1 Control of Biodeterioration in Food

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1.1 OVERVIEW

All food undergoes deterioration to some degree once harvested or slaughtered. The deterioration may include loss of nutritional value, organoleptic and colour changes, and most importantly, safety may become compromised. It is the challenge of the food industry to control this deterioration and maintain the safety of the food, while making sure that the food is as convenient, nutritious and available as it can possibly be.

Biodeterioration is defined as *any undesirable change in the property of a material caused by the vital activities of organisms*.[1] It is applicable to many materials e.g. food, wood, paper, leather, fuels, cosmetics, building materials and building structures. Biodeterioration may be as a result of the metabolic processes of one of many micro-organisms or it cay be caused by insect, rodent or bird damage. An incredibly broad and diverse field, all biodeterioration has as a common theme that it affects materials and substances that we need and value, and that it can largely be controlled by proper understanding of the materials and the possible spoilage organisms and mechanisms.

Biodeterioration is also specifically different from biodegradation in that the changes are 'undesirable'. Biodegradation occurs when complex materials are broken down by micro-organisms to form simple end-products. Within a biological ecosystem, there are micro-organisms that produce a host of enzymes that can biodegrade natural as well as some synthetic products; this is very important for maintaining the stability of the ecosystem and is extremely important for water purification and sewage treatment, and is widely used in the food industry. The main differences between biodeterioration and biodegradation are the undesirability and uncontrollability of the former.[2]

Another important feature of biodeterioration is that it is caused by organisms. According to the definition, it is not the degradation that occurs naturally in some organic materials or foods caused by intrinsic enzymes, i.e. those enzymes present in the product that cause degradation or decay after death. For example, loss of food quality by intrinsic enzymes is an important topic as it can cause quality deterioration and render food unacceptable. Reactions due to these enzymes will not be considered in this text, but are important to bear in mind as their activities can make nutrients from the product available and accessible to micro-organisms so that biodeterioration reactions can follow.[2,3]

1.2 A SUMMARY OF THE DIFFERENT KINDS OF BIODETERIORATION

1.2.1 Chemical biodeterioration

There are two modes of chemical biodeterioration. Both have a similar result, i.e. the material becomes spoilt, damaged or unsafe, but the cause or biochemistry of the two is quite different:[2,4]

- Biochemical assimilatory biodeterioration – the organism uses the material as food i.e. an energy source.
- Biochemical dissimilatory biodeterioration – the chemical change in the food is as a result of waste products from the organisms in question.

1.2.2 Physical biodeterioration

- Mechanical biodeterioration – this occurs when the material is physically disrupted/damaged by the growth or activities of the organisms.
- Soiling/fouling – with this kind of biodeterioration the material or product is not necessarily unsafe, but as its appearance has been compromised, it is rendered unacceptable. The building up of biofilms on the surface of a material can affect the performance of that material.

See Table 1.1 and Fig. 1.1.

Living organisms can be divided on the basis of their nutritional requirements into autotrophs and heterotrophs (see Table 1.2). Autotrophic organisms see all inorganic materials as a potential source of nutrients, while heterotrophic organisms can only use organic matter. The organisms responsible for biodeterioration of food are usually chemoheterotrophs, however it is important to realize that even the packaging that the food is stored in and the warehouses themselves, can be a source of nutrients for some micro-organisms, and it is therefore important to control the humidity, temperature and duration of storage of food, as far as possible.[4,6]

Table 1.1 Examples of the diversity of biodeterioration.

Affected material	**Example**	**Type of biodeterioration**
Stone, marble, concrete	Deterioration of stone monuments	Chemical assimilatory: where calcium and other minerals are used as a food source Chemical dissimilatory: where acid by-products dissolve the surfaces Mechanical: where root damage can undermine and weaken structures Fouling: where biofilms can affect the aesthetics of the structure
Wood	Rotting of wooden floorboards and timber structures	Chemical assimilatory: where the cellulose and lignin in the wood are used as food by fungi and other organisms Dissimilatory: where acid and other by-products result in breakdown of the structure
Leather	Loss of strength and structure of leather objects	Chemical assimilatory: by proteolytic bacteria, which break down the proteins
Paper	Degradation of books	Chemical assimilatory: most commonly by fungi
Paint	Water-based paints	Chemical assimilatory: by bacteria and fungi, results in thinning of the paint and production of off odours
Museum artefacts	Discoloration and degradation of valuable relics	Chemical assimilatory and chemical dissimilatory: by bacteria and mould, resulting in weakening of structures and discoloration of the objects
Food	All foods: animal matter and vegetable based	The most important is chemical assimilatory: the food is used as a food source as it is nutritionally compromised and can have toxins associated with it as by-products of the microbial activity
Metal	Biodeterioration of the wreck of the RMS *Titanic*	Chemical assimilatory: attack on the steel by communities of bacteria and fungi
Fuels	Fuels in tanks	Chemical assimilatory: most commonly the C-10 to C-18 hydrocarbons are broken down to form shorter chain hydrocarbons that, together with the biofilms, can clog fuel lines
Lubricants	Lubricants in metal working lines	Chemical assimilatory: resulting in the loss of lubricating properties and therefore functionality
Teeth	Tooth decay	Chemical dissimilatory: waste products from oral acidogenic bacterial growth cause tooth decay
Glass	Leaching, staining of stained glass windows	Chemical dissimilatory: by waste products from growth of fungi and Cyanobacteria Mechanical: filamentous organisms can cause stress cracking

