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Module
on
Biochemical Spoilage Of Foods

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TEXT

Types of food spoilage

Microbial spoilage

Bacteria, yeasts and moulds spoil food after harvesting, during handling, processing and storage. Except the microorganisms that are specially cultivated under controlled conditions for their beneficial effects, all microorganisms that multiply on or in foods are frequently the major cause of food deterioration. They are found everywhere; they however are not generally found within healthy living tissues, but are always present to invade the flesh of animals and plants when there is a break in their skin or if the skin is weakened by disease or death.

Spoilage of food is the result of microbial activity of a variety of microorganisms. The microbial flora that colonizes a particular food depends highly on the characteristics of the product and the way it is processed and stored. The parameters affecting proliferation of microorganisms in foods can be categorized into four groups: (i) intrinsic parameters; (ii) extrinsic parameters; (iii) modes of processing and preservation; and (iv) implicit parameters.

Intrinsic parameters

Intrinsic parameters are the physical, chemical and structural properties inherent in the food itself. The most important intrinsic factors are water activity, acidity, redox potential, available nutrients and natural antimicrobial substances.

Extrinsic parameters

Extrinsic parameters are factors in the environment in which a food is stored, notably temperature, humidity and atmosphere composition.

Modes of processing and preservation

Physical or chemical treatments often result in changes in the characteristics of a food product, determining the microflora associated with the product.

Implicit parameters

Implicit parameters are mutual influences, synergistic or antagonistic, among the primary selection of organisms resulting from the influence of the above mentioned parameters. Thus, implicit parameters are the result of the development of a microorganism which may have a synergistic or antagonistic effect on the microbial activity of other microorganisms present in the food product. Synergistic effects include production or availability of essential nutrients due to the growth of a certain group of microorganisms allowing development of other organisms which otherwise were unable to grow. Likewise, changes in pH value, redox potential and water activity may enable the development of microorganisms less tolerant to these inhibitory factors, yielding secondary spoilage. Antagonistic processes include competition for essential nutrients, changes in pH value or redox potential or the formation of antimicrobial substances e.g., bacteriocins which may negatively affect the survival or growth of other microorganisms. Another important phenomenon, which deserves attention in food preservation, is the homeostasis of microorganisms. If the homeostasis of a microorganism i.e., their internal equilibrium, is disturbed by preservative factors in foods, they will not multiply, i.e. they remain in the lag-phase or even die, before their homeostasis is re-established. For instance, in an acid food they will actively expel protons against the pressure of a passive proton influx. Another important homeostatic mechanism regulates the internal osmotic pressure (osmohomeostasis). Cells have to maintain a positive turgor by keeping the osmolarity of the cytoplasm higher than the environment and they generally achieve this using so-called osmoprotective compounds such as proline and betaine.

Bacteria in food spoilage

Spoilage is most rapid and evident in proteinaceous foods such as meat, poultry, fish, shellfish, milk and some dairy products. These foods are highly nutritious, possess a neutral or slightly acid pH and high moisture content and therefore permit growth of a wide range of microorganisms. The pattern of microbial spoilage has been found to be similar for these types of proteinaceous foods (Fig. 1). Initially, specific spoilage organisms (SSO) are present in low quantities and constitute only a minor part of the natural microflora. During storage, SSO generally grow faster than the remaining microflora and produce the metabolites responsible for off-odours, off-flavours, slime and finally cause sensory rejection. The cell concentration of SSO at rejection may be called the minimal spoilage level and the concentration of the metabolite that corresponds to spoilage can be used as an objective chemical spoilage index (CSI). Changes in the extrinsic conditions (e.g., refrigeration, MAP) are the only way to delay spoilage. However, storage at adequate low temperatures will not prevent spoilage but will limit spoilage to psychotropic microorganisms. In general they comprise, in addition to some Gram-positive rods (lactic acid bacteria) and spore-forming bacteria (Clostridia), largely the Gram-negative, rod-shaped, non spore-forming bacteria (Pseudomonaceae). Although several yeasts and moulds are psychrotrophic, they do not generally compete well with bacteria at low temperatures but they may become important in situations where bacteria have difficulty in growing, i.e. in acid foods, or foods with high sugar or salt concentration. For convenience, the spoilage microorganisms will be divided into broad categories: Gram-negative rod shaped bacteria, Gram-positive spore forming bacteria, lactic acid bacteria, other Gram-positive bacteria (e.g., *Brochothrix thermosphacta),* yeasts and moulds.

