

## Module I Principles of Shelf Life

### Chapter 2. Modes of Food Deterioration and Food Losses

Objectives: By the end of this module, you will have learnt

- a) How some of the physical mechanisms result in food spoilage?
- b) What are the major chemical reactions that cause spoilage in foods?
- c) What is the role of microorganisms in food spoilage?
- d) What can be done to prevent food spoilage?

The mechanisms responsible for food deterioration and food losses are complex and often more than one mechanism may be involved. The following list includes some of the key mechanisms:

Physical instability

Chemical spoilage

Microbial spoilage

Since all foods originate as biological materials, they experience spoilage and deterioration over time. A food is considered to be spoiled when it is no longer acceptable to the consumer. In its extreme manifestation, spoiled food may be harmful if consumed as it may cause illness or even death. Other changes that may lead to unacceptability include development of off-color, changes in aroma, textural changes and/or loss of nutritional content. More than one change may simultaneously occur causing spoilage.

We will consider each of these mechanisms and illustrate their role in food spoilage.

#### 2.1 Physical Changes

Mechanical damage caused during handling of foods can lead to consumer unacceptability as well as further deterioration of the product. Fresh fruits and vegetables deteriorate when bruised during harvesting, packaging, transport and distribution. Enzymatic browning caused by rupture of cells brings about color change and facilitates growth of microorganisms. Processed foods such as crackers, ready-to-eat cereals and snack chips that are dry and brittle may break down due to mishandling during transportation and distribution.

Most food products are hygroscopic in nature; they gain or lose moisture depending upon the humidity levels in the surrounding environment. Typical influence of moisture exchange causes changes in texture, e.g. dried foods such as crackers upon gaining moisture lose their crunchiness and become soggy, whereas soft textured foods (that have desirable chewy attributes) become hard and brittle. The exchange of water may also occur in multi-component foods depending on the differences of water activity. Staling in bakery products is enhanced due to moisture transfer from the crumb that has high water activity to the crust that has low water activity. The role of glass transition temperature (at which

the product changes from “glassy” to a “rubbery” state) and its impact on the moisture mobility within a food product has been extensively studied during the past two decades. A common temperature-influenced defect in food powders is the caking phenomenon. In humid environment, as powders gain moisture, their glass transition temperature decreases, and they become amorphous and stick together resulting in caking.

Temperature is another major factor that influences physical stability of foods. Both constant and fluctuating temperatures, as well as low and high temperatures may cause food deterioration. Fresh fruits and vegetables continue to respire after harvest and generate heat. The respiration rate is decreased by lowering the product temperature. As ripening continues after harvest in climacteric fruits, there is increased evolution of ethylene. Ethylene also acts as a plant growth regulator and causes accelerated senescence. A higher temperature causes more ethylene production and a faster advance to senescence in such products. Lower temperatures in the range of 5 to 15°C can also be harmful to certain fruits and vegetables (such as bell peppers) that are sensitive to chilling injury. Chilling injury causes water soaking, pitting, discoloration and development of off-flavors.

In frozen foods held at subfreezing temperatures during storage, fluctuation of storage temperature can cause sublimation of ice at the product surface resulting in a common defect called “freezer burn.” With temperature fluctuations, ice crystals in frozen foods grow in size. This recrystallization phenomenon is commonly observed during storage of ice cream where the texture becomes grainy over time.

Crystallization of sugar and fats can also bring about unacceptable changes in foods stored at ambient temperatures. Amorphous or “glassy” sugar becomes “rubbery” due to water uptake or increase in temperature. In rubbery state, as sugar crystallizes it expels water and become grainy in texture. In chocolates, if moisture condenses on the surface, it draws out sugar from the interior causing an unacceptable “grayish” appearance. Fat migration and recrystallization of cocoa fat in chocolates also cause white discoloration that is commonly called “fat bloom.” Fat crystallinity in chocolate occurs due to fluctuations in temperature.

Bread staling, due to starch retrogradation, caused by storage temperature, is highest at the commonly used refrigeration temperatures.

Foods created as emulsions, such as mayonnaise, margarine, and salad dressings, can experience creaming or coalescence of droplets, defects that lead to unacceptability. Since emulsions are thermodynamically unstable, improper dispersion of phases at the time of preparation or mishandling with extremes of temperatures or vibration can cause product degradation.

