauerkraut, cheeses, and meats, it is desired that conditions are suitable for growth of certain desired bacteria (e.g., lactic acid bacteria). In other foods, however, it is important that conditions not be suitable for growth of bacteria that can cause spoilage or sickness. In fact, many foods are refrigerated, frozen, or heat-processed to kill or slow down the growth of the bacteria present.

Figure 2.4 illustrates the death of bacteria in a food that is being heated for preservation. You will note that the shape of the survivor line is just the reverse of that for the growth phase in Figure 2.2.

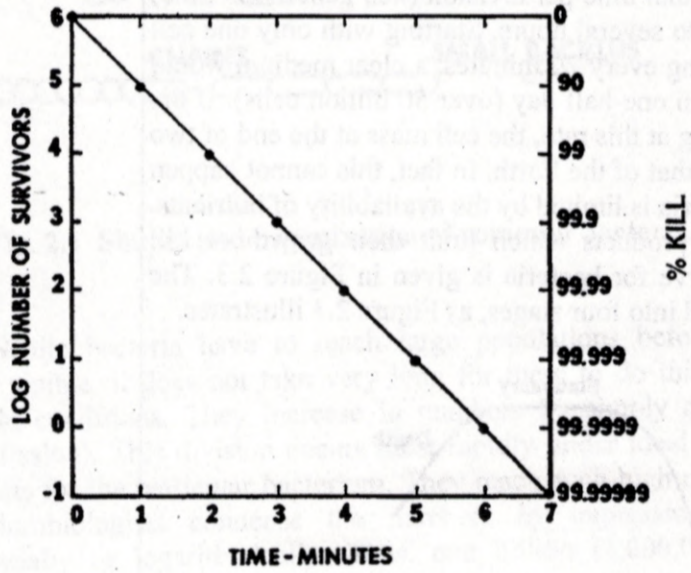

Fig. 2.4 Example of rate of killing of bacteria by heat. A given percentage of the living cells present are killed in each increment of time, one-minute increments in this example. The rate of destruction is logarithmic, i.e., a plot of the log of survivors versus time is a straight line.

Notes

Some bacteria form resting bodies called endospores or, more commonly, spores. These might be considered analogous to plant seeds, but spores are quite different. The sporulation cycle is illustrated in Figure 2.5. As indicated in that figure, in some bacteria the cell in which the spore is formed (the sporangism) is swollen, while in others this is not true.

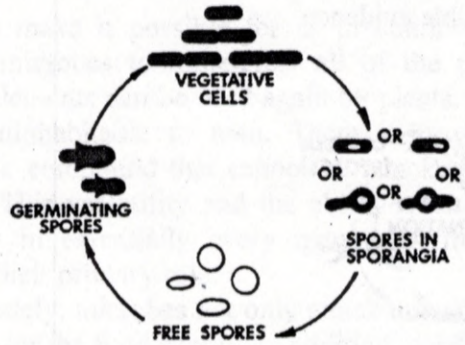

Fig. 2.5 The sporulation cycle of bacteria. The spores are very refractile as compared to cells, and the spores will not stain with simple stains.

The spore is very different from the vegetative cell, not only in shape but also in other characteristics. Spores have no detectable metabolic activity, and they are extremely resistant to heat, irradiation, dehydration, chemical treatments, and other unfavorable environments. Heating some spores at boiling water temperatures (212°F/100°C) only encourages them to germinate as soon as the temperature is reduced to a favorable level. Therefore, low-acid canned foods (pH greater than 4.6) in which spore-forming organisms can grow must be heated at temperatures above boiling; e.g., they must be heated in a retort. This high heat treatment is necessary to kill spores of the deadly bacterium, *Clostridium botulinum*, as we soon will learn. Alternatively, low-acid foods may be acidified to a finished equilibrium pH of 4.6 or below, which will prevent growth and toxin production by *Clostridium botulinum*. However, certain other undesirable bacteria may grow, depending upon the product. Some products must be heated, or preservatives added, to prevent growth of the vegetative cells of such bacteria. More on this later.

