



## A review of factors influencing food deterioration and the role of food preservation

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### Abstract

Food is essential for human survival, providing the nutrients necessary for maintenance, growth, and reproduction. However, food products are inherently perishable and require adequate protection against spoilage to achieve the desired shelf life. Microorganisms are the primary agents of food spoilage, posing significant risks to consumer health if not controlled. In addition to microbial activities, deterioration may result from enzyme activities, animal consumption, particularly insects and rodents, and physical damage that can occur at various stages of the food supply chain. Consequently, it is imperative to implement measures that mitigate food deterioration to ensure the availability of safe, nutritious, and wholesome foods all year round. Food deterioration is caused by various factors, which are usually grouped into intrinsic, extrinsic, and miscellaneous categories. This paper delves into these factors and stresses the importance of preservation techniques that help minimize or prevent these changes. The discussion concludes with a look at modern preservation methods, aimed not only at enhancing the quality and shelf life of food products but also at reducing risks, protecting the environment, and enhancing the food's functional, sensory, and nutritional attributes.

**Keywords:** food spoilage, intrinsic, extrinsic, miscellaneous factors, mechanical factors, advanced preservation techniques

### Introduction

Food deterioration is the loss of quality caused by natural decay (spontaneous breakdown of complex organic molecules), contamination with microorganisms, or damage from mechanical forces. Food deterioration refers to any change in the nutritional, physical, or chemical properties of food. When these changes make the food unsafe to eat, it is considered food spoilage. In other words, food deterioration is the process that results in food spoilage. Spoiled food products may pose health risks, including foodborne illnesses, and are typically characterized by signs such as off odors, discoloration, mold growth, or slimy texture.

Foods are always a good environment in which microbes can thrive, and the application of modern-day sophisticated packaging systems with added preservatives is one of the effective methods of protecting food products from microbial contamination (Majumdar *et al.*, 2018) [13]. Food spoilage causes the loss of one-third of the world's food produced for the consumption of humans every year (Garcha, 2018) [8]. The problem of food losses is critical in developing countries of the world, as food losses have a negative impact on food security for poor people, food quality and safety, economic development, and the environment (Rawat, 2015) [15].

### Causes of Food Deterioration

The principal factors that cause deterioration/spoilage in foods can be broadly categorized into three: (1) Intrinsic Factors (internal or inherent factors), (2) Extrinsic Factors (external or operating from outside), and (3) Miscellaneous Factors (diversified)

#### Intrinsic Factors

The word 'intrinsic' describes something that belongs to a thing by its very nature, originating from within rather than from external circumstances. Intrinsic factors, therefore, refer to the inherent or natural characteristics of a specific food item, such as its enzyme activity, water activity, pH

level, nutrient composition, natural antimicrobial compounds, and biological structures.

#### 1. Enzyme Activity

Enzymes are naturally found in all foods and can cause food spoilage by speeding up chemical changes. Once activated, many enzymatic reactions change the quality of foods through loss of flavour, colour, and texture. They cause food deterioration through speeding up the process of decay by breaking down the tissues and components of the food in various ways, such as oxidation, browning, and ripening. The major sources of enzymes are fruits and vegetables. Enzymes are also produced during microbial spoilage of foods and are often involved in texture breakdown. For example, extracellular heat-stable enzymes such as proteinases and lipases are produced by psychrotrophic bacteria that multiply. Also, the bacterial proteinases and lipases from psychrotrophic bacteria such as *Pseudomonas* and *Aeromonas* can cause flavour and texture defects in raw meat and fish (Erkmen and Bozoglu, 2016) [5]. Proteinases and lipases can cause deterioration in raw milk through hydrolysis of proteins and lipids within 3 – 7 days (Erkmen and Bozoglu, 2016) [5]. Cream and butter can also be more susceptible to spoilage by heat-stable lipases than proteinases.

Fruits and vegetable deterioration are caused by enzymes such as peroxidase, lipoxygenase, chlorophyllase, and catalase. The ripening of fruits is caused by the activities of some enzymes (e.g., pectinesterase and polygalacturanase), which increase and consequently cause tissue softening. Inadequate or incomplete inactivation of enzymes often shortens the shelf life of packaged foods. This factor is particularly relevant for frozen fruits and vegetables that are only blanched before freezing, as psychrotrophic bacteria can synthesize enzymes even at low temperatures.