## **2.2 Chemical Spoilage**

Chemical and biochemical changes occurring in foods during storage are generally undesirable except in a few instances such as aging of wine, cheese or ripening of fruits. Often, a chemical reaction or breakdown of chemical components results in food spoilage. Some of the notable chemical changes include protein degradation, lipid oxidation, nonenzymatic browning, and chemical spoilage of carbohydrates.

Among chemical changes, oxidation is one of the key culprits. For example, roasted coffee exposed to air loses its flavors as oils present in coffee are oxidized. In case of beer, off flavors develop with oxidation of its flavor components. Many essential nutrients, such as vitamins are oxidized in the presence of air resulting in their reduced efficacy. In case of freshly cut apples or lettuce, the enzyme catalase is catalyzed in presence of air resulting in browning which is considered unattractive.

The development of off-flavors in many foods containing oils and fats is often the result of rancidity. Lipolytic/hydrolytic rancidity: reactions such as lipolysis catalyzed by enzyme lipases produce free fatty acids(FFA). Many foods contain lipase enzymes, e.g. dairy products, cocoa powder, desiccated coconut. The free fatty acids cleaved from the triglyceride molecules cause rancid off flavors.

**Oxidative rancidity** : Oxidative rancidity is either enzyme initiated such as due to lipoxygenase that are widely present in foods, or due to metal ions such as  $\text{Cu}^{2+}$ . In both cases, the intermediate products of oxidation include hydroperoxides that cause production of off-flavors. Examples of foods susceptible to oxidative rancidity include spray dried milk fats, infant milk, and chocolate. Presence of polyunsaturated fatty acids causes rancidity, such as in instant potato powder.

**Chemical Hydrolysis**: Hydrolysis of a chemical compound may cause food deterioration, e.g. in carbonated drinks containing aspartame, hydrolysis reactions under ideal pH and temperature will reduce sweetness.

Lipid oxidation is one of the most common spoilage reactions in oils and foods containing fats such as nuts, fried foods, meats, milk powder, and coffee. Unsaturated fatty acids are oxidized in the presence of oxygen causing changes in color, and development of off flavor. The rate of oxidation is influenced by the location and number of double bonds on the fatty acids and triglycerides. Light, heat, and trace metals can catalyze the lipid oxidation reaction.

Carbohydrates spoil due to retrogradation and browning reactions. Retrogradation occurs in starches that have been previously gelatinized. While during gelatinization the crystallinity is lost, during retrogradation, crystals begin to form again due to re-association. Retrogradation is more common with amylose since they are smaller unbranched molecules. A common example of this spoilage is staling of bread and bakery products.

Protein degradation is often catalyzed by enzymatic activity. For example, protease plasmin can survive pasteurization temperatures and cause deterioration of dairy proteins in milk resulting in coagulation and gelation. Proteases also cause mushiness in meats by breaking down meat proteins. Oxidative changes in meats results in undesirable brown color, where myoglobin and oxymyoglobin is converted into metmyoglobin.

Nonenzymatic browning (NEB), also called Maillard browning, involves proteins (amino groups) and reducing sugars. The reaction has several steps which ultimately lead to the formation of volatiles and dark pigments. It can also bring about changes in the texture and loss in nutritional value (in particular lysine, an essential amino acid). Maillard browning is most pronounced when the water activity is

between 0.6 and 0.8. Other contributing factors to Maillard browning include metal ions such as copper and iron, and high pH. NEB occurs in several dehydrated products such as instant potato, and egg white.

Hydrolytic reactions are another cause of spoilage in foods. They cause breakdown of polysaccharides and oligosaccharides. Several enzymes play an important role in these reactions, e.g. polygalacturonase and pectin lyase breakdown pectin that cause softening of vegetables. In lipids, hydrolytic rancidity results from cleavage of free fatty acids (FFA) from triglyceride molecules in the presence of moisture. FFAs are short chain molecules and they cause odor and rancid flavors. Inactivating lipolytic enzymes with heating (above 60°C) and reducing the presence of moisture helps minimize these reactions.