2.2.3 Yeasts and Molds

The fungi of importance to the food processor are commonly referred to as yeasts and molds. Representative types are illustrated in Figure 2.6. There is no sharp line of demarcation between the two groups. However, yeasts commonly reproduce by budding and are referred to as

"budding fungi." The most common molds grow by elongation of threads called hyphae and reproduce by fragmentation of the threads and by production of specialized seed-like spores. They produce masses of hyphae which are called mycelia (singular, mycelium). However, some filamentous yeasts also produce hyphae and specialized spores in addition to reproduction by budding. While the cells of most of the yeasts and molds are somewhat larger than most bacteria, they are still much too small to be seen as individuals. There can be millions of these on or in a food without any visible evidence.

Notes

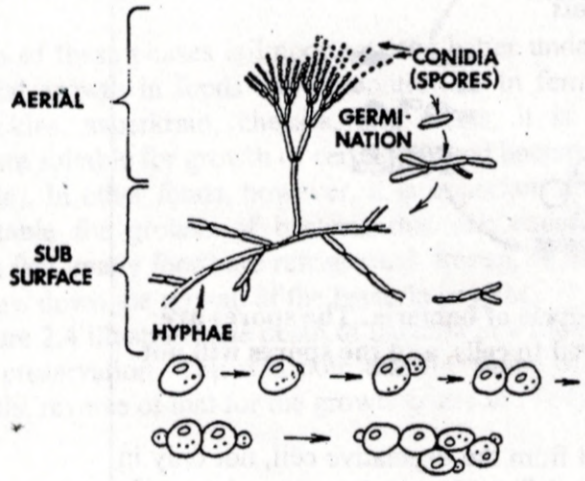

Fig. 2.6 Typical shapes and modes of reproduction of molds (top) and yeasts (bottom). Most molds reproduce both by fragmentation of hyphae and by spores produced on fruiting structures. Yeasts characteristically reproduce by budding.

2.2.4 Where are Microorganisms Found?

Microorganisms may be found practically everywhere in nature except inside of intact, healthy living tissues, and there may be exceptions to this. The soil is teeming with all types of bacteria, bacterial spores, yeasts, and molds, and they are also present in the air we breathe. The intestinal tract of man and animals and the rumen of cows contain very high populations of bacteria. It is possible to wash one's hands or the surfaces of fruits or vegetables many times and still find high populations of bacteria in the washings.

While the yeasts and molds are both widely distributed, there are certain places where they are most troublesome. The yeasts are a constant threat in sugar and organic acid solutions, and the molds grow well on moist surfaces of walls and equipment. A number of molds also grow on walls of refrigerators and on the surfaces of refrigerated food.

Notes

2.2.5 What Do Microorganisms Do?

Microbes make it possible for us to continue to live on the Earth. Without microbes to mineralize all of the plant and animal residues so the elements can be used again by plants, our world would soon become uninhabitable to man. There is no known naturally occurring organic compound that cannot be attacked by one or more microorganism. This versatility and the ability of these organisms to multiply rapidly in essentially every natural environment uniquely equips them for their primary role.

Unfortunately, microbes not only attack unwanted materials but compete with us for the food supply. In addition, some microorganisms invade and cause disease of humans, animals, and plants. Others produce poisons (toxins) when they grow in foods which can result in illness and sometimes death if consumed.

In a number of instances, certain microbes have been harnessed to produce useful products. A number of bacteria and molds are used to produce antibiotics to help fight other microbes. Yeasts are used to produce alcohol and alcoholic beverages. Lactic acid bacteria are used to ferment cucumbers, cabbage, milk, etc. Still other systems have been developed to encourage microorganisms to digest sewage and industrial wastes. It is quite probable that many more uses will be found for microorganisms in the future. They have great potential for the production of food, fodder, and fertilizer, and for the conversion of waste organic matter to natural gas.

