OFF-FLAVORS IN FOODS: 3. CHEMICAL CHANGES

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Abstract

Flavor is one of the most important quality attributes of food and food products. Off-flavors (OFs) may damage food products and be unfit for consumption. The OFs may be due to incidental contamination of food from environment or may occur in the food itself by biochemical and chemical reactions such as lipid oxidation, nonenzymatic browning or Maillard reaction or result from processing conditions. Protein, lipid and sugar components of food are the major sources of chemical reactions producing OFs along with other catalysts such as heat, light, metals and enzymes.

Introduction

Foods contain a number of constituents which may undergo chemical changes during preparation and processing. These constituents may either react with other constituents or simply degrade into off-flavor (OF) components. The major reactions leading to OFs include lipid oxidation, nonenzymatic browning (Maillard reaction), enzymatic changes, and photocatalyzed reactions.

Lipid Oxidation

Edible oils and fats may be of vegetable, animal or fish origin. In the majority of cases the origin, or method of production, transport, and storage give the products totally unacceptable flavors, odors, and colors.

The deterioration of fats is usually described as "rancidity" which arises from partial decomposition due to the action of heat, light, contamination by certain metals or by the presence of microorganisms. There are basically two kinds of rancidity known scientifically as "oxidative" and "hydrolytic". The latter is sometimes called "soapy" rancidity (Barnes and Galliard, 1982; Rossell, 1984; Richardson, 1985).

Oxidative rancidity, as the name implies, arises from the action of oxygen on the fats-normally from the presence of air. It is accelerated by exposure to light, heat, certain metals and sometimes moisture. Nonenzymatic, or chemical oxidation of fatty acids is related to the number of double bonds in the carbon chain of the molecule; linolenic acid (3 double bonds) oxidizes much more rapidly than linoleic acid (2 double bonds) which in turn is less stable than oleic acid (1 double bond). Thus fish and vegetable oils with the greatest proportions of polyunsaturated fatty acids tend to be the least stable to rancidity (Richardson, 1985; Barnes and Galliard, 1982). Oxidative rancidity becomes a more serious problem as the degree of unsaturation in the oil increases.

Phospholipids have also been shown to easily oxidize or discolor during heating or prolonged storage. Autoxidation of phospholipids by the action of atmospheric oxygen occurs on the unsaturated fatty acids. The very highly unsaturated fatty acids in the phospholipid molecule are susceptible to oxidation and lead to the formation of strongly flavored decomposition products at a relatively early stage of the oxidation process (Min and Stasinopoulos, 1985).

Lipid oxidation typically involves the reaction of molecular oxygen with unsaturated fatty acids via a free radical mechanism. The mechanism may be presented as follows:

Initiation

$$R1H \rightarrow R_1. + H.$$

$$R1H + O_2 \rightarrow R_1OO. + H.$$

Propagation

$$R. + O_2 \rightarrow R_1OO.$$

$$R_1OO. + R_2H \rightarrow R_1OOH + R_2$$

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Termination

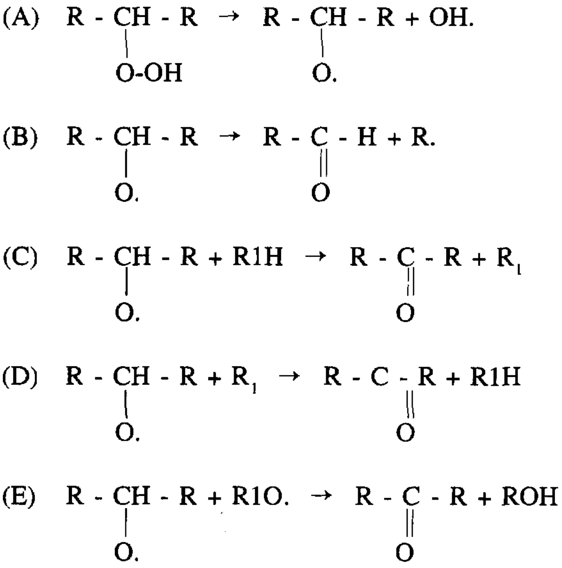
$$\mathrm{ROO.+R.} \rightarrow \mathrm{ROOR}$$

$$\mathrm{R.+R.} \rightarrow \mathrm{RR}$$

$$\mathrm{ROO.+ROO.} \rightarrow \mathrm{ROOR+O_2}$$

Where RH is unsaturated lipid; R., lipid radical; and ROO., lipid peroxy radical (Heath and Reineccius, 1986). Lipid oxidation is a self-propagation reaction, i.e., once started it continues itself.

Off flavors arise from lipid oxidation via secondary reaction products. Lipid hydroperoxides are normally flavorless and very unstable and break down to produce shot chain volatile flavor compounds as the following reactions.



(A) $\mathrm{R - \underset{\substack{|\\ O\text{-}OH}}{CH} - R} \rightarrow \mathrm{R - \underset{\substack{|\\ O.}}{CH} - R + OH.}$

(B) $\mathrm{R - \underset{\substack{|\\ O.}}{CH} - R} \rightarrow \mathrm{R - \underset{\substack{\|\\ O}}{C} - H + R.}$

(C) $\mathrm{R - \underset{\substack{|\\ O.}}{CH} - R + R1H} \rightarrow \mathrm{R - \underset{\substack{\|\\ O}}{C} - R + R_1}$

(D) $\mathrm{R - \underset{\substack{|\\ O.}}{CH} - R + R_1} \rightarrow \mathrm{R - \underset{\substack{\|\\ O}}{C} - R + R1H}$

(E) $\mathrm{R - \underset{\substack{|\\ O.}}{CH} - R + R1O.} \rightarrow \mathrm{R - \underset{\substack{\|\\ O}}{C} - R + ROH}$

Steps B-E result in the production of short chain saturated or unsaturated aldehydes, ketones and alcohols. These primary reaction products can undergo further oxidation if unsaturated, or secondary reactions to yield a host of OF volatiles. The final products are generally aldehydes, ketones, acids, alcohols, hydrocarbons, furans, lactones or esters. The unsaturated aldehydes and ketones have the lowest sensory thresholds and are, therefore, most often cited with being responsible for oxidized flavors (Heath and Reineccius , 1986; Kochhar, 1993).

Methyl ketones, lactones and esters are also formed primarily by hydrolytic reactions. Methyl ketones contribute a piercing sweet fruitiness, ranging from C_3, pungent, sweet, through C_7 blue cheesy to C_{11} fatty, sweet. Some aliphatic acids contribute to the flavor by being sour, fruity, cheesy or animal-like. Their contribution depends on number of carbons ranging from C_2 vinegary, C_3 sour, Swiss cheesy, C_4, sweaty cheesy, C_8 goat cheesy, C_9 paraffinic to C_{14}-C_{18} with very little odor. The contribution of each of these compounds to the flavor of food also depends on its flavor threshold (Hamilton, 1994).

The chemical oxidation of unsaturated fatty acids in foods can be catalyzed by light and by certain metals, especially iron and copper, and the metallo-protein, for example, hemoglobin, myoglobin, catalase and peroxidase. Even when metallo enzymes, such as catalase and peroxidase, are heated to inactivate their normal enzyme activity, the iron present is still a potent catalyst to lipid oxidation. In addition, enzymatic oxidation may occur and in materials derived from plants, the enzyme lipoxygenase is widespread. This enzyme catalyzes fatty acid hydroperoxide formation in a similar manner to the nonenzymatic systems above (Barnes and Galliard, 1