Another important class of chemical reactions that cause quality deterioration is influenced by light. They depend on the wavelength, exposure time, light intensity, temperature, and available oxygen. For example, fresh milk exposed to sunlight acquires off-flavor characterized as "cardboard," and butter becomes rancid faster next to fluorescent light. Similarly, vitamins such as riboflavin, ascorbic acid, and color pigments are sensitive to light.

### **2.3 Microbial Spoilage**

Microorganisms are a major cause of food spoilage. Pathogenic organisms cause foodborne illnesses and even fatalities. Presence of water in foods encourages the growth of both spoilage and pathogenic microorganisms. The microbial presence in foods depends on the intrinsic factors such as water activity, pH, total acidity, preservatives and nutrients, and extrinsic factors such as the processing method and conditions during storage including temperature, humidity and gas composition. Physiological factors also play a role in microbial proliferation. The shelf life of perishable foods is seriously influenced by the presence and growth of bacteria, fungi including molds and yeasts, viruses, and parasites.

There are several indicators of microbial spoilage of foods. For example presence of visible slime on meats caused by *Pseudomonas* spp, haze in beer due to lactic acid bacteria, and mold on bread. The structural properties of foods may be modified as a result of enzymatic activity of spoilage microorganisms on food components such as carbohydrates, proteins, or fat. For example, the development of soft rot in fruits. During microbial fermentation, carbohydrates break down and result in production of gas ( $\text{CO}_2$  and  $\text{H}_2$ ) and formation of lactic acid, ethanol, acetic acid. For example, souring of milk by *Streptococcus cremoris*, and souring of sausages by *Lactobacillus* spp. There are also flavor and color changes, for example, oxidation of ethanol, resulting in acetification of wines by *Acetobacter* spp., development of purple spots on bread by *Bacillus subtilis*, and "flat-sour" changes in canned vegetables by *Bacillus stearothermophilus* and *B. coagulans*.

In case of pathogenic microorganisms, often there are no visual indicators, but their presence leads to serious health impairment or fatality. There are toxigenic organisms that include *Clostridium botulinum*, *Staphylococcus aureus*, and *Bacillus cereus* that cause food poisoning-intoxication. For example, *Staphylococcus aureus* can cause illness within two hours of ingesting contaminated food. There are also infective organisms, for example, upon contamination, *Salmonella* species, may survive or grow in a food; with more growth, there is an increased likelihood that the dosage will become infective. The bacteria then grow in the gut of the person and may lead to food poisoning-infection.

Food processors use a variety of means to prevent or slow down the growth of microorganisms. Common measures include, reducing the initial load of microorganism, use of low temperature during storage, reducing water activity, lowering the pH, use of preservatives and proper packaging. Table 1 shows some of the pathogenic microorganisms and their minimum growth conditions.

Table 1 Pathogens and their minimum growth conditions

Pathogen	Minimum Growth Conditions			Common Food Systems
	Temperature (°C)	a <sub>w</sub>	pH	
Bacillus cereus	10	0.92	4.9	Fish, fresh meats, water
Campylobacter jejuni	25	0.95	4.9	Meats, milk
Clostridium botulinum	3.3	0.93	4.6	Improperly canned foods
Escherichia coli O157:H7	15	0.95	4.0	Vegetables, meats, poultry, milk
Listeria monocytogenes	0	0.92	4.3	Poultry, dairy products, meats, vegetables
Salmonella spp.	7	0.94	4.0	Poultry, meats, dairy products
Staphylococcus aureus	6 (10 for toxin)	0.9 (for toxin)	4.5 (for toxin)	Meats, poultry
Vibrio parahaemolyticus	5	0.94	4.8	Fish and seafood
Yersinia enterocolitica	-2	0.96	4.2	Fresh meats, milk, seafood

(Anderson and Singh (2004), Banwart (1989), Cousin (1996), Robinson (2000), Jay (2000))

Bacteria are single-celled organisms of 1-5 micron size. They can be of different shapes, such as round, rod, spiral and they reproduce by binary fission. When subjected to harsh conditions many bacteria form spores as a measure of protection.