2.2.6 Factors Influencing Microbial Growth

The same factors which influence all living things influence the growth, activity, and survival of microorganisms (Table 2.1). However, microorganisms vary more widely in their responses to individual factors than do plants and animals. As noted previously, there are microorganisms adapted to the extremes of natural environments.

TABLE 2.1
FACTORS INFLUENCING GROWTH, ACTIVITY, AND SURVIVAL OF MICROORGANISMS

Notes

- Nutrients Available
- Oxygen Availability
- Moisture – Water Activity and Salt Concentration
- Temperature
- pH and Acidity
- Chemicals
- Light

Some bacteria, such as the lactic acid bacteria, require sugar to grow. Many yeasts require sugar in the absence of oxygen, but will use acids such as acetic or lactic acid when oxygen is present. Practically all molds require oxygen and will grow on sugars and a variety of acids, alcohols, and other organic compounds. Those organisms which require oxygen for growth are called **aerobes** (aero = air), those which cannot develop in the presence of oxygen are called **anaerobes** (prefix an = no), and those which are able to multiply either in the presence or absence of oxygen are called **facultative** anaerobes. The ever-dangerous *Clostridium botulinum* and its relatives such as *Clostridium perfringens* are anaerobes which cannot grow in oxygen. Some other food-borne bacteria that cause disease (for example, *Staphylococcus* and *Salmonella)* are facultative. The lactic acid bacteria (*Lactobacillus*, *Pediococcus*, *Lactococcus,* and others) are aero-tolerant bacteria in that they metabolize sugar like anaerobes, but they will tolerate the presence of oxygen. In fact, they are termed **microaerophilic** because they grow better in the presence of small amounts of oxygen.

All living things have a high water content and require moisture for growth. Dehydration is an excellent way to preserve some foods. As a group, the molds are capable of growth at lower moisture levels than other microorganisms. They grow on surfaces on which only very thin layers of condensate accumulate. For example, molds grow on leather boots stored in a damp closet or basement. These microbes are the most troublesome in dehydrated foods.

Notes

Microbial growth and activity are influenced not only by the total water content, but by the types of materials dissolved in the water (solutes) and their concentration. These solutes influence the availability of water for microorganisms and explain why some foods have to be dried to much lower moisture levels than others in order to preserve them. The availability of water is measured by determining the **water activity** (a_w). The water activity is directly related to the vapor pressure of the water in the solution and is determined by measuring the equilibrium relative humidity of the air over the solution in a closed container (Fig. 2.7). Relative humidity divided by 100 equals water activity. If the air over water in a closed container becomes saturated, the relative humidity is 100 percent, which is equal to a water activity of 1.0. Any solution which results in a lower relative humidity has a lower water activity.

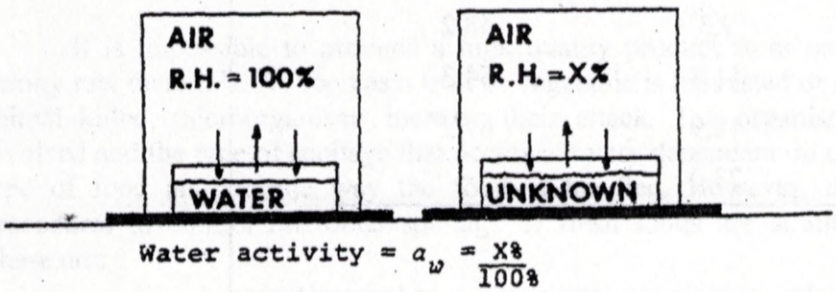

Fig. 2.7 Measurement of water activity (a_w). The relative humidity (R.H., percent saturation) of the air over the solution in a closed container is measured after allowing time for equilibration.