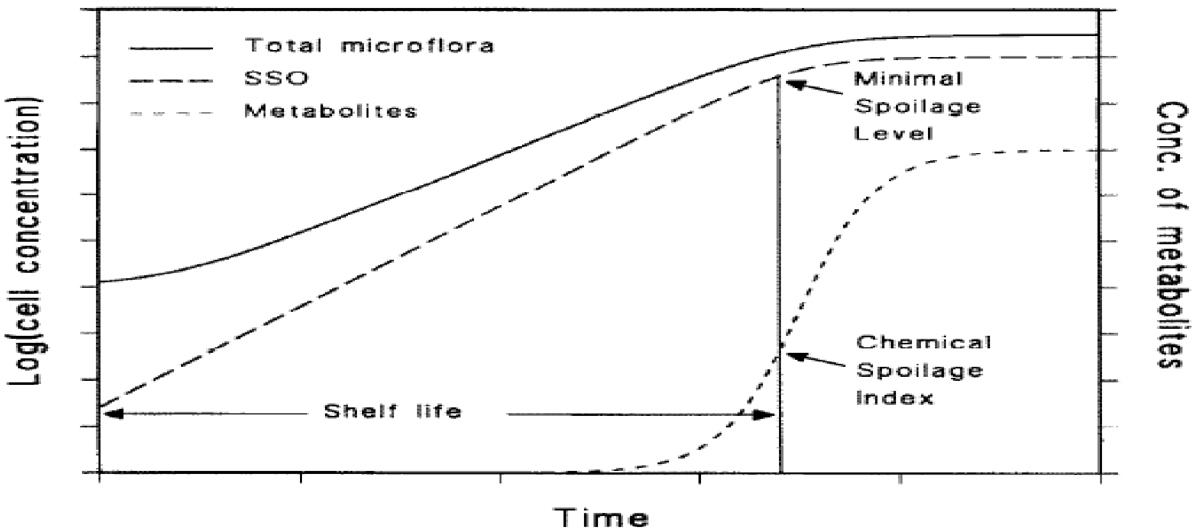

Fig. 1: General pattern of microbial spoilage. SSO, specific spoilage organisms; MSL, minimal spoilage level; CSI, chemical spoilage index.

Gram negative rod shaped bacteria

Pseudomonas spp. are the most common spoilage organisms, particularly in aerobically stored foods with a high water content and natural pH, e.g., red meat, fish, poultry, milk and dairy products. *Pseudomonas* spp. like most of the other Gram negative rod shaped bacteria, usually comprise only a small proportion of the initial microflora of fresh foods. They are however, widely distributed in the environment and may contaminate foods from many sources and are able to utilize it wide range of materials as substrates for growth. Food spoilage due to pseudomonades may occur in a number of ways. In foods of animal origin the non-protein nitrogen fraction (NPN) will be first metabolized. Subsequently the production of lipases or proteases will liberate fatty and amino acids which after metabolism can also result in off-odours, off-flavours and rancidity. At later stages the production of extracellular slime and the development of often pigmented growth become visible. A number of other Gram-negative rod shaped bacteria may also grow rapidly at chill temperatures and spoil foods, such as *Aeromonas, Photobacterium, Shewanella and Vibrio.* Some or all of the above bacteria have been shown to contribute to the spoilage of chilled red meat, cured meats, poultry, fish, shellfish and milk and dairy products. *Vibrio* spp. are unusual as most are halophilic (Salt loving) and so may cause spoilage of sea-fish and cured meats. Like the Pseudomonads other Gram negative bacteria also cause food spoilage due to NPN metabolism. Subsequently foods will spoil by the production of enzymes (resulting in odour and flavour defects), slime production and the formation of visible often pigmented colonies. At a temperature above 5-10°C enterobacteriaceae generally dominate over *pseudomonas* spp. and become responsible for spoilage. *Vibrionaceae* spoil fish at higher temperatures. Spoilage is characterised by the production of gas, acid, slime, rope, bitter flavours and off-odours. The presence of enterobacteriaceae is often used as an indication for possible faecal contamination, inadequate processing or post-process contamination.