#### 2. Water Activity (a<sub>w</sub>)/Moisture Content in Food

Moisture content is an important factor for bacterial growth;

moisture loss or uptake in food is very important in controlling or preventing microbiological or enzymic food spoilage. The ratio between the vapor pressure of the food with its surrounding air and the vapor pressure of the food with pure water under identical conditions is called water activity (aW) and is measured as equilibrium relative humidity (ERH) (Majumdar *et al.*, 2018) [13]. Its scale ranges from 0 to 1.00 (bone dry to pure water).

$$\text{Water Activity (aW)} = \text{ERH} / 100$$

Bacteria require higher levels of available moisture than yeasts or moulds. At 20% available water, their growth is good, but it is limited when reduced to 10%, and at 5% there is no bacterial growth (Tucker, 2003) [16].

### 3. pH Level

All foods naturally have some level of acidity or alkalinity in them. The pH of a food is among the important parameters used to restrict microbial growth in food preservation. Foods with a pH over 4.5 are often referred to as *low-acid* foods, while those with a pH of 4.5 and below are referred to as *high-acid* foods. Microorganisms that can grow below 7.0 are called acidophiles, for example, yeasts (4.5–6.5) and filamentous fungi (3.5–6.8). Microorganisms that can grow best at neutral pH are called neutrophiles, while those that grow best under alkaline conditions are called alkaliphiles, for example, bacteria (6.0–8.0). This critical pH limit is used to determine whether a heat-preserved food receives a pasteurization or sterilization treatment. Sterilisation processes (typically in the range 115.5–135°C) using heat have greater cooking effects on product quality than the relatively mild heat treatment of pasteurisation processes (typically 75–105°C). Pasteurisation often requires foods to be acidified before thermal treatment (e.g., pickled vegetables). A pH near neutrality (7.0) is ideal for the growth of most microorganisms. This explains why fish, when compared with meat, has a shorter storage life under chilled conditions, because meat has a lower pH (or higher acidity) than fish, which has a higher pH or lower acidity.

### 4. Nutrient Composition

Microorganisms easily utilize nutrients present in food as sources of energy, and in the process, release chemicals (metabolites) that will make the food unpleasant to taste or they will cause illness, especially if the food is not properly preserved. Bacteria require nutrients such as water, proteins, carbohydrates, and lipids for growth and small quantities of vitamins and trace elements to support and catalyse metabolism. They release their enzymes into the surrounding food that catalyse the breakdown of nutrients into soluble forms to aid transport through their cytoplasmic

membranes. For example, the enzyme amylase is released by various *Bacillus* species, such as *subtilis*, *amyloliquefaciens*, and *licheniformis*, which catalyzes the breakdown of complex carbohydrates into simple sugars that can be absorbed through the cell membrane (Tucker, 2003) [16].

### 5. Oxidation–Reduction Potential (Eh)

A system's oxidation-reduction potential (Eh) is one of the inherent parts of food material that protects it from degradation by microorganisms (Majumdar *et al.*, 2018) [13]. Aerobic microorganisms require a positive Eh value (oxidized) to grow, whereas anaerobic microorganisms require a negative Eh value (reduced) to grow on the food products. Some bacteria can be facultatively anaerobic, which means that they can consume oxygen from the air if present, but can also grow in its absence. Oxygen content in the food mostly increases during mincing, cutting, chopping, and grinding of foods; this leads to maximum positive Eh and supports microbial growth. Exposure of food to oxygen can cause rancidity, browning, and texture changes. Adjusting the atmosphere above a packaged food is used as a means to prevent bacterial growth, typically in combination with chilled storage as a further hurdle to growth (Tucker, 2003) [16]. This allows foods to be manufactured with minimal or no heat processing, yet delivers an extended shelf life.