The effects of salt and sugar on water activity is shown in Table 2.2. Most common bacteria, including all of those of public health significance, will not grow when the water activity is 0.85 or less. However, many yeasts and molds have been found to grow below this level, and some will grow down to a water activity level of 0.60. Therefore, yeasts and molds often are found to be responsible for spoilage of foods preserved by high sugar (low a_w) concentrations. Salt solutions affect some microorganisms at concentrations much lower than necessary

to reduce the water activity to an inhibitory level. A number of molds that can grow in other environments with very low water activity values cannot grow in salt solutions with a water activity level of 0.96.

Notes

TABLE 2.2
APPROXIMATE WATER ACTIVITY (a_w) VALUES OF VARIOUS SALT OR SUGAR SOLUTIONS AT 25°C

a_w	% Salt	% Sucrose
1.0	0.0	0.0
0.99	1.7	15.4
0.98	3.4	26.1
0.96	6.5	39.6
0.94	9.3	48.2
0.92	11.8	54.3
0.85	18.9	67.2
0.80	23.0	–

In general, microbes grow more slowly at lower temperatures. However, there are bacteria which will grow at freezing temperatures and others which will grow at 149°F (65°C). Those that prefer low temperatures are called **psychrophiles** (cold-loving), and those that grow at high temperatures are called **thermophiles**. Most bacteria prefer intermediate temperatures (**mesophiles**) of 80-100°F (25-40°C). The yeasts and molds prefer lower temperatures for growth. Their optimum temperatures are usually near 70-85°F (20-30°C). However, a number of molds can grow well at refrigerator temperatures.

Most molds and yeasts are very sensitive to temperatures of 160°F (71°C) or higher and are killed within a very few minutes. One exception is a species of mold called *Byssochlamys fulva,* which is heat-resistant and has caused spoilage of pasteurized fruit. Most bacterial cells are reasonably sensitive to this pasteurization temperature, but some of them are quite resistant. These are known as **thermoduric** bacteria. Bacterial spores are resistant to heat at 160°F (71°C).

The pH and the acidity have both independent and combined effects on the growth, activity, and survival of microorganisms. Since these factors are of prime importance in the preservation of acid foods, they will be discussed in detail in the following chapters. Many chemicals used as food preservatives are organic acids, and the effects of these will also be discussed later.

Most microorganisms are sensitive to some degree to ultraviolet light. Even the relatively low amounts of ultraviolet in sunlight prevents the growth of filamentous yeasts on the surface of cucumber brine tanks. However, ultraviolet has no penetrating power and will only affect microbes on surfaces directly exposed to it. Bacterial spores are relatively insensitive to ultraviolet light.

Notes

2.3 MICROBIAL SPOILAGE

2.3.1 Fresh Foods

It is impossible to produce a high quality product from poor quality raw materials. As soon as a fruit or vegetable is harvested or an animal killed, microorganisms increase their attack. The organisms involved and the type of spoilage that occurs are very dependent on the type of food and on the way the food is handled. However, the procedures to control microbial spoilage of fresh foods are similar. These are:

(1) prompt handling – process as soon after harvest as possible;
(2) TLC (tender loving care) – the surfaces of fruits and vegetables provide a natural barrier from microbial attack; prevent mechanical damage to tissues;
(3) low temperatures – cool fresh foods immediately after harvest and store at low temperatures.

2.3.2 Spoilage During Manufacture

Foods must be moved rapidly through the manufacturing operation, and the manufacturing facilities and equipment must be kept clean and sanitary. Foods to be acidified should not be held for prolonged periods in water or brine without sufficient acid to prevent the development of food poisoning organisms. Spoilage microorganisms will build up rapidly when provided an opportunity, and those most adapted to the environment will predominate. For example, molds grow quickly on the surfaces of equipment in a moist environment. Food coming into contact with such surfaces will become contaminated and spoil rapidly. Since molds can utilize acids, the pH of an acid food can be increased to an unsafe level (pH above 4.6) by heavy mold growth.

