Food microbiology

Food microbiology is the study of the microorganisms that inhabit, create, or contaminate food. Of major importance is the study of microorganisms causing food spoilage. "Good" bacteria, however, such as probiotics, are becoming increasingly important in food science. In addition, microorganisms are essential for the production of foods such as cheese, yogurt, other fermented foods, bread, beer and wine.

Food safety

Food safety is a major focus of food microbiology. Pathogenic bacteria, viruses and toxins produced by microorganisms are all possible contaminants of food. However, microorganisms and their products can also be used to combat these pathogenic microbes. Probiotic bacteria, including those that produce bacteriocins, can kill and inhibit pathogens. Alternatively, purified bacteriocins such as nisin can be added directly to food products. Finally, bacteriophages, viruses that only infect bacteria, can be used to kill bacterial pathogens. Thorough preparation of food, including proper cooking, eliminates most bacteria and viruses. However, toxins produced by contaminants may not be heat-labile, and some are not eliminated by cooking.

Fermentation

Fermentation is one way microorganisms can change a food. Yeast, especially *Saccharomyces cerevisiae*, is used to leaven bread (تخمير الخبز), brew beer and make wine. Certain bacteria, including lactic acid bacteria, are used to make yogurt, cheese, hot sauce, pickles, fermented sausages and dishes such as kimchi. A common effect of these fermentations is that the food product is less hospitable to other microorganisms, including pathogens and spoilage-causing microorganisms, thus extending the food's shelf-life. Food fermentations are ancient technologies that harness microorganisms and their enzymes to improve the human diet. Fermented foods keep better, have enhanced flavours, textures and aromas, and may also possess certain health benefits, including superior digestibility. For vegetarians, fermented foods serve as palatable, protein-rich meat substitutes.

Probiotics

Probiotics are living organisms that, when consumed, have beneficial health benefits outside their inherent nutritional effects. There is a growing body of evidence for the role of probiotics in gastrointestinal infections, irritable bowel syndrome and inflammatory bowel disease. *Lactobacillus* species are used for the production of yogurt, cheese, sauerkraut, pickles, beer, wine, cider, kimchi, chocolate and other fermented foods, as well as animal feeds such as silage.

Microbial biopolymers

A huge variety of biopolymers, such as polysaccharides, polyesters, and polyamides, are produced by microorganisms. These products range from viscous solutions to plastics. The genetic manipulation of microorganisms has permitted the biotechnological production of biopolymers with tailored material properties. Industrial microbiology can be used for the biosynthesis of xanthan, alginate, cellulose, cyanophycin, poly(gamma-glutamic acid), levan, hyaluronic acid, organic acids, oligosaccharides and polysaccharides, and polyhydroxyalkanoates. Several microbially-produced polymers are used in the food industry.

Describe the conditions favorable to the growth of bacteria in food

Bacteria are everywhere. Some are beneficial, such as those used to make fermented dairy and meat products. Others cause spoilage. And, a small percentage are harmful or pathogenic.

When bacteria grow, they increase in numbers not in size. This process is called cell division (or doubling). Under ideal conditions, the number of bacteria can double every 30 minutes. Therefore, one becomes two, two become four, four become eight, and so on. If you start with one bacterial cell, after 12 hours there

would be as many as 33,000,000 (about 400 million bacteria clumped together would be about the size of a grain of sugar). The rate at which bacteria grow is different for each type or organism and is affected by many factors.

Factors Affecting Microbial Growth

Intrinsic factors: The parameters of plant and animal tissues that are an inherent part of the tissues are referred to as intrinsic factor. These parameters are as follows: 1. pH. 2. Moisture content. 3. Oxidation–reduction potential (Eh). 4. Nutrient content. 5. Antimicrobial constituents . 6. Biological structures.

Extrinsic factors: The extrinsic parameters of foods are not substrate dependent. They are those properties of the storage environment that affect both the foods and their microorganisms. As follows: 1. Temperature of storage. 2. Relative humidity of environment. 3. Presence and concentration of gases. 4. Presence and activities of other microorganisms.

Implicit factors: Physiological properties

process factors: Heating, cutting,….