### 6. Natural Antimicrobial Compounds

Some foods have inherent antimicrobial properties. Plants have the natural ability to synthesize, through the secondary metabolism, several compounds that have antimicrobial and antioxidant actions, varying according to their constituents, which have complex structures (Campêlo *et al.*, 2019) [2]. These natural components provide antimicrobial and antioxidant properties to the food during adverse conditions. Indian spices, which include cloves, cinnamon, and nutmeg, contain natural essential oils, such as eugenol, cinnamic aldehydes, allicin, and thymol, respectively, which provide antimicrobial defence against microbial degradation (Majumdar *et al.*, 2018) [13].

### 7. Biological structure

Biological structures of plant- and animal-derived foods, such as the test of seeds, peels, skins and vegetables, shells, animal hide, egg cuticle, shell, and membranes, constitute natural protection against the entry and growth of pathogenic microorganisms inside the food. Peels, skins, and shells constitute natural protection against this kind of spoilage.

**Table 1.** Major Effects of Food Deterioration

Microbiological	Enzymatic	Chemical	Physical	Mechanical
Growth of Microorganism Off-flavour Toxin production	Browning Color change Off-flavour	Color loss Flavour loss Non-enzymatic browning Nutrient loss Oxidation reduction Rancidity	Collapse Controlled release Crystallization Flavour encapsulation Phase changes Recrystallization Shrinkage Transport of Component	Bruising due to vibration Cracking Damage due to pressure

Source: (Rahman, 2007) [14].

Any physical damage during the entire food supply chain will destroy the physical barriers and allow the penetration of microorganisms. The effects of these food deteriorations are summarized in Table 1.0 above.

### Extrinsic Factors

These refer to those factors that are not part of the essential nature of food that contribute to food deterioration. They come or operate from outside, and include the following:

microbial growth, temperature changes, relative humidity, atmospheric gases, invader pests, and light.

**1. Microbial Growth**

Microorganisms, which include bacteria, yeast, and mold, can cause spoilage and contamination. Microbial deterioration of a food involves the multiplication and growth of billions of cells of microorganisms (Derosier and Derosier, 1997) [4]. Microorganisms attack most foods and produce chemicals (metabolites) that will make the food unpleasant to taste or they will cause illness. Food products contaminated by a variety of pathogenic causes food-borne diseases or illness, while the ones contaminated by spoilage microorganisms cause significant economic losses for the food industry due to undesirable effects on the food properties. When improper processing is employed, certain microorganisms survive and multiply in the product. The

larger the initial population of organisms, the more rapidly the food is attacked. It is estimated that microbial activities alone cause as much as 25% loss of all food produced after harvest (Bondi *et al.*, 2017) [1]. Spoilage of food due to the growth of spoilage microorganisms hurts the shelf-life, textural characteristics, and overall quality of the finished products, affects consumer choices, and results in significant commercial losses.

The four sources of microbial contaminants are soil, water, air, and animals (insects and mites, rodents) (Table 2.0). Microorganisms are all small living organisms that are too small to be visible to the naked eye. Moulds belong to a large category of multicelled threadlike fungi, and are therefore visible to the naked eye. For this reason, mouldy food is often discarded. Microorganisms are ubiquitous; they are seen everywhere in the atmosphere, water, soil, plants, and animals.

**Table 2.** Organisms That Cause Food Spoilage

Microorganisms	Insects and mites	Rodents	Man
a. Fungi: mold and yeast b. Bacteria c. Phages d. Protozoa	a. Directly by eating (infestation) b. Indirectly by spreading diseases (e.g. fruitfly, housefly)	a. Directly by consuming food b. Indirectly by spreading diseases	Pilferage, adulteration, and tampering Mishandlings

Source: adapted from Rahman (2007) [14].

**2. Temperature changes**

Temperature is a very important factor in food deterioration. Temperature regulation is the most commonly used method to kill or control the number of microorganisms present within foods and on packaging material surfaces. However, regulation of storage temperature is more important than reliance on the packaging to protect foods from heat. Each microorganism has (i) an optimum temperature at which it grows best, (ii) a minimum temperature below which growth no longer takes place, and (iii) a maximum temperature above which all development is suppressed. Microorganisms are classified into five groups based on their preferred range of temperature (Tucker, 2003) [16]:

- **Psychrotrophic (cold-tolerant):** This group of microorganisms can reproduce in chilled storage conditions, sometimes as low as 4 °C. They are the easiest to be destroyed by heat since they are only adapted to survive in extremes of cold
- **Psychrophilic (cold-loving):** These organisms have an optimum growth temperature of around 20 °C.
- **Mesophilic (moderate-temperature range):** Their optimal growth temperature range of 20 °C and 44 °C. They are particularly significant to packaged foods, where they present the greatest concern.
- **Thermophilic (heat-loving):** These microorganisms grow optimally at temperatures between 45 °C and 60 °C. Generally, they become problematic only when packaged foods are processed or stored under warm climatic conditions.
- **Thermoturic (heat-enduring):** While unable to reproduce at very high temperatures, they are capable of surviving exposure to heat above 70 °C.