Gram positive, spore forming bacteria

Many foods undergo a heating or pasteurization process. Thus microorganisms capable of surviving this process are significant (e.g., *Bacillus* and *Clostridium spp.)* particularly if they are able to grow at chill temperatures. Growth of the spore forming bacteria tends to be much slower than that of the Gram negative bacteria, but most of these latter bacteria are eliminated by heat processing. The *Bacillus spp.* are largely aerobic in nature. Perhaps, best recognized is *B. cereus* which may grow at low temperatures (5°C or less) and produce enzymes which result in 'sweet curdling' and 'bitty cream' in milk. Other Bacillus spp. may grow at temperatures of 0-2°C. Most spoilage *Clostridium* spp. are unable to grow at refrigerator temperatures (i.e. 5°C or less), but at slightly higher temperatures may produce gas resulting in 'late blowing' of hard cheeses during maturation. Recently some psychotrophic *Clostridium* spp. have been observed to spoil vacuum-packed meat and fish with extended shelf life such as vacuum-packed beef and ham and sous-vide cooked beef.

Lactic acid bacteria

Lactic acid bacteria spoil foods by the fermentation of sugars to form lactic acid, slime and CO_2, leading to a drop in pH and off-flavours. These bacteria tend to grow slowly at refrigeration temperatures and are under aerobic conditions generally out-competed by pseudomonads. Generally, they are present in the initial microflora in low numbers and are therefore rarely responsible for the spoilage of fresh proteinaceous foods. Lactic acid bacteria, however, have been identified as the major spoiling microorganisms of vacuum-packed meat and poultry and are also suggested as possible spoilers of lightly preserved fish products. Cured and fermented meat products may also be spoiled by lactic acid bacteria, as the pH or other preservation methods in the food again prevent the growth of the normal spoilage microflora. Typical lactic acid bacteria are identified as *Lactobacillus, Streptococcus, Leuconostoc and Pediococcus spp*.

Other Gram-positive bacteria

Brochothrix thermosphacta is a Gram positive rod shaped bacteria which may be occasionally present on fresh meats. The increased use of modified atmosphere packaging and vacuum packaging will often allow *Br. thermosphacta* to dominate the microflora. *Micrococcus* spp. are able to grow in the presence of salt and may be responsible for the spoilage of cured meat products such as bacon producing slime, souring or pigmented growth. These microorganisms also often predominate in freshly collected milk. Many strains are thermoduric and may survive milk pasteurisation causing subsequent spoilage, particularly if the other more rapidly growing spoilage organisms have been eliminated by the heat treatment.

Milk and dairy products

During extended refrigerated storage of milk heat-stable enzymes of microbial origin may be formed. These can biochemically alter the products, eventually causing spoilage. Two types of enzymes are particularly important in the formation of off-flavours: (i) lipases and (ii) proteinases.

Lipases

Lipase activity has been reported for most psychotrophs isolated from milk and milk products. *Pseudomonas, Flavobacteria*, and *Alkaligenes* species are the most lipolytic bacteria. Microbial lipases are heat stable. Lipase activity in milk leads to the preferential release of medium and short-chain fatty acid from triglycerides, hydrolysis of as little as 1-2'% triglycerides leading to rancid off-flavour. Milk naturally also contains high levels of indigenous lipase. It is therefore extremely likely that indigenous as well as microbial lipases are important in development of lipolytic rancidity in milk.

Proteinases

The major cause of bitterness in milk and milk products is the formation of bitter peptides due to the action of proteinases. Proteinase activity has been detected in many bacterial species, in particular *Pseudomonas, Aeromonas, Serriatia* and *Bacillus* species. Heat stability of proteinases from several bacterial species has also been reported. Strict quality control is therefore critical in UHT milk products to ensure that heat-stable proteinases do not cause bitter off-flavours. The most investigated source of bitter peptides is the casein.