Many factors affect bacterial growth but the most important ones are:

1. **Water** -- Bacteria need water to dissolve the food they use for energy and growth. Water allows the food to get into the cells, is used for the many chemical reactions necessary for life and growth, and allows waste products to escape.
2. **Food/Nutrients** -- All bacteria require energy to live and grow. Energy sources such as sugars, starch, protein, fats and other compounds provide the nutrients.
3. **Oxygen** -- Some bacteria require oxygen to grow (aerobes) while others can grow only in the absence of oxygen (anaerobes). However, many bacteria grow under either condition and they are facultative anaerobes.
4. **Temperature** -- Bacteria in general are capable of growing over a wide range of temperatures and are usually classified according to the temperature at which they grow to:

   Psychrotrophic bacteria (البكتيريا المحبة للبرودة) are those that are capable of growing at 32°F - 45°F but their optimum is from 68°F to 86°F. They cause spoilage in foods stored under refrigeration. Several pathogenic bacteria are psychotrophic – Yersinia and Listeria.

   Mesophilic bacteria. Most bacteria are capable of growing at 60°F - 110°F and belong in this group. Most pathogenic bacteria grow at these temperatures.

   Thermophilic bacteria. These microorganisms grow at higher temperatures such as 110°F - 150°F. Temperature is the most widely used method of controlling bacterial growth. Bacteria grow slowly at temperatures below 45°F and thermal destruction occurs at temperatures above 140°F. But in the temperature danger zone -- between 40°F and 140°F -- many bacteria are not controlled.
5. **pH** -- pH is a measure of acid or alkali in a product. It is indicated on a scale from 0 to 14, with seven being neutral. If the pH value is below 7, the food is classified as acid; if it is above 7, the food is classified as alkaline. Most bacteria grow well at neutral pH, but many can reproduce in a pH range from 4.5 - 10.0.

Although each of the major factors listed above plays an important role, the interplay between the factors ultimately determines whether a microorganism will grow in a given food. Often, the results of such interplay are unpredictable, as poorly understood synergism or antagonism may occur. Therefore, predictions about whether or not a particular microorganism will grow in a food can, in general, only be made through experimentation. Also, many microorganisms do not need to multiply in food to cause disease.

Microorganisms and Food Spoilage

Spoiled Food

1. Damage or injuries that make food undesirable for human consumption.
2. Can be the result of:
    a. insect damage
    b. physical injury
    c. enzymatic degradation
    d. microbial activity

Basic Types of Food Spoilage

1. Appearance: when a food "looks bad," what is this referring to?
    a. Microbial growth
        mycelia or colonies visible on surface
        development of cloudiness in liquids
    b. Changes in food color due to heme or chlorophyll breakdown
        colony pigments, growth of mycelia, etc.
2. Textural changes (feel)
    a. Slime formation
        due primarily to surface accumulation of microbial cells
        also be a manifestation of tissue degradation
    b. Tissue softening due to enzymatic degradation (e.g. soft rot in veggies)
3. Changes in taste and odor
    a. Development of:
        1. nitrogenous compounds (ammonia, amines, etc.)
        2. sulfides
        3. organic acids

The numbers and types of MO in a food are largely determined by:

1. Environment from which the food was obtained.
2. Microbiological quality of the food in its raw or unprocessed state (intrinsic factors).
3. Handling and processing sanitation.
4. Effectiveness of packaging, handling and storage conditions in restricting microbial growth (extrinsic factors).

Specific Food Groups

A. Fresh Meats:

Chemical composition:

-75% water
-18% protein
-3% fat, 1% ash, traces of CHO, vitamins, etc.

1. Whole Meats:

The microflora of fresh meat is composed primarily of:

1. Gram negative aerobic rods such as *Pseudomonas, Acinetobacter* and *Moraxella.*
2. *Bacillus* and clostridia (e.g. *C. perfringens*) are also common on all types of meat.

Although subsurface portions of meat are generally sterile, some parts such as lymph nodes may be heavily contaminated. Mechanical disruption of the tissue during processing can distribute microorganisms from the meat surface throughout the product.

Fresh meats are among the most perishable foods (الأطعمة القابلة للتلف).

Storage temperature is the single most important control factor for meat spoilage.

Sources of Contamination

Several genera of **molds** grow on the surface of meat and can cause spoilage, but cannot grow on meat stored below 5°C.