2.3.3 Spoilage of Finished Products

Notes

It is easy to recognize gross microbial spoilage of food packaged in glass containers. As noted earlier, when microbes grow to high populations in clear liquid, the liquid becomes turbid. In time, the microbes will settle on the surfaces of the food and the bottom of the container as a whitish deposit. Cans must be opened to detect this type of spoilage. If the spoilage organism produces much gas, it will result in swelling of a jar cap or the ends of a can. Gross spoilage is also frequently detectable by odor or chemical analysis. It is always unwise to taste any food suspected to have undergone spoilage.

2.3.4 Warning!

Clostridium botulinum may grow and produce toxin in a food with a pH slightly above 4.6 or higher without producing obvious changes in the food. Do not trust any pasteurized canned food with a pH greater than 4.6.

Microbial spoilage resulting from underprocessing of acid foods is usually due to lactic acid bacteria, or to yeasts since these are both acid-tolerant organisms which can grow anaerobically. If the canned food has been pasteurized, spoilage is usually due to lactic acid bacteria, as the yeasts are more sensitive to heat. In contrast, where preservation is dependent on sugar and acid concentrations, yeasts are more commonly the cause of spoilage.

If a jar or can of acid food spoils as a result of leaking, molds and/or filamentous yeasts usually grow on the surface. These will use the acid in the food, increase the pH, and then a variety of microorganisms may initiate growth, including *Clostridium botulinum*.

2.4 FOOD POISONINGS AND INFECTIONS

Classic food-borne illnesses (gastroenteritis) are characterized by a rapid onset of symptoms, including vomiting, diarrhea, and varying degrees of prostration. In some instances, such illnesses are the result of poisons (toxins) produced by a microorganism growing in the food prior to its being eaten (intoxications), while in other instances the same symptoms result from the growth of the microorganism in the intestinal tract (infections). There are still other diseases which may be transmitted by food which have symptoms quite different from classic food-borne illnesses. Table 2.3 summarizes the kinds of illnesses which may result from eating food. The food handler needs to be aware of all these possibilities and utilize all practical safeguards to prevent their occurrence.

Notes

TABLE 2.3
SOME IMPORTANT MICROORGANISMS RESPONSIBLE FOR FOOD-BORNE DISEASES

- FOOD POISONINGS (Intoxications)
  - *Staphylococcus aureus*
  - *Clostridium botulinum*
  - *Aspergillus flavus*
- FOOD INFECTIONS
  - *Salmonella* spp.
  - *Shigella*
  - *Vibrio* spp.
  - *Clostridium perfringens*
  - *Campylobacter jejuni*
  - Norwalk viruses
  - *Escherichia coli* 0157:H7
  - Parasitic protozoa
  - *Listeria monocytogenes*
  - Hepatitis A virus

2.4.1 Food Poisonings (Intoxications)

When either *Staphylococcus aureus* or *Clostridium botulinum* are allowed to grow in a food, they produce poisons (toxins) which they release into the food. The organism then may die and the toxin remain in the food to cause the characteristic illness. Food-borne intoxication is another term used by professionals to describe this type of illness.

Notes

Staphylococcal food poisoning is very common in the United States. The illness is characterized by severe diarrhea, vomiting, and stomach cramps, which usually start three to six hours after eating the food. The patient recovers in one or two days. The illness is practically never fatal, but the patient may wish he or she was dead. The foods involved are frequently custards, salads, gravies, and dressings. Such foods are easily contaminated by human carriers and are frequently held at room temperature for long periods, allowing the organism to grow and produce toxin. Normal cooking may kill the organism, but will not destroy the toxin. While staphylococci are able to grow anaerobically, they are neither heat-resistant nor acid-tolerant. They will grow in the presence of 7 to 8 percent salt, but not at low pH.

Botulism is the type of food poisoning which is usually associated with canned foods. Unfortunately, the toxin produced by *Clostridium botulinum* is lethal at very low levels. It is much more potent than cyanide or cobra venom. It has been calculated that one-half pound of pure botulinum toxin would be enough to kill all of the humans in the world. Survival or death depends greatly on the amount of toxin eaten (dosage) and on how quickly the illness is diagnosed and treatment initiated. The mortality frequency has been reduced from about 80 to less than 10 percent during recent years.