Meat and fish

Off-flavours which develop due to surface microbial contamination are major causes of spoilage in meat. The first signs of spoilage to be caused by the formation of fruity, sweet-smelling esters, followed by the formation of putrid sulphur compounds. *Pseudomonas* species as the main bacterial contamination. Many putrid odours arise due to decomposition of proteins and amino acids by anaerobic bacteria. Volatiles produced include indole, methane thiol, dimethyl disulphide and ammonia. Rancidity problems which occur are usually due to oxidation of unsaturated lipids and are not associated with microbial growth. In the case of fish, a four phase pattern for the changes in flavour quality after harvest has been described. Initial microbial contamination and growth is by aerobes, which act on carbohydrates giving carbon dioxide and water. As the surface becomes covered and slime builds up, conditions become more favourable to the growth of anaerobes. Reduction of trimethylamine oxide to the unpleasant fish-smelling trimethylamine, catalysed by trimethylamine-N-oxide reductase, is carried out by many bacteria. Many off-flavours are also associated with the breakdown of sulphur-containing amino acids. Typical volatile products are hydrogen sulphide methyl mercaptan and dimethyl sulphide.

Yeasts and moulds in food spoilage

Yeasts and moulds can be found in a wide variety of environments, such as in plants, animal products, soil, water and insects. This broad occurrence can be explained by the fact that yeasts and moulds can utilize a variety of substrates such as pectines and other carbohydrates, organic acids, proteins and lipids. Moreover, yeasts and moulds are relatively tolerant to low pH, low water activity, low temperature and the presence of preservatives. It is also notable that yeasts can utilize food ingredients, such as organic acids like lactic, citric and acetic acids, that are generally considered to have an inhibitory effect on the growth of many microorganisms. Even common preservatives such as benzoate, propionate and sorbate can be utilized by some yeast species. Contamination of foods and beverages by yeasts and moulds has been extensively reported. Contemporary work has also reported the occurrence of yeasts in fresh seafood, packaged meats, delicatessen salads, and in fresh vegetables. Changes induced by spoilage of yeasts and moulds can be of a sensory nature, recognizable in the product's appearance by the production of slime, quite often pigmented growth on the surface, fermentation of sugars to produce acid, gas or alcohol or the development of off-odours and off-flavours. In addition to visible spoilage, moulds can also spoil foods through the formation of mycotoxins. It has now been established that more than 200 different types of moulds do form substances that are orally toxic to man, when growing in certain foods. Although most research has been carried out on the metabolites of *Aspergillus,* it is quite obvious that in addition to the so-called aflatoxins, many other mycotoxins may be of great significance.

Degradation of food components by microbial spoilage

Carbohydrates

The general formula of carbohydrates is $C_x(H2O)_y$. The carbohydrates are divided into monosaccharides, disaccharides and polysaccharides. For utilization, bacteria first break down complex carbohydrates into their constituent monosaccharides.

Polysaccharides: Plant cells and tissues have a fibrous substance embedded in an amorphous support matrix. The fibrous material resists tension and the matrix resists compression. In plants, the primary fibrous substance is cellulose.

Plants have a rather wide range of matrix compounds. In higher plants, the matrix polysaccharides are classified into a group of acidic polysaccharides called pectins and a heterogeneous group of neutral polysaccharides called hemicelluloses. When stiffness is needed, a nonpolysaccharide , lignin, is incorporated. In algae (seaweeds), such things as carageenans and agar are the matrix materials.

Pectin: Pectolytic enzymes are produced by a wide range of microorganisms, especially those causing soft rot. The pectic enzymes include pectin esterase, polygalacturonase, pectate transeliminases and lyases. The random splitting of glycosidic bonds results in softening and liquefaction.

The pectic enzymes are found in plant tissues as well as in many types of microorganisms. The plant enzymes act during the ripening of fruit to cause a softening effect. This is desirable to an acceptable level, but continued action by these enzymes causes excessive softness and a mushy product. When a microorganism is isolated from a softened fruit, the softening could have been caused by either the enzymes from the organism or the plant tissue. The degradation of pectin was reviewed Chesson (1980). Perhaps this breakdown is the primary spoilage defect of plant tissues.