Usually, fresh cut meats in the refrigerator at high humidity undergo bacterial spoilage by: Gram negative aerobes like *Pseudomonas, Acinetobacter* and *Moraxella* spp.

The intrinsic and extrinsic parameters of ground beef favor these bacteria so strongly that they are almost exclusive spoilage agents.

Meat spoilage is characterized by the appearance of off odors and slime, which are manifest when surface loads exceed **10^7 CFU/cm^2**.

The slime is due to the accumulation of bacterial cells.

Interestingly, meat spoilage (including poultry and fish) occurs without any significant breakdown of the primary protein structure. Instead, spoilage bacteria utilize glucose, free amino acids or other simple nitrogenous compounds to attain population of about **10^8 CFU/cm^2**, at which point the organoleptic quality of the meat (الصفات الحسية للحوم) will clearly reveal it is spoiled.

2. Ground Meats:

*Same MO as whole meats, but always have higher microbial loads. Why?

- greater surface area which gives microbes better access to the food and also traps air to favor the growth of gram-negative, aerobic bacteria like Pseudomonas spp.
- Every handling or processing (storage utensils مواعين التخزين , cutting knives, grinders) step can contribute additional contamination to the final product.
- One heavily contaminated piece (e.g. a lymph node) can contaminate an entire lot when they are ground together.

*Use of: (a) soy protein extenders باسطات اللحوم من بروتين الصويا (b) mechanically deboned meat (MDM) اللحوم منزوعة العظم ميكانيكيا

-Does not change the microflora significantly but does raise the pH of meat which leads to more rapid spoilage

-Ground beef pH=5.1-6.2, add extenders raise it to 6.0-7.0)

3. Vacuum packaged meats

- 80% of beef leaves packing plant in vacuum package.
- not all O_2 is removed during packaging but residual is consumed by respiration of aerobic MO and the tissue itself
- results in increased CO_2 levels and thus get a longer shelf life.

Impermeable films used:

1. CO_2 levels are higher
2. Eh lower (Oxidation–reduction (O/R) potential -(symbol =Eh))

The microflora shifts from predominantly G^- aerobes to G^+ anaerobes and microaerophilic lactic acid bacteria (LAB) like *Lactobacillus, Carnobacterium* and *Leuconostoc.*

- if nitrites have been added to the vacuum packaged meat (e.g. to inhibit *C. botulinum* in hams, bacon), LAB domination is even more pronounced

In general, vacuum packaged meats are considered very safe foods and free from most pathogenic species of bacteria.

-with the possible exception of *S. aureus* and *Y. enterocolitica*

Spoilage in vacuum packaged meats is manifest by:

1. Slime development
2. **Greening** caused by microbial production H_2O_2 or H_2S.
   H_2O_2 production in meat has been associated with several types of lactic acid bacteria (primarily *Lactobacillus*)

The oxidant (H_2O_2) reacts with nitrosohemochrome (cured meat color لحم مقدد) to form a green porphyrin compound.

H_2S greening occurs in fresh meats that have been vacuum packaged and stored between 1-5°C.

H_2S reacts with myoglobin to form sulphmyoglobin in meats with a pH above 6.0.

H_2S is produced by:

1. *Shewanella putrefaciens* and *Pseudomonas* spp. (when O_2- permeable films are used).
2. Some lactobacilli (when O_2- impermeable films are used).

Off odors which result from:

1. the release of short chain fatty acids
2. the production of volatile compounds like acetoin, diacetyl and H_2S (and many other compounds, depending on the dominant spoilage bacterium)

The type of spoilage bacteria that will dominate is influenced by several factors that include:

1. Is the meat product raw or cooked?
   Cooked products have a higher pH (>6.0) which may allow growth of G- facultative anaerobic pathogens like *Yersinia enterocolitica*.
   Raw products have a pH of about 5.6 which favors lactic acid bacteria, esp. *Lactobacillus, Carnobacterium,* and *Leuconostoc.*
2. Nitrite concentration in meat.
   High nitrite conc. favors lactic acid bacteria.
   Low nitrite levels may allow growth of *Brochothrix thermosphacta* (G+ rod, fac. anaer, growth at 0-30°C from pH 5.0-9.0 catalase+).
   B. thermosphacta is an important spoilage bacterium in anaerobically stored meats kept at low temperature, but the bacterium is inhibited by nitrite.