There are seven different types of botulinum toxin separated on the basis of the antitoxins which neutralize them. However, all are similar in that they are extremely poisonous, cause the same symptoms, and are inactivated by boiling. Symptoms appear within a few hours to several days after eating the food. Characteristic symptoms are vertigo (dizziness), double vision, difficulty in swallowing and breathing, vomiting, and constipation. When death occurs, it is usually the result of respiratory failure.

Clostridium botulinum is a spore-forming, anaerobic bacterium. Although this bacterium cannot survive and grow in air, its spores are resistant to air. The spores are widely distributed in soil, so essentially all raw foods must be considered to have spores present. The spores of most types are quite heat-resistant, and boiling water temperatures cannot be relied upon to destroy them. Fortunately, this bacterium cannot grow and produce toxin at pH 4.6 or below. This makes it possible to pasteurize acidified foods safely at temperatures of 212°F (100°C) or below. **However, one must be absolutely sure that the final pH of all water phases (water in liquids and solids) inside the container are at this pH or below!**

With respect to botulism, some of the most potentially dangerous canned foods are those with relatively low pH values (pH 4.7-5.5). *Clostridium botulinum* may grow poorly in such foods and produce no obvious changes in appearance, odor, or flavor. However, it may produce

considerable amounts of toxin. Also, such canned foods are frequently not cooked before eating. Thus, any toxin formed would not be destroyed.

While some strains of *Clostridium botulinum* have been found to grow in food with salt concentrations of 7 percent, no toxin was found. No growth of these organisms has been observed in the presence of 10 percent salt. Also, foods having a water activity of 0.85 or below, in general, will not allow growth or toxin production by this organism or other bacterial pathogens.

Notes

2.4.2 Food Infections

Classic symptoms of food infection are produced during the growth of some species of *Salmonella*, *Vibrio parahaemolyticus*, *Listeria monocytogenes*, and some strains of *Clostridium perfringens* in the intestinal tract. Some symptoms characteristically appear 12-36 hours after eating a food containing large numbers of living cells (the organism must be able to grow in the food) of one of these organisms. Characteristically, the illnesses run their course within one to three days, and the patient recovers. In infections by *Listeria monocytogenes*, incubation periods of one to several weeks may occur and may result in flu-like symptoms, diarrhea, and mild fever. This bacterium is particularly dangerous to pregnant women (may cause abortion) and to immunologically compromised people (may cause death).

Contamination of foods with *Salmonella* may be by a human carrier or by rats and mice which commonly harbor these bacteria. Fortunately, these bacteria are neither very acid-tolerant nor heat-resistant. *Vibrio parahaemolyticus* requires salt for growth and is associated with raw seafood. It will not grow below pH 4.8. *Clostridium perfringens*, like *Clostridium botulinum*, is an anaerobic, spore-forming bacterium that is commonly found in soil. Therefore, almost any fresh food may be contaminated with spores, and it is necessary to handle the food so that the germination and growth of these spores is prevented. While the spores will survive normal pasteurizing temperatures and may remain dormant for long periods in an acid food, the organism is unable to grow at low pH. This same organism is frequently the cause of gas gangrene.

2.4.3 Food as a Disease Vector

We have heard the story of Typhoid Mary. Like Mary, some people may be carriers of the causative bacterium, *Salmonella typhi*, but show no symptoms. Procedures are now available for identifying such carriers, and carriers are not allowed to work as food handlers. Dysentery and cholera, which also are transmitted by food, are caused by bacteria. Amoebic dysentery is caused by a protozoan and hepatitis by a virus. In

all of these instances, the causative organism is found in the feces of infected persons and is usually transmitted to the food by way of the hands. However, they may also reach the food by way of insects. It is very apparent that good sanitation practices must be enforced where food is handled for public consumption. None of these pathogens (patho = disease, genic = producing) are heat-resistant and would be destroyed by most pasteurization procedures.