Cellulose: Only a few species of bacteria can decompose cellulose, but several filamentous fungi are capable of doing so. Cellulose is either hydrolyzed directly to glucose or to intermediates such as cellobiose.

The presence of readily metabolized substances such as glucose represses the production of the inducible cellulases. Hence the breakdown of cellulose is of secondary importance in the deterioration of plant tissues.

Starch: This polysaccharide is an important component of many plant products. Several bacteria and molds possess an extracellular enzyme, diastase or amylase, which hydrolyze starch. Starch is converted either directly to glucose or through intermediate such as maltose.

Monosaccharides: Glucose is the main carbohydrate used as a carbon and energy source. The breakdown of these sugars can proceed by several pathways. There are various systems for the metabolism of glucose such as the glycolysis, pentose-P-phosphoketolase and Entner Doudoroff pathways. Pyruvic acid is a key compound in the metabolism of glucose. Some of the metabolic products resulting from carbohydrates include organic acids, alcohols, CO_2, H_2 and H_2O. In aerobic respiration, pyruvate is converted into CO2 and H2O by means of the tricarboxylic acid cycle (TCA). Only the aerobic and some facultatively anaerobic microorganisms possess cycle.The pyruvic acid can be decarboxylated to form acetaldehyde and CO2. The acetaldehyde can remain or be reduced to ethyl alcohol, oxidized to acetic acid or condensed to form acetoin or acetylmethylcarbinol (AMC). The AMC can be oxidized to diacetyl which has a butter flavour or reduced to 2, 3-butanediol. Pyruvate can be aminated to form alanine.

Table 1: Some products of carbohydrate metabolism

Organisms	**Products**
Leuconostoc mesenteroides	Lactic acid, Ethyl alcohol, CO_2
Leuconostoc cremoris	Acetic acid, Acetoin, Diacetyl
Saccharomyces (yeast)	Ethyl alcohol, CO_2
Clostridium botulinum	Butyric acid, Propionic acid, Isobutyric acid, Isovaleric acid, Propyl alcohol, Isobutyl alcohol, Butyl alcohol, Isoamyl alcohol
Propionibacterium	Propionic acid, Acetic acid, Isovaleric acid, Formic acid, Succinic acid, Lactic acid, CO_2
Escherichia coli	Lactic acid, Acetic acid, Formic acid CO_2, H_2
Bacillus cereus	Acetoin, Glycerol, 2, 3-Butanediol Lactic acid, Succinic acid, Formic acid, Acetic acid, CO_2

Lipids

The principle lipids in foods are fats. Fats are esters of glycerol and fatty acids and are called glycerides. Many foods contain fat that is susceptible to hydrolysis, oxidation and other chemical processes that result in the formation of various compounds. Both desirable and undesirable flavour changes in foods are associated with these compounds.

The enzymes that hydrolyze triglycerides are called lipases. The designation of true lipase is given to enzymes that attack only water-insoluble substrates.

The oxidative deterioration of fats involves the reactions of unsaturated fatty acids with oxygen to give hydroperoxides. The hydroperoxides are not flavour compounds, but readily decompose to carbonyl compounds resulting in off-flavour or odour. The carbonyl compounds re mixtures os saturated and unsaturated aldehydes and ketones.

Deteriorated fat is called rancid. The simple release of fatty acids is called hydrolytic rancidity and oxidative deterioration is oxidative rancidity. Hydrolytic rancidity is important in fats. Short-chain water soluble fatty acids (butyric, caproic and caprylic) cause obnoxious rancid flavours in milk.

Except for the release of volatile fatty acids, the main flavour changes are not due to hydrolysis, but to oxidation. The oxidation of the fat is more often due to tissue enzymes or autoxidation than to microbial activity. Certain species of *Aspergillus* and *Penicillium* produce oxidative enzymes that catalyze the oxidation of free fatty acids to methyl ketones. There are many lipolytic microorganisms. Some of the genera that contain lipolytic species or strains are listed in Table 1. With the breakdown of fats, various products are formed, including glycerol, free fatty acids, aldehydes, ketones and alcohols.