Yeasts are single-celled fungi, 3-5 micron in size. They are either round or cylindrical. Their growth occurs as a result of binary fission or budding. While yeasts cause food spoilage, they are also used in fermentation processes, such as brewing beer and leavening of bread. Yeasts are present in wide range of habitats including soil, water, plants and animals. When growth conditions are ideal (such as availability of nutrients and compatible environmental factors) yeasts begin propagating. Although no food borne yeasts are known to cause food infection or poisoning, they cause food spoilage. Among various indicators of spoilage caused by yeasts include production of gas, changes in texture and taste, discoloration, change in flavor, and turbidity in liquids. Yeasts belong to either Ascomycetes ( e.g. Saccharomyces, Candida) or Basidiomycetes (e.g. Rhodotorula, Cryptococcus). Being mostly unicellular, they propagate by budding. Their primary mode of sexual reproduction is by sporulation. The most prevalent yeasts in context to foods belong to six groups as shown in Table 2.

Table 2. Food borne yeasts

Food-borne yeasts	Genera and Species	Examples, Characteristics
Strongly fermentative Yeasts	<i>Saccharomyces cerevisiae</i>	Beer, wine, spirit, baker's yeast
Weakly fermenting Yeasts	<i>Debaryomyces hansenii</i>	Salt tolerant, develop film on liquids
Apiculate yeasts	<i>Hanseniaspora uvarum</i>	Occur on grapes, cause fruit fermentation, not very tolerant to alcohol
Hyphal yeasts	<i>Yarrowia lipolytica</i>	Cause spoilage in meat and dairy products, due to strong lipolytic and proteolytic activity
Imperfect yeasts	<i>Candida</i>	Common species include <i>C. tropicalis</i> , <i>C. stellata</i>
Red yeasts	<i>Rhodotorula</i> and <i>Sporobolomyces</i>	Cause hydrolytic activities and grow at low temperatures

Mold cells are larger in size, 30-100 microns, and their structure involves branches and chains. They can have different colors and shapes and ones with branched structure are visible to naked eye. Molds reproduce sexually or asexually by producing spores.

Viruses are small organisms, only 0.02 – 0.25 micron in size. They contain DNA or RNA and protein for reproduction. Viruses do not grow in foods, but they can survive when present in foods. They enter the food due to contamination from other sources such as rodents, insects, food handlers and even infected water.

In order to cause food spoilage, microorganisms must first be present in food. Contamination at any location within the food chain may result in the microorganisms to enter the food. Once present, the growth of microorganisms depends upon favorable conditions such as appropriate nutrients, temperature, water activity, pH, and oxygen. Water activity, instead of just the presence of water, is a major factor influencing the growth of microorganisms. At water activity of less than 0.6, virtually no microorganism can grow. Below a water activity of 0.88 most yeasts cannot grow, except osmophilic yeasts can grow at water activity of 0.6. Most molds cannot grow under a water activity of 0.8, some xerophilic molds can grow at a water activity of 0.65.

A pH near 7.0 is ideal for growth of most microorganisms. Oxidation-reduction potential expressed as  $E_h$  value also influences bacterial growth. Microbes that grow aerobically require positive  $E_h$  values. Anaerobic microbes require negative  $E_h$  values for growth. Facultative aerobes can grow both at positive and negative  $E_h$  values.

Temperature is an important environmental factor for microbial growth. Table 1 shows temperature ranges where different classes of microorganisms grow.

Microorganisms do not grow well at high concentrations of  $CO_2$ . At concentrations above 10%  $CO_2$ , the microbial growth is reduced. Microorganisms require nutrients to grow such as carbon, nitrogen, water,

vitamin and minerals. As sources of carbon, small molecule carbohydrates and simple sugars are highly susceptible to microbial growth. Bacteria require the most nutrients, and molds require the least. During growth certain microorganisms produce enzymes that enhance spoilage. For example, microorganisms can produce proteases that degrade proteins, some bacteria and molds can produce pectinolytic enzymes, such as polygalacturonase, pectinesterases, or pectin lyases, that degrade pectin in fruits and vegetables. In foods rich in fats such as meats, fish, milk and dairy products, some microorganisms produce lipases, that cause hydrolytic rancidity.

#### **2.4 Review Questions:**

1. What factors cause changes in texture of solid foods? Give examples and discuss underlying mechanisms.
2. What chemical reaction(s) causes deterioration of foods containing high fat content? Discuss with examples.
3. What is non-enzymatic browning? Give examples of products degraded by non-enzymatic browning.
4. What are some of the spoilage indicators in foods resulting from growth of yeasts?

#### **2.5 References and Additional Reading:**

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