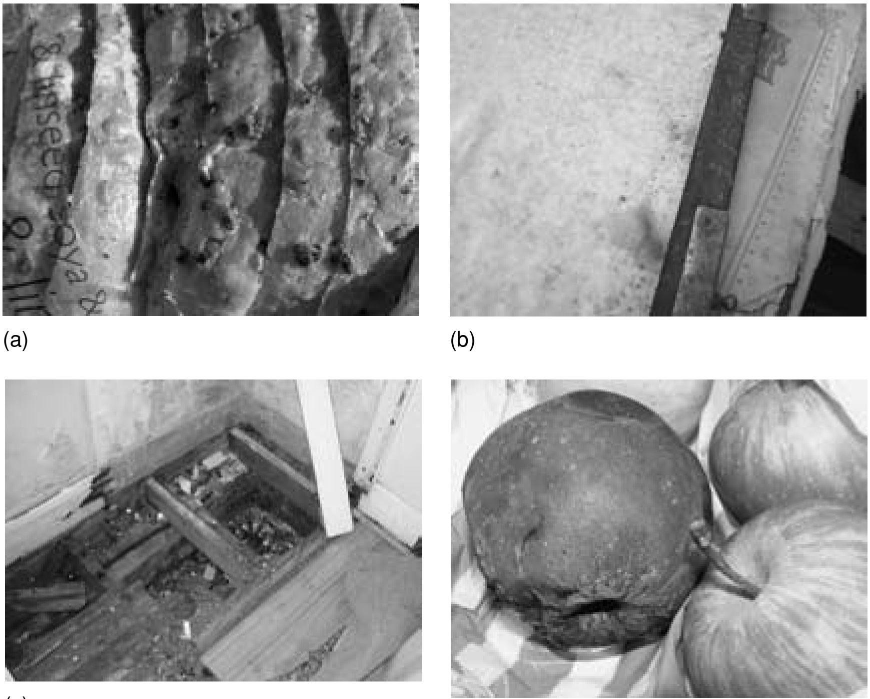

Fig. 1.1 Some common biodeterioration problems. (a), Mouldy bread; (b), mould on antique book; (c), rotten floorboards; (d), soft rot on apples. See also Colour plate 1.

1.3 KINDS OF LIVING ORGANISMS INVOLVED IN BIODETERIORATION

Living organisms that can cause biodeterioration are referred to as *biodeteriogens*.[2] Animals, insects and higher plants can be easily identified by visual observation and by examining their morphological and physiological characteristics. Organisms like bacteria, fungi and algae are less easy to identify and need to be isolated to be examined. Growth of these organisms under laboratory conditions is often difficult and specialized methods using fluorescent dyes and antibodies or examination using a scanning electron microscope must be used. In some instances, identification can only be made using DNA techniques.

1.3.1 Bacteria

Bacteria are a large diverse group of microscopic, prokaryotic, unicellular organisms. They can be of various shapes (spherical, rod-like or spiral) and may be motile or non-motile. They include both autotrophic and

Table 1.2 Classification of micro-organisms on the basis of their nutritional requirements.