**3. Relative humidity of the storage environment**

Relative humidity (RH) of air is defined as the ratio of the vapor pressure of air to its saturation vapor pressure. And the equilibrium relative humidity (ERH) of a food product is

defined as the RH of the air surrounding the food that is in equilibrium with its environment (Kong and Singh, 2011) [9]. When a food is exposed to a constant humidity, the product will gain or lose moisture until the ERH is reached. At this equilibrium, the ERH (in percent) equals the water activity multiplied by 100, i.e., ERH (%) =  $a_w \times 100$ . When Low-moisture-content foods are stored in a high-humidity environment, it will increase the redox potential as well as water activity of the food by transferring the water in the gas phase to the food (Rawat, 2015) [15]. A change in the relative humidity of the storage environment can lead to deteriorative changes in some foods. For instance, tuberous and leafy vegetables lose water when kept in atmospheres with low moisture and subsequently wilt, while dried foods kept in high humidity may pick up moisture and become soggy (Rahman, 2007) [14].

**4. Atmospheric gases**

Though some bacteria obtain oxygen from their food (anaerobic), all bacteria need a supply of oxygen gas to oxidise their food to produce energy and for growth. Some bacteria are facultative anaerobic microorganisms, which means that they can consume oxygen from the air if present, but can also grow in its absence. Oxygen and carbon dioxide are the two major gases that affect microbial growth as well as other parameters, such as redox potential and pH of the food. For the storage of fruits, such as apples and pears, 10% carbon dioxide is preferred and is called ‘controlled atmosphere storage’ because microorganisms are unable to grow in this atmosphere (Rawat, 2015) [15]. However, moderately high lipid foods or other oxygen-sensitive components start to deteriorate on exposure to oxygen. For instance, fats undergo oxidative rancidity when they come into contact with oxygen. Therefore, adjusting the atmosphere above a packaged food, as in modified atmosphere packaging (MAP), can be used to prevent bacterial growth and deliver food products with extended storage life, especially in combination with chilling storage.

However, fresh foods that are respiring and have a high equilibrium relative humidity require a high degree of permeability to allow exchange of oxygen and carbon dioxide with the atmosphere, without excessive loss of moisture that would cause a loss of weight and shriveling.

## 5. Invader Pests and Rodents

Pests generally cause food deterioration by direct attack and infestation of foods. Insects and mice spoil and infest cereal grains and the food products by direct eating. Rodents consume foods packed in flexible films and in the process can spread diseases directly or indirectly. Storage environment for keeping food products should be washed, dried, sanitized, and protected from rodents' entrance before storing of foods to prevent breeding of insects, pests, and attack by rodents. Food packages should protect its content from dust, and other soils that could contaminate the product. Metal, glass, and stronger flexible packaging materials can prevent insect infestation, but only metal and glass containers can protect foods against rodents and birds.

## 6. Light/UV light

The food package should filter harmful ultraviolet light. Chemical or physical changes can occur in food as a result of exposure of food to light. Light could result in vitamin loss, fat oxidation, as well as colour loss (e.g., anthocyanins and lycopene, which are unstable to light). Also, transparent (non-black) water tanks kept under the sun encourage rapid growth of algae and bacteria. This is the reason why black non-transparent water storage tanks are preferred to transparent ones. Black or shaded tanks prevent sunlight from fostering bacterial growth in the interior part of the water tank and may make its content unfit for drinking.