Table 1: Some genera containing lipolytic species or strains

Bacteria	Fungi
Acinetobacter	*Absidia*
Aeromonas	*Alternaria*
Alcaligenes	*Aspergillus*
Bacillus	*Candida*
Chromobacterium	*Cladosporium*
Corynebacterium	*Endomyces*
Enterobacter	*Fusarium*
Flavobacterium	*Geotrichum*
Lactobacillus	*Mucor*
Micrococcus	*Neurospora*
Pseudomonas	*Penicillium*
Serratia	*Rhizopus*
Staphylococcus	*Torulopsis*
Streptomyces	

Proteins

Proteins are composed of amino acids combined by peptide linkages. These linkages are broken by the addition of water catalyzed by enzymes.

The proteins are degraded through proteoses, peptones, polypeptides and dipeptides to amino acids. The enzymes that hydrolyze the peptide linkages of proteins are called proteases. These proteases convert the proteins into diffusible polypeptides and dipeptides which can enter the bacterial cell. The polypeptides and dipeptides are without offensive odour.

The native proteins are resistant to attack by microorganisms. These are low molecular weight compounds such as dipeptides and free amino acids in fresh meat, fish and poultry tissue. These substances are readily used by the microflora. Spoilage of the protein type foods may be evident before any significant amount of protein is degraded. In advanced spoilage, some protein is hydrolyzed by proteolytic enzymes, whether produced by the tissues or the microorganisms.

Amino acids: The degradation of amino acids is of primary importance in the spoilage of protein foods. The products that are formed depend upon (1) the type of microorganisms; (2) the types of amino acids; (3) temperature; (4) the amount of available oxygen and (5) the types of inhibitors that might be present.

There are many amino acids and hence many products of amino acid dissimilation. Some products that are formed anaerobically are foul smelling. This form of degradation is called putrefaction. Aerobic degradation, with oxidation of the metabolic products is called decay. The two reactions of icroorganisms on amino acids are decarboxylation or deamination. Other reactions of the amino acids include the following:

Oxidative reduction

$3CH_3CHNH_2.COOH + 2H_2O \rightarrow 2CH_3CH_2COOH + CH_3COOH + 3NH_3 + CO_2$

The overall reaction results in two organic acids- ammonia and carbon dioxide.

Anaerobic degradation-release of hydrogen

$5COOH.CH_2.CH_2.CHNH_2.COOH + 6H_2O \rightarrow 6CH_3COOH + 2CH_3CH_2CH_2COOH + 5CO_2 + 5NH_3 + H_2$

The overall reaction involving, in this case, glutamic acid yields acetic acid, butyric acid, carbon dioxide, ammonia and hydrogen.

Transamination

Although the amino acid is not degraded in this reaction, transaination does alter the composition of the substrate, which will determine the final degradation product.

COOH.CH2.CH2.CHNH2.COOH + COOH.CH2.CO.COOH → COOH.CH2.CH2.CO.COOH + COOH.CH2.CHNH2.COOH

In this example, glutamic acid reacts with oxaloacetic acid to form α-keto glutaric acid and aspartic acid.

Mutual oxidation and reduction

Some amino acids (alanine, leucine, phenylalanine and valine) can serve as hydrogen donators aand are oxidized while others (arginine, glycine, hydroxyproline, ornithine and proline) can serve as hydrogen acceptors and are reduced.

Tryptophan can enter reactions resulting in many products. One product indole is used in the identification of certain microorganisms. Another product is skatole. Small amounts of skatole are present in the perfume of the jasmine and orange blossoms. It is one of the two most important nitrogenous substances found in natural perfumes. In larger concentrations, skatole is a foul-smelling compound. It is found prominently in fecal material.