Nutritional classification	Source of energy	Source of carbon	Examples of organisms
Autotrophs			
Photoautotroph (photolithotroph)	Sunlight (light energy)	Carbon dioxide (CO_2)	*Aerobic* Algae Cyanobacteria Purple sulphur bacteria Green sulphur bacteria
Chemoautotroph (chemolithotroph)	Redox reactions (chemical energy)	Carbon dioxide (CO_2)	*Aerobic* Hydrogen bacteria Sulphur-oxidizing bacteria Nitrifying bacteria Iron bacteria
Heterotrophs			
Photoheterotroph (photo-organotroph)	Sunlight (light energy)	Organic carbon or carbon dioxide (CO_2)	*Aerobic* Photosynthetic bacteria *Anaerobic* Purple non-sulphur bacteria
Chemoheterotroph (chemo-organotroph)	Redox reactions (chemical energy)	Organic carbon	*Aerobic* Respiratory bacteria Fungi *Anaerobic* Fermentative bacteria Sulphur reducing bacteria Denitrifying bacteria

heterotrophic species, and can be aerobic or anaerobic, and many species can thrive under either condition. They have relatively simple nutritional needs, and are easily adaptable and can readily change to suit their environment.

1.3.2 Fungi

Fungi are a large group of small chemoheterotrophic organisms. They do not contain chlorophyll and therefore cannot make their own food by using sunlight. They are, however extremely adaptable and can utilize almost any organic material. Their growth is characterized by unicellular or multicellular filamentous hyphae, which can often be the cause of physical biodeterioration.

1.3.3 Algae, mosses and liverworts

Algae, mosses and liverworts are eukaryotic unicellular or multicellular organisms. They are photoautotrophic and need moisture, light and inorganic nutrients to grow.

1.3.4 Higher plants

Higher plants are photoautotrophic organisms with specialized tissues and organs that show functional specialization.

1.3.5 Insects

Insects include a large group of aerobic heterotrophic organisms. They need to feed on organic matter, but as a group are diverse in what they can consume. They can feed off all processed and unprocessed foods, as well as non-food items like binding materials and adhesives. Since some insects are attracted to the tight, dark places that abound in storage areas, and since stored foods and materials are handled infrequently, insects may do significant damage before they are discovered. Some examples of insect pests are silverfish, psocids, cockroaches, borer beetles, weevils and moths. Insects can be infected by disease-causing organisms such as bacteria, viruses and fungi. Besides causing significant biodeterioration themselves, insects can contaminate food or other organic matter.

1.3.6 Birds, mammals and reptiles

Birds, mammals and reptiles are aerobic heterotrophic organisms that have fairly sophisticated food requirements. They can be very resourceful in their acquiring of food and can cause extensive physical damage. Their waste products can also serve as a source of nutrients for other biodeteriogens and can also be corrosive.

1.4 FOOD BIODETERIORATION

From Man's earliest history, control of biodeterioration of food has been a concern. The basic principles for control that were applied thousands of years ago are still applicable today:

- Eat food as soon after harvesting as possible.
- Physically protect food from pests by storing in sealed containers.
- Preserve by drying, salting or adding spices.

In our modern, urbanized world we find it impractical to eat food immediately after harvesting and there are times that it must travel thousands of kilometres to get to our plate. Therefore other appropriate methods of food preservation have been developed.

Food is made up from water, proteins, fats, carbohydrates and a host of vitamins and minerals. Each of these can be a target for micro-organisms and pests, and as a result each must be considered in the method of food preservation and of storage used.

Some micro-organisms are better adapted to food spoilage than others and hence knowing and understanding food and the organisms that can cause biodeterioration will certainly help in ensuring that they do not get an opportunity to thrive and cause any spoilage of the food.[7] All of the issues mentioned above will be considered in this text.

In addition to the microbiological aspects of food biodeterioration it is important to ensure that food is not degraded, spoiled or rendered susceptible to further or unnecessary spoilage owing to poor procedures and hygiene in farming, harvesting, storage and distribution. The impact of insects and mammals on the damage to cereals and other dry staples and on fruit and vegetables is enormous. These infestations are also initiation points in that their action renders the food susceptible to microbial attack. This is particularly relevant to developing economies in less well resourced parts of the world where dependence on primary staples is critical.

Some general examples of this sort of biodeterioration include borers, worms, pecking, gnawing, physical bruising, etc. Some examples include:

- flies that carry pathogenic bacteria, but which can also cause damage because they lay eggs, the larvae of which then invade the meat or foodstuff causing further deterioration
- snails on salad leaves
- aphids on various crops.

1.4.1 The composition of food

Food can be of animal or plant origin. It is made up mainly from varying proportions of carbohydrates, fats and proteins which provide energy and are the building blocks for growth and are essential for maintaining a healthy body. There are also small amounts of vitamins and minerals that are also essential for the body to function properly. Water is also an important component of food and is vital for cellular functions (Table 1.3).