4. Processed meats (hot dogs, sausage and luncheon meats)

These products are composed of a variety of blended ingredients, any of which can contribute microorganisms to the food.

Yeasts and bacteria are the most common causes of spoilage, which is usually manifest in **3 ways**:

A. **Slimy spoilage**

Like other meat products, this occurs on the surface and is caused by the buildup of cells of yeasts, lactobacilli, enterococci or *Brochothrix thermosphacta.*
Washing the slime off with hot water can restore the product quality.

B. **Sour spoilage.**
Results from growth of lactic acid bacteria (which originate from contaminated ingredients like milk solids) under the casing.
These organisms ferment lactose and other CHOs in the product and produce organic acids. Taste is adversely affected but the product is not harmful if eaten.

C. **Greening** due to H_2O_2 or H_2S production.
Because greening indicates more extensive product breakdown, I would not recommend eating green wieners.

Reasons Cured meats (bacon, hams) are resistant to spoilage:

1. Use of nitrite/nitrate
2. Smoking or brining of hams
3. The high fat content (thus low a_w) of bacon

Instead, spoilage of these products is often caused by molds from several genera including *Aspergillus, Fusarium, Mucor, Penicillium, Rhizopus* and *Botrytis.*

5. Poultry:

a. general trends are the same as other fresh meats
b. similar microflora on fresh birds
c. whole birds have lower counts than cut-up parts
d. additional processing steps add to the microbial load

When poultry is in the advanced stages of spoilage, the skin will often fluoresce under UV because so many fluorescent pseudomonads are present.

Off odors generally appear before sliminess develops.

The same bacteria can produce visceral taint, a condition manifest by off odors in the abdominal cavity or poultry.

Point to remember:

During the initial stages of spoilage, the skin supports bacterial growth better than does the tissue (which remains essentially free of bacteria for some time). Thus, the skin can sometimes be removed to salvage the food.

6. Fish:

a. Fish have high nitrogen content but no carbohydrate.
b. The microbial quality of fish and especially shellfish is heavily influenced by the **quality of the water** from which they were harvested.

Unsanitized (غير مطهرة) processing steps are principal culprits(المتسبب الرئيس) in fish products with high microbial loads.

- In general, frozen fish products have lower counts than fresh products.
- Bacteria on fresh fish are concentrated on the outer slime, gills and intestine.
- Spoilage of salt- and freshwater fish occurs in similar ways; the most susceptible part of the fish to spoilage is the gill region, and the best way to detect spoilage in fresh fish is to sniff (شم) this area for off odors produced by *Pseudomonas and Acinetobacter-Moraxella* bacteria.
- The odors include ammonia, triethylamine, H_2S and other compounds.
- If fish are not viscerated quickly, bacteria will move through the intestinal walls and invade the meat that lies next to the abdominal cavity.

Spoilage of **crustaceans** (shrimp, lobsters, crabs and crayfish) is similar, but these products have some CHO (0.5%) and more free amino acids so spoilage can occur more rapidly.

Mollusks الرخويات: oysters, clams, mussels, squid and scallops المحار وبلح البحر والحبار و الاسكالوب have more CHO (3-5%) and less nitrogen than either fish or shellfish.

- Microflora of mollusks can vary a great deal depending on the quality of the water from which they were harvested.
- Shellfish are filter feeders and can be expected to contain almost any microorganism or virus that occurs in the water where they were obtained.
- If these products were taken from clean waters, then the usual *Pseudomonas* and *Acinetobacter-Moraxella* types of spoilage bacteria dominate.

B. Vegetables

Typical composition:

-88% water
-8.6 % CHO. Includes readily available mono- and disaccharides like glucose and maltose, as well as more complex oligosaccharides, which are available to fewer types of microorganisms.
-1.9% protein
-0.3 % fat
-0.84 % minerals
-also contain fat and water soluble vitamins and nucleic acids (<1%).
-pH of most veggies is around 6.0; within the growth range of many bacteria

Vegetables are a good substrate for yeasts, molds or bacteria

- It is estimated that 20% of all harvested fruits and vegetables for humans are lost to spoilage by these microorganisms.
- Because bacteria grow more rapidly, they usually out-compete fungi for readily available substrates in vegetables. As a result, bacteria are of greater consequence in the spoilage of vegetables with intrinsic properties that support bacterial growth (favorable pH, Oxidation–reduction (O/R) potential - =Eh).