On the other hand, light can have a destructive effect on bacteria because of the ultraviolet (UV) component that causes chemical changes in the cell proteins. Bacteria prefer to grow in conditions where light is excluded. This effect is utilized by using UV light to sterilise bottled water, where the limitation of transparency is not a restriction (Rawat, 2015) [15]. Transparent packages (that allow passage of light) possess the attribute of allowing the buyers to see the contents in the pack. This can be used to attract buyers due to direct sighting and consequently increase sales of the food product.

## Miscellaneous Factors

These include mishandling/physical injury, pilferage, tampering, and adulteration.

### 1. Mishandlings/Mechanical factors

Physical damage due to the mishandling of food is one of the causes of food deterioration and spoilage. The biological structure of some foods, such as peels, skins, and shells, acts as a natural barrier against this kind of spoilage. And any damage of these physical barriers during harvesting, packaging, transport, storage, preparation of foods, and during processes, such as slicing, chopping, grinding, and shucking will destroy the natural protection and allow the penetration of microorganisms (Majumdar *et al.*, 2018) [13], which can lead to consumer unacceptability and deterioration, as well as ultimate reduction of shelf life. For example, (i) tuberous and leafy vegetables lose water when kept in atmospheres with low humidity and, subsequently, wilt; (ii) dried foods kept in high humidity may pick up

moisture and become soggy (Rahman, 2007) [14]; and (iii) rupture of cells, in some fruits such as apples and bananas, leads to enzymatic browning (caused by the action of polyphenol oxidase) which brings about color change and facilitates microbial deterioration.

### 2. Pilferage, Tampering, And Adulteration

Pilferage usually occurs during handling, storage, or distribution. The habit of some consumers of *grazing* (opening packs, tasting the food, and returning it to the shelves) and several cases of deliberate poisoning of packaged foods in attempts to blackmail companies have caused food manufacturers to modify package designs (Fellows, 2000) [6]. Pilferage and tampering make the packaged food products highly exposed to contamination.

## Food Preservation

Food preservation refers to various techniques used to prevent food from deteriorating after being harvested or slaughtered. It typically entails managing or stopping the growth of microorganisms or reducing quality deterioration caused by microbial spoilage or undesired chemical changes, like the rancidity resulting from fat oxidation over time.

### 1. Roles of Food Preservation

The roles of food preservation include the following

#### 1. Destruction/Removal of microorganisms

Heat destroys spoilage microorganisms and inactivates enzymes before foods are packed in hermetically sealed containers. Examples of heat treatments include blanching, pasteurization, and sterilization (canning). Physical removal of microorganisms from food products can be achieved through a process known as Filtration.

Mild heat treatments, especially blanching, are intended to inactivate the majority of the enzymes present in fruits and vegetables, without imposing excessive thermal damage to the food, and hence they use relatively mild temperatures (90–100°C) and short heating times (1–10 min). The renewed activity that often seems to be present in the thawed food after frozen storage is attributed to enzyme regeneration (Tucker, 2003) [16]. Some other enzymes may require several minutes at sterilization temperatures to affect a complete peroxidase inactivation. It is therefore usually necessary to use heat treatment to inactivate enzymes (i.e., denature the protein) present in food and on packaging surfaces using heat or chemical means to preserve and extend the shelf life of foods.

#### 2. Inhibiting growth of microorganisms

The preservation methods that inhibit or prevent microbial growth include i. Refrigeration (slows down the rate of microbial growth) ii. Freezing (prevents microbial growth) iii. Addition of solutes such as sugar, salt, acidifiers such as citric acid, or chemical preservatives such as sodium benzoate.

On the use of chemical preservatives for food preservation, there is mounting pressure on food producers to eliminate chemical preservatives or replace them with natural substitutes. Recent advances in the industry highlight the successful use of natural bioactive compounds, beneficial microbial starter cultures, and antioxidants to develop products that are free from synthetic preservatives (Kourkoutas and Proestos, 2020) [10].

### 3. Moisture Removal

Food dehydration through drying (e.g. sun drying, oven drying, freeze drying, spray drying, etc) slows down or prevents microbial growth and enzyme reactions.

Foods with higher available water require secondary techniques such as preservatives, pH control, refrigeration, and pasteurization processes to protect them against yeasts and molds.