1.4.1.1 Water

Water is essential for life and is abundant in all food products (unless there have been steps taken to remove it or formulate it without water). As micro-organisms cannot grow without water, the presence or absence of water is very important to the status of food and its potential for

Table 1.3 The composition of some common foods.

Food	**% Water**	**% Protein**	**% Fat**	**% Carbohydrate**	**% Sugar**	**% Starch**
Fruit						
Apple (fresh)	87.7	0.3	0.1	8.9	8.9	trace
Banana, flesh only (ripe, fresh)	75.1	1.2	0.3	23.2	20.9	2.3
Grapes (fresh)	81.8	0.4	0.1	15.4	15.4	0.0
Cherries (fresh)	82.8	0.9	0.1	11.5	11.5	0.0
Cherries (glace)	23.6	0.4	trace	66.4	66.4	0.0
Peaches (fresh)	88.9	1.0	0.1	7.6	7.6	0.0
Raisins	13.2	2.1	0.4	69.3	69.3	0.0
Vegetables						
Baked beans (canned in tomato sauce)	71.5	5.2	0.6	15.3	5.9	9.4
Carrots (raw, young)	88.8	0.7	0.5	6.0	5.6	0.2
Potato (raw)	81.7	1.7	0.3	16.1	1.3	14.8
Pumpkin (raw)	95.0	0.7	0.2	2.2	1.7	0.3
Sweet potato (raw)	73.7	1.2	0.3	21.3	5.7	15.6
Meat/Fish						
Bacon, streaky	41.8	14.6	39.5	0.0	0.0	0.0
Beef, rump steak (raw)	66.7	18.9	13.5	0.0	0.0	0.0
Beef, salted and dried	29.4	55.4	1.5	0.0	0.0	0.0
Cod fillets (raw)	82.1	17.4	0.7	0.0	0.0	0.0
Pilchards, in tomato sauce (canned)	70.0	18.8	5.4	0.7	0.6	0.1
Miscellaneous						
Bread, white	37.3	8.4	1.9	49.3	2.6	46.7
Butter	15.6	0.5	81.7	Trace	Trace	0.0
Cheese, Cheddar	36.0	25.5	34.4	0.1	0.1	trace
Eggs (chicken)	75.1	12.5	10.8	Trace	Trace	0.0
Flour, white, plain	14.0	9.4	1.3	77.7	1.5	76.2
Milk, cows, whole	87.8	3.2	3.9	4.8	4.8	0.0

Data from McCance and Widdowson's *The Composition of Foods*, 5th Edition.

biodeterioration. Many food processing techniques use the modification of water as the basis for preservation – by making it unavailable to the micro-organisms so that they cannot grow, e.g. drying, salting, freezing, emulsification, making pectin gels, etc.[7,8]

The chemical formula for water is H_2O. Each molecule of water is made up from two hydrogen atoms and one oxygen atom. A strong covalent bond holds the hydrogen atoms to the oxygen atom, but as the oxygen atom attracts the electrons more strongly than the hydrogen, the bond is slightly ionic, with the hydrogen being slightly positively charged and the oxygen being slightly negatively charged. As a result of this, the water molecule is polar and there are weak bonds (hydrogen bonds) between the negative and positive charges between molecules. The hydrogen bond, although weak, is very important as it is what causes water to be a liquid at room temperature and influences much of its chemistry and allows it to bond with sugars, pectins, starches and proteins.

Another important characteristic of water, as far as food science is concerned, is that frozen water is less dense than liquid water. (In liquid water the molecules are free to pack together closely and 'slide' past each other, whereas in ice the molecules form more-or-less rigid bonds with their neighbours, which creates the solid structure but also holds them further apart.) This means that ice floats on liquid water, but more importantly, when food is frozen, the volume increases by about 9%.

1.4.1.2 Carbohydrates

Carbohydrates are organic compounds that contain carbon, oxygen and hydrogen. They can be simple sugars or complex molecules. They have the general formula $C_nH_{2n}O_n$. Food carbohydrates include monosaccharides (e.g. glucose), disaccharides (e.g. lactose, sucrose) and polysaccharides (e.g. dextrins, starches, celluloses, pectins).

Monosaccharides and disaccharides are also referred to as sugars. They are readily digested and metabolized by the human body to supply energy, but can also be easily metabolized (fermented) by micro-organisms.