Microflora of vegetables is primarily composed of:

1. G+ bacteria like lactic acid bacteria (e.g. leuconostocs, lactobacilli, streptococci.
2. Coryneforms and staphylococci (the latter coming from the hands of employees during processing.

Staphylococci are usually unable to proliferate but cross-contamination can introduce them into other foods where growth conditions are more favorable.

Soft rot (التعفن اللين)

a. One of the most common types of bacterial spoilage.
b. caused by *Erwinia carotovora* and sometimes by *Pseudomonas* spp., which grow at 4°C
Softening can also be caused by endogenous enzymes.

Flavr Savr tomatoes story(قصة الطماطم صنف فلافرسلافر):

a. polygalacturonase (PB); hydrolyzes a (1-4) glycosidic bond in pectin which leads to softening.
b. Calgene made antisense RNA to tomato *pb*geen, constructs soften slower and so can be harvested after they are ripe (better flavor).
c. First commercially avail (الأولى ذات جدوى تجاريا). genetically engineered vegetable.

Mold spoilage

a. In vegetables where bacterial growth is not favored (e.g. low pH), molds are the principal spoilage agents.
b. Most molds must invade plant tissue through a surface wound such as a bruise or crack.
c. Spores are frequently deposited at these sites by insects like *Drosophila melanogaster*, the common fruit fly.
d. Other molds like *Botrytis cinerea*, which causes grey mole rot on a variety of vegetables, are able to penetrate fruit or vegetable skin on their own.

The microflora of vegetables will reflect:

a. the sanitation of processing steps
b. the condition of the original raw product

Soil-borne MO such as clostridia are common on raw vegetables, and some species, like *C. botulinum,* are of such great concern that they are the focus of processing steps designed to destroy MO.

Sources of Contamination

1. Surface contamination – Soil, water, air, human pathogens from manure (night soil)
2. Harvesting - hand picking vs. machines
   high damage if crop is ripe...harvest before ripe
   Geotrichium candidum – mold on harvestors
3. Packaging: containers reused-sanitized
4. Processing plant
5. Markets – handling, cross-contamination

C. Fruits

Average composition

-85% water
-13% CHO
-0.9% protein (a bit low on nitrogen sources)
-0.5% fat
-0.5% ash
-trace amounts of vitamins, nucleotides, etc.
-less water and more CHO than veggies
-low pH (1.8-5.6)

Like vegetables, fruits are nutrient rich substrates but the pH of fruits does not favor bacterial growth. As a result, **yeasts and molds are more important than bacteria** in the spoilage of fruits.

a. Several genera of yeasts can be found on fruit.
b. Because these organisms grow faster than molds, yeast often initiate fruit spoilage.
c. then molds finish the job by degrading complex polysaccharides in cell walls and rinds.

Specific Spoilage Organisms:

1. Blue rot – *Penicillium,* fruits
2. Downy mildews – *Phytophora*, large masses of mycellium (grapes)
3. Black rot – *Aspergillus,* onions
4. Sour rot – *Geotrichum candidum*

D. Other Foods

1. Dairy Products - Milk is a very rich medium

Raw milk flora may include:

a. All MO found on the cow hide(جلود البقر) (which include soil and fecal bacteria), udder (ثدي الحيوان), and milking utensils
b. Can include G-, G+, yeasts and molds.

When properly handled and stored, the flora of pasteurized milk is primarily G+ bacteria.
Psychrotropic pseudomonads are common in bulk stored raw milk (produce heat stable enzymes that can reduce milk quality and shelf life)
- Pasteurization kills most G^- (incl. Pseudo.), yeasts and molds
-some G^- enzymes, thermotolerant G^+ bacteria and spores survive
-Psychrotropic *Bacillus* spp. are also common in raw milk

Pasteurized fluid milk – spoiled by a variety of bacteria, yeasts and molds.
a. In the past, milk was usually soured by LAB such as enterococci, lactococci, or lactobacilli, which dropped the pH to 4.5 where milk proteins coagulate (curdling).
b. Today, milk is more frequently spoiled by aerobic sporeformers such as *Bacillus*, whose proteolytic enzymes cause curdling.
c. Molds may grow on the surface of spoiled milk, but the product is usually discarded before this occurs.