When sulfur containing amino acids such as cystine or methionine are degraded, hydrogen sulfide as well as mercaptans, organic disulfides and other sulfur containing (thio) compounds may be formed. The decarboxylation of the diamino acids, lysine and ornithine yield cadaverine and putrescine accordingly:

$NH_2.(CH_2)_4.CHNH_2.COOH \rightarrow NH_2.(CH2)_5.NH_2 + CO_2$

$NH_2.(CH_2)_3.CHNH_2.COOH \rightarrow NH_2.(CH_2)_4.NH_2 + CO_2$

Arginine is degraded through ornithine to putrescine. By the dissimilation of amino acids, many diverse products such as carbon dioxide, hydrogen, ammonia, hydrogen sulfide, organic acids, alcohols, amines, diamines, mercaptans and organic disulfides may be formed. The production of ammonia and amines tends to cause an increase in the pH.

Other deterioration

Besides the changes caused by the degradation of carbohydrates, fats and proteins, microorganisms can create unacceptable foods by changing the appearance of the food, either by mold growth or by altering the colour of a pigment. Also microorganisms can metabolize sugar and produce dextrin's or levans that feel like slime on the surface of foods such as meat, poultry or fish or a condition called ropiness in such foods as milk or bread.

Appearance

When microbial growth can be observed on a food, it usually is considered to be unacceptable. Pigmented bacteria can, at times, be observed on a food. Mold mycelia indicate potential spoilage, however, mold growth on certain types of cheeses such as Roquefort and Camembert, to develop the distinctive flavours.

Various pigments (chlorophyll, carotene, myoglobin) are present in foods. The degradation of chlorophyll and carotene is related to the lipolytic breakdown of fats. A lipase in peas effectively degrades chlorophyll to pheophytin and the degradation of both chlorophyll and pheophytin is related to an increase in fat peroxide. Carotene is fat soluble and its destruction is related to fat decomposition. The myoglobin pigment of meat muscle can be altered by oxidation-reduction rections. Myoglobin is dark red to purple and is present in the interior part of meat. When the muscle tissue is cut and exposed to oxygen, the myoglobin is oxygenated to oxymyoglobin, which is bright red and is the usual pigment associated with meat. In myoglobin and oxymyoglobin, the iron is in ferrous form. When it becomes oxidized to the ferric form, metmyoglobin is formed. This pigment is dark brown. Although these pigment changes do not necessarily make the food inedible, a consumer may consider the product unacceptable.

Slime formation

Several bacteria produce microbial polysaccharides (dextrans, levans or amyloses) from various disaccharides present in food. These polysaccharides form unpleasant slime in and on food, causing the food to be both unpalatable and unacceptable to the consumer. An example of this is the slimy or ropy texture of fruit concentrate or ilk when infected with *Leuconostoc mesenteroides, Bacillus subtilis*, or *E. coli*. Sucrose and maltose are readily used by *L. mesenteroides, B. subtilis*, or *E. coli* to produce amylases and dextrans. *B. megaterium* and *B. subtilis* produce levans, which are long chain polysaccharides.

Dextran is a glucose polymer. Sometimes it is encountered as a slime in large globular masses during the processing of cane or beet sugar. It increases the viscosity of the sugar solution and retards filtration and crystallization. These globular masses are due primarily to activities of *L. mesenteroides* and *L. dextranicum* although *Streptococcus salivarius* and *S. bovis* are able to synthesize from sucrose and raffinose a dextran type insoluble carbohydrate. Slime on refrigerated fresh meat and poultry that appears soon after off-odor is caused by the growth of *Pseudomonas*.

Chemical spoilage

Although chemical and physical spoilage processes cannot be totally separated, their main contributions to food spoilage are characterized by flavour and colour changes due to oxidation, irradiation, lipolysis (rancid) and heat. These changes may be induced by light, metal ions or excessive heat during processing or storage. Chemical processes also may bring about physical changes such as increased viscosity, gelation, sedimentation or colour change.