Notes

2.4.4 Factors Affecting Growth of Food Pathogens

As discussed in section 2.2.6, many factors influence the growth, activity, and survival of microorganisms. The acidified foods regulation (21 CFR Part 114) was written specifically to protect the food supply from growth and toxin production by *Clostridium botulinum*. This bacterium cannot grow and produce its deadly toxin at pH 4.6 or lower. However, certain other pathogenic bacteria can grow in foods at less than pH 4.6. Table 2.4 summarizes the factors known to affect growth of certain food pathogens.

Some pathogens, such as certain strains of *Escherichia coli*, can grow well below pH 4.6. Thus, it is important that food manufacturers not depend on pH alone to assure food safety. For this reason, 21 CFR Section 114.80 (1) stipulates that "acidified foods shall be thermally processed to an extent that is sufficient to destroy the vegetative cells of microorganisms of public health significance, and those of non-health significance capable of reproducing under the conditions in which the food is stored, distributed, retailed, and held by the user. Permitted preservatives may be used to inhibit reproduction of microorganisms of non-health significance (in lieu of thermal processing)." Also, good sanitation practices in the processing of wholesome foods is very important. We will deal with this more fully in Chapter 6.

In interpreting Table 2.4, it is important to recognize that the conditions under which the pH limits and other factors in the table were determined may not be the same as in your food product. For example, the test conditions for *Escherichia coli* in Table 2.4 indicate that it will grow below pH 4. In a food that contains salt, sugar, and other ingredients, this bacterium may not be a problem either with or without pasteurization. The processor must be sufficiently familiar with the food item and cite a process authority to assure that the process used for preservation results in a safe food product. More information on this general subject is given in Chapter 5, which deals with scheduled processes.

TABLE 2.4
FACTORS AFFECTING GROWTH OF SELECTED PATHOGENS[a]

Pathogen	Minimum a_w	Minimum pH	Maximum pH	Maximum Salt (%)	Minimum Temperature (^oF)	Maximum Temperature (^oF)	Oxygen requirement
Campylobacter jejuni	.99	4.9-5.5	8.0	1.5-2	86-90	108-113	Microaerophilic[b]
Clostridium botulinum Type A	.93-.96	4.7	9.0	10	50	118-122	Anaerobe[c]
Clostridium botulinum Type E	.93-.96	4.7-4.8	9.0	4.5-6	38	86	Anaerobe[c]
Escherichia coli	.93-.95	3.6-4.7	9.5	7.5-8	33-37	113	Facultative anaerobe[d]
Listeria monocytogenes	.92-.95	4.8	9.6	8-12	36	113	Facultative anaerobe[d]
Salmonella spp.	.92	4.0	9.0	8	41	115-117	Facultative anaerobe[d]
Shigella spp.	.96	3.5-4.5	<10	6	>46	<113	Facultative anaerobe[d]
Staphylococcus aureus	.83-.86	4.0	10.0	18-20	41-43	113-118	Facultative anaerobe[d]
Vibrio cholerae	.95	3.6-6.0	9.6	6-8	46	108	Facultative anaerobe[d]
Vibrio parahaemolyticus	.94	4.8-5.0	9.6	8-10	41	109	Facultative anaerobe[d]
Vibrio vulnificus	.95	6.3	9.0	6	41	111	Facultative anaerobe[d]
Yersinia enterocolitica	.95-.96	4.1-4.4	9.0	6-7	30-34	111	Facultative anaerobe[d]

[a]From *Fish and Fishery Products Hazards and Controls Guide*. 1996. Interim First Edition, U.S. Food and Drug Administration.
[b]Requires limited levels of oxygen.
[c]Requires the absence of oxygen.
[d]Grows either with or without oxygen.