Butter; high lipid content and low a_w (Water activity النشاط المائي) make it more susceptible to surface mold growth than to bacterial spoilage.
- Some pseudomonads can be a problem; "surface taint"
- putrid smell, caused by the production of organic acids (esp. isovaleric) from *P. putrefaciens*
- Rancidity due to butterfat lypolysis caused by *P. fragi* are common.

Cottage cheese can be spoiled by yeasts, molds and bacteria.
- The most common bacterial spoilage is "**slimy curd**" caused by *Alcaligenes* spp. (G^- aerobic rod bound in soil, water, and intestinal tract of vertebrates).
- Like *Campylobacter*, these species do not oxidize CHOs but instead use amino acids and TCA intermediates.
- *Penicillum, Mucor* and other fungi also grow well on cottage cheese and impart stale or yeasty flavors.

Ripened Cheeses – (1) low a_w, (2) low pH and (3) high salt inhibit most spoilage microorganisms except surface mold growth.
- Spores of *C. butyricum, C. sporogenes* and others can germinate in cheeses (e.g. Swiss) with intrinsic properties that are less inhibitory (e.g. lower salt, higher pH).
-These organisms may metabolize citrate, lactose, pyruvate or lactic acid and produce butyrate or acetate plus CO_2 or H_2 gas which "blows" the cheese.

Eggs
- Eggs have several intrinsic parameters which help to protect the nutrient-rich yolk from microbial attack. These include the shell and associated membranes, as well as lysozyme, conalbumin, and a high pH (>9.0) in the white. Freshly laid eggs are generally sterile, but soon become contaminated with numerous genera of bacteria.
- Eventually, these MO will penetrate the eggshell and spoilage will occur. Pseudomonads are common spoilage agents, but molds like *Penicillium* and *Cladosporium* sometimes grow in the air sac and spoil the egg.

Cereal and Bakery Goods
- These products are characterized by a low a_w which, when stored properly under low humidity, restricts all MO except molds. *Rhizopus stolonifera* is the common bread mold, and other species from this genus spoil cereals and other baked goods.
- Refrigerated frozen dough products (منتجات العجين المجمدة) have more water and can be spoiled by lactic acid bacteria.

Fermented Foods

- The low pH of these products does not allow growth of pathogens, but spoilage can occur.
- Yeasts, molds and lactic acid bacteria can also spoil fermented vegetables such as sauerkraut and pickles, as well as other acid foods like salad dressings and mayonnaise. Spoilage in fermented vegetables is often manifest by off odors or changes in the color (chromogenic colony growth) or texture (softening) of the product. In mayonnaise or salad dressing, the first signs of spoilage are usually off odors and emulsion separation.

Foodborne pathogens:

Foodborne pathogens are the leading causes of illness and death in less developed countries, killing approximately 1.8 million people annually. In developed countries, foodborne pathogens are responsible for millions of cases of infectious gastrointestinal diseases each year, costing billions of dollars in medical care and lost productivity. New foodborne pathogens and foodborne diseases are likely to emerge, driven by factors such as pathogen evolution, changes in agricultural and food manufacturing practices, and changes to the human host status. There are growing concerns that terrorists could use pathogens to contaminate food and water supplies in attempts to incapacitate thousands of people and disrupt economic growth.

Enteric viruses

Food and waterborne viruses contribute to a substantial number of illnesses throughout the world. Among those most commonly known are hepatitis A virus, rotavirus, astrovirus, enteric adenovirus, hepatitis E virus, and the human caliciviruses consisting of the noroviruses and the Sapporo viruses. This diverse group is transmitted by the fecal-oral route, often by ingestion of contaminated water and food .

Protozoan parasites

Protozoan parasites associated with food and water can cause illness in humans. Although parasites are more commonly found in developing countries, developed countries have also experienced several foodborne outbreaks. Contaminants may be inadvertently introduced to the foods by inadequate handling practices, either on the farm or during processing of foods. Protozoan parasites can be found worldwide, either infecting wild animals or in water and contaminating crops grown for human consumption. The disease can be much more severe and prolonged in immunocompromised individuals.