1.4.1.3 Fats

Fats are the second most important source of energy in the diet, after carbohydrates. The yield of energy from fats is greater than that of carbohydrates, with fats yielding more than double the amount of energy as an equivalent weight of carbohydrate. They are also an essential part of the diet, and are utilized in membrane, cell, tissue and organ structures. Fats or oils (triglycerides) are a group of naturally occurring organic compounds – esters comprised of three molecules of fatty acid covalently bonded to one molecule of glycerol. The properties of a fat are determined by the type and length of fatty acids that are bonded to the glycerol molecule.

Fats are designated as saturated or unsaturated, depending on whether the fatty acid moieties contain all the hydrogen atoms they are capable of holding (saturated) or whether they have capacity for additional hydrogen atoms (unsaturated). To put it another way, all the carbon–carbon bonds are single bonds in saturated fats, but unsaturated fats/oils have at least one carbon–carbon double bond. Saturated fats are generally solid at room temperature; unsaturated and polyunsaturated fats are liquids. Unsaturated fats may be converted to saturated fats by the chemical addition of hydrogen atoms (hydrogenation).

1.4.1.4 Proteins

Proteins are the most abundant molecules in cells, making up about 50% of the dry mass. Protein molecules range from soluble globules that can pass through cell membranes and set off metabolic reactions (e.g. enzymes and hormones) to the long, insoluble fibres that make up connective tissue and hair. Proteins are made up from amino acids, of which 20 are used by living organisms. Each amino acid has specific properties, depending on its structure, and when they combine together to form a protein, a unique complex molecule is formed. All proteins have unique shapes that allow them to carry out a particular function in the cell. All amino acids are organic compounds that contain both an amino (NH_2) and a carboxyl (COOH) group.

Proteins are very important foods, both nutritionally and as functional ingredients. They serve primarily to build and maintain cells, but their chemical breakdown also provides energy, yielding almost the same amount of energy as carbohydrates on a weight-for-weight basis.

1.4.1.5 Minerals and trace elements

Living organisms need countless numbers of minerals and trace elements for them to be able to function adequately. Among these are calcium, iodine, iron, magnesium, manganese, phosphorus, selenium and zinc.

1.5 A DESCRIPTION OF THE MECHANISMS OF FOOD BIODETERIORATION

1.5.1 Fermentation

Many different types of fermented foods are consumed worldwide (See Fig. 1.2). Many countries have their own unique types of fermented food, representing the staple diet and the (raw) ingredients available in that particular place. Some of the more obvious fermented fruit and vegetable products are the alcoholic beverages: beer and wine. However, several fermented fruit and vegetable products arise from lactic acid fermentation and are extremely important in meeting the nutritional requirements of a large proportion of the global population.[10]

Food fermentation can be brought about by bacteria, yeasts or moulds. When micro-organisms metabolize and grow, they release by-products. In food fermentation some of the by-products have a preserving effect in the food by lowering the pH and/or producing alcohols. Most food spoilage organisms cannot survive in either alcoholic or acidic environments,

Fig. 1.2 Examples of foods derived from fermentation. See also Colour plate 2.

therefore the production of these by-products can prevent a food from spoilage and extend the shelf life. The fermentation by-products also change the texture and flavour of the food substrate, e.g. in the case of milk, the acid causes the precipitation of milk proteins to solid curd.[11,12,13,14]

The most important bacteria in desirable food fermentation are the *Lactobacillaceae*, which have the ability to produce lactic acid from carbohydrates, and the acetic acid producing *Acetobacter* species. Yeasts play an important role in the food industry, e.g. in the leavening of bread and the production of alcohol and invert sugar. The most beneficial yeasts in terms of desirable food fermentation are from the *Saccharomyces* family, especially *S. cerevisiae*. Moulds do not play a significant role in the desirable fermentation of fruit and vegetable products, however, some do impart characteristic flavours to foods and others produce enzymes, e.g. moulds from the genus *Penicillium* are associated with the ripening and flavour of cheeses. Moulds are aerobic and therefore require oxygen for growth. They produce a large variety of enzymes, and can colonize and grow on most types of food.

Many of the changes that occur during fermentation of foods are the result of enzymes produced by micro-organisms. Enzymes are complex proteins produced by living cells to carry out specific biochemical reactions. They initiate and control reactions, rather than being used as part of a reaction. They are sensitive to temperature, pH, moisture content, nutrient concentration and the concentration of any inhibitors. Enzymes each have specific requirements for optimum performance. Extremes of temperature and pH will denature the protein and destroy enzyme activity. In food fermentation enzymes have several roles: the breakdown of starch, the conversion of sugars and the modification of proteins.