2.5 Summary

Notes

General microbiology:

(1) Man and microbes are in a constant race for food, and man must use all his talents to win.

(2) The first priority for food processors is to ensure that all foods are safe to eat, the second priority is to prevent food spoilage, and the third priority is to make sure that the food is of the highest possible quality.

(3) Millions of bacteria per milliliter must be present in a clear liquid food before turbidity is seen, but some divide so quickly that many billions of cells can be produced from one cell in less than one-half day.

(4) Spores of bacteria are very resistant to environmental stresses. They survive for years in unfavorable environments and initiate growth when conditions become favorable. Some spores are completely insensitive to boiling temperatures.

(5) Yeasts and molds are usually somewhat larger than bacteria, but there can be millions of these on a food without any visible evidence.

(6) Microorganisms are everywhere in nature. One has to assume that all fresh foods are either contaminated or susceptible to contamination by all kinds of microbes.

(7) Like all living things, microbes are influenced by the nutrients available, the oxygen supply, moisture levels and activity (a_W), temperature, pH, acidity, and light. However, there are microbes which prefer, or are able to survive in, extreme environments.

(8) Some bacteria require oxygen (aerobes), some can grow either with or without oxygen (facultative anaerobes), and others cannot survive in the presence of oxygen (anaerobes). The yeasts are mostly either aerobic or facultative, while practically all molds are aerobic.

(9) Water activity is a measure of the availability of water. Microorganisms of public health significance will not grow when the water activity is 0.85 or less.

(10) Some microbes grow and prefer temperatures near freezing (psychrophiles), others prefer temperatures very near those used for pasteurization (thermophiles), but the majority prefer intermediate temperatures (mesophiles).

Microbial spoilage:

Notes

(1) Fresh foods must be handled promptly and with tender loving care to prevent mechanical damage. When practical, they should be cooled and stored at low temperatures.

(2) Foods should be processed rapidly in a clean and sanitary manner.

(3) In acidified foods, molds are capable of using sufficient acid to increase the pH of a food above the safety point.

(4) Gross spoilage of canned foods is easy to recognize, but *Clostridium botulinum* may grow and produce toxin in a food with a pH above 4.6 without producing obvious changes in the food.

(5) If a jar or can of acid food leaks, aerobic yeasts and molds may grow on the surface and use enough acid to raise the pH above 4.6. This could allow spores of *Clostridium botulinum* to germinate and grow.

Food infections and poisonings:

(1) "Food poisoning" results from eating foods containing poisons (toxins) produced during the growth of a microorganism in the food. "Food infections" result from eating food containing certain living microorganisms which infect the intestinal tract.

(2) *Clostridium botulinum* is a spore-forming anaerobic bacterium which produces a very lethal poison during growth in a food.

(3) Spores of *Clostridium botulinum* are common in soil, and these spores are not destroyed by pasteurization.

(4) *Clostridium botulinum* will not grow or produce toxin at pH 4.6 or below, when the water activity is 0.85 or below, or in 10 percent salt brine.

(5) The botulism toxin is destroyed by boiling for 15 minutes.

(6) Pasteurized foods with a pH slightly above pH 4.6 are potentially very dangerous. *Clostridium botulinum* may grow poorly and fail to cause any apparent changes in the food, but will still produce toxin. Also, some of these foods are routinely served without heating.

(7) It is absolutely essential that the final pH of all water phases inside a container of pickled, fermented, or acidified food is at pH 4.6 or below.

(8) Some infectious diseases may be transmitted through foods. All foods should be protected insofar as possible from contamination by such organisms by the use of good sanitary practices.

(9) While growth and toxin production by *Clostridium botulinum* does not occur at pH 4.6 (and below), there are other types of pathogenic bacteria that can grow well below pH 4.6. Thus, acidified foods must be thermally processed to destroy vegetative cells of microorganisms of public health and non-health significance that are capable of reproducing in the food, or permitted preservatives can be used instead of thermal processing to prevent growth of microbes of non-health significance.

Notes