### 4. Enzyme Inactivation

This can be achieved by the following preservation methods: i. blanching (wet heat treatment that stops enzymatic reactions usually in fruits and vegetables), ii. Heat sterilization (e.g. pasteurization, canning), and iii. Freezing (this slows down the rate of enzymic reactions).

### 5. Prevention of Contamination

Sanitation and hygiene practices play a huge role in preventing food contamination. Also, appropriate packaging (e.g. aseptic packaging) also preserves food by providing physical barriers that prevent contact with microorganisms, insects, mites, and rodents. It is important to eliminate all sources of contamination and sterilize the packaging materials before packaging.

Packaging plays a major role in maintaining the sterility of adequately processed products after thermal processing. However, foods that have been adequately processed can still be contaminated when:

- contaminated air or water is drawn through pinholes as the headspace vacuum forms in hermetically sealed containers;
- Inadequate heat seals in polymer films caused by contamination of the seal with product or faulty heat sealer settings
- Lids or caps are poorly sealed
- damage such as tears or creases to the packaging material.

### 6. Control of Oxidation

Oxygen can be removed through i. vacuum packaging, ii. addition of antioxidants (e.g. vitamin C, vitamin E), and iii. modified atmosphere packaging which replaces oxygen with inert gases (e.g. Nitrogen, carbon dioxide, etc). Removal/control of oxygen helps extend the shelf life by reducing oxidation and spoilage.

### 7. Quality Maintenance

In order to retain quality such as texture and nutrients in food products, some of the preservation methods employed include: i. Flash freezing, ii. Controlled atmosphere storage (for fruits and vegetables,) iii. Addition of texture modifiers or stabilizers (e.g. emulsifiers, thickeners etc.), and iv. Suitable packaging.

Foods that have a low equilibrium relative humidity, such as dehydrated foods, biscuits, and snack foods, require packaging that has a low permeability to moisture, or they will gain moisture from the atmosphere and lose their crispness. If the water activity rises above a level that permits microbial growth, they will spoil. Maintaining the relative humidity of the storage environment is also an important factor in food preservation. For foods such as eggs, biscuits, and ready-to-eat cereals that are brittle or easily damaged due to mishandling during transportation and distribution. It is important to design a suitable package

that should provide resistance against mechanical forces (impact, abrasion, vibration, compression forces, etc), caused by impacts during handling or by vibration during transport, especially for very fragile and delicate food products, which include biscuits, crisps, and eggs. These brittle and easily damaged foods require a higher level of protection from a package, including cushioning using tissue paper, foamed polymer sheets, or paper-pulp that is formed into shaped containers for individual pieces (e.g., egg cartons, fruit trays) (Fellows, 2000) <sup>[6]</sup>.

### 2. Benefits of Food Preservation.

Food preservation is important because it offers several benefits, which include the following (Landers, 2021) <sup>[12]</sup>

1. Prolonging the shelf life of fresh perishable foods so that they can be stored for longer periods, thereby boosting supply.
2. Making seasonal foods available year-round.
3. Enhancing dietary variety.
4. Saving time and energy by reducing the effort needed to prepare meals, as they have already undergone partial processing.
5. Stabilizing food prices by reducing the supply-demand gap.
6. Minimizing food waste by preventing spoilage or deterioration.
7. Enhancing public nutrition.
8. Preserved foods allow consumers to diversify their diets, helping to prevent nutritional deficiencies.

### Advanced Food Preservation Techniques

In recent years, food preservation has led to the creation of advanced techniques aimed not only at enhancing quality and shelf life but also at reducing risks, protecting the environment, and improving functional, sensory, and nutritional qualities. (Mukhopadhyay *et al.*, 2017) <sup>[17]</sup>. The preservation techniques include: (1) Nanotechnology in Food Preservation, (2) Hurdle System, (3) Ultrasound, (4) Edible Films, and (5) Encapsulation. Others include bio-preservation, freeze drying, vacuum packing, modified atmosphere etc. These recent food preservation methods focus on producing more nutritious, fresher, minimally processed, and safer food, which is expected to be in high demand in the future. Detailed information on these preservation techniques could be found in Sanjeet and Mishra (2023) <sup>[18]</sup>, Kumar (2019) <sup>[11]</sup>, and Ganguly (2013) <sup>[7]</sup>.

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