Mycotoxins

Molds produce mycotoxins, which are secondary metabolites that can cause acute or chronic diseases in humans when ingested from contaminated foods. Potential diseases include cancers and tumors in different organs (heart, liver, kidney, nerves), gastrointestinal disturbances, alteration of the immune system, and reproductive problems. Species of *Aspergillus*, *Fusarium*, *Penicillium*, and *Claviceps* grow in agricultural commodities or foods and produce the mycotoxins such as aflatoxins.

Yersinia enterocolitica

Yersinia enterocolitica includes pathogens and environmental strains that are ubiquitous in terrestrial and fresh water ecosystems. Evidence from large outbreaks of yersiniosis and from epidemiological studies of sporadic cases has shown that *Y. enterocolitica* is a foodborne pathogen.

Vibrio

Vibrio species are prevalent in estuarine and marine environments, and seven species can cause foodborne infections associated with seafood. *Vibrio cholerae* O1 and O139 serotypes produce cholera toxin and are agents of cholera.

Staphylococcus aureus

Staphylococcus aureus is a common cause of bacterial foodborne disease worldwide. Symptoms include vomiting and diarrhea that occur shortly after ingestion of *S. aureus* toxin-contaminated food. The symptoms arise from ingestion of preformed enterotoxin, which accounts for the short incubation time. Staphylococcal enterotoxins are superantigens and, as such, have adverse effects on the immune system.

Campylobacter

Campylobacter spp., primarily *C. jejuni* is one of the major causes of bacterial gastroenteritis in the U.S. and worldwide.

Listeria monocytogenes

Listeria monocytogenes is Gram-positive foodborne bacterial pathogen and the causative agent of human listeriosis. *Listeria* infections are acquired primarily through the consumption of contaminated foods, including soft cheese, raw milk, deli salads, and ready-to-eat foods such as luncheon meats and frankfurters.

Salmonella

Salmonella serotypes continue to be a prominent threat to food safety worldwide. Infections are commonly acquired by animal to human transmission though consumption of undercooked food products derived from livestock or domestic fowl.

Shigella

Shigella species are members of the family Enterobacteriaceae and are Gram negative, non-motile rods. Four subgroups exist based on O-antigen structure and biochemical properties: *S. dysenteriae* (subgroup A), *S. flexneri* (subgroup B), *S. boydii* (subgroup C) and *S. sonnei* (subgroup D). Symptoms include mild to severe diarrhea with or without blood, fever, tenesmus and abdominal pain. Further complications of the disease may be seizures, toxic megacolon, reactive arthritis and hemolytic uremic syndrome. Transmission of the pathogen is by the fecal-oral route, commonly through food and water.

Escherichia coli

More information is available concerning *Escherichia coli* than any other organism, thus making *E. coli* the most thoroughly studied species in the microbial world. For many years, *E. coli* was considered a commensal of human and animal intestinal tracts with low virulence potential. It is now known that many strains of *E. coli* act as pathogens, inducing serious gastrointestinal diseases and even death in humans. There are six major categories of *E. coli* strains that cause enteric diseases in humans, including the:

1. enterohemorrhagic *E. coli*, which cause hemorrhagic colitis and hemolytic uremic syndrome,
2. enterotoxigenic *E. coli*, which induce traveler's diarrhea,
3. Enteropathogenic *E. coli*, which cause a persistent diarrhea in children living in developing countries,
4. Enteroaggregative *E. coli*, which provokes diarrhea in children,
5. Enteroinvasive *E. coli* that are biochemically and genetically related to *Shigella* species and can induce diarrhea,
6. diffusely adherent *E. coli*, which cause diarrhea and are distinguished by a characteristic type of adherence to mammalian cells.

Clostridium botulinum and Clostridium perfringens

Clostridium botulinum produces extremely potent neurotoxins that result in the severe neuro-paralytic disease, botulism. The enterotoxin produced by *C. perfringens* during sporulation of vegetative cells in the host intestine results in debilitating acute diarrhea and abdominal pain.