Spoilage by enzyme action

Food spoilage can also come about through the action of enzymes presents in the food. Enzymes are chemicals which are present in all food. They speed up chemical changes that result in loss of flavour, colour and texture. As enzymes are mainly composed of protein, they are sensitive to heat. Enzymes speed up the process of decay by breaking down the tissues and components of the food in the various ways such as oxidation, browning and ripening. Enzymes which are endogenous to plant tissues can have undesirable or desirable consequences. Examples involving endogenous enzymes include a) the post-harvest senescence and spoilage of fruit and vegetables; b) oxidation of phenolic substances in plant tissues by phenolase (leading to browning); c) sugar - starch conversion in plant tissues by amylases; d) post-harvest demethylation of pectic substances in plant tissues (leading to softening of plant tissues during ripening, and firming of plant tissues during processing).

Enzymatic oxidation

Lipoxygenase occurs in many plants and catalyzes the oxidation of unsaturated fatty acids containing a cis, cis 1, 4-penttadiene system to their corresponding monohydroperoxides. These peroxides have the same structure as those obtained by autoxidation. Lipoxygenase is a metal bound protein with a Fe-atom in its active centre. Plant lipoxygenases produce cis, trans conjugated monohydroperoxides as primary products. Naturally occurring substrates include linoleic, linolenic and arachidonic acids.

Browning

Enzymatic activities in fruits and vegetables can cause browning of tissues. Typically these reactions are catalyzed by phenol oxidase enzymes, which react with phenol compounds and oxygen to form undesirable brown pigments. When you cut or bruise food such as apple or yam, the exposed surface will discolour and turn brownish due to the activity of enzymes. Polyphenoloxidases (PPO) and peroxidases found in fruit tissues can catalyze oxidation of certain endogenous phenolic compounds to quinones that polymerize to form intense brown pigments.

Over ripening

Enzymes are involved in the process that causes ripening in fruits and vegetables. Unripe bananas for example contain starch which is gradually converted to sugars, until the banana becomes very sweet and its skin colour changes from green to yellow. Eventually, the skin colour changes to dark brown and it is no longer fit to be consumed. The activity of enzymes in food makes it easier for the micro-organisms responsible for food spoilage to enter the food.

Protein degradation

Protein degradation can involve reactions with protein and other ingredients brought about by enzymatic activity. Protein hydrolysis is achieved by enzymes collectively called proteases. Proteases bring about the cleavage of long protein chains and form fragments of amino acids. Enzymes hydrolyzing peptide bonds in the interior of the amino acid chain are called endo-peptidases whereas proteases hydrolyzing peptide bonds at either the amino- or carboxy- terminal end of the protein are called exo-peptidases. One of the spoilage causing protease is ‘Protease plasmin’. Plasmin can survive pasteurization temperature and can cause degradation of dairy proteins in milk and cause coagulation and gelatinization. Other protease can act on the proteins in meat and cause the meats to become mushy.

Oxidative rancidity

Lipid oxidation is one of the most common causes of deterioration of food quality. The unsaturated fatty acid components undergo oxidation due to exposure to atmospheric air giving rise to oxidative rancidity in fat rich foods. The susceptibility to and the rate of oxidation increase as the number of double bonds in the fatty acid increases. Among the products of oxidative rancidity are hydroperoxides, ROOH. These have no taste, but they decompose easily to form aldehydes, ketones and acids, which give rancid flavours. The rate of oxidative rancidity and course of reaction is influenced by light, local oxygen concentration, high temperature, the presence of catalysts (generally transition metals such as iron and copper) and water activity. Control of these factors can significantly reduce the extent of lipid oxidation in foods. Many foods or food ingredients (plants, fruits. roots and meats) contain components which possess so called antioxidant properties. Examples of well known natural antioxidants are ascorbic acid, vitamin E, carotenoids and flavonoids. Antioxidants inhibit lipid oxidation by acting as hydrogen or electron donors, and interfere with the radical chain reaction by forming non radical compounds that will not propagate further radical reaction.

Non-enzymatic browning

Non-enzymatic browning is one of the major causes of deterioration which occurs during storage of dried and concentrated foods. The non-enzymatic browning, or Maillard reaction, can be divided into three stages: a) early Maillard reactions which are chemically well-defined steps without browning; b) advanced Maillard reactions which lead to the formation of volatile or soluble substances; and c) final Maillard reactions leading to insoluble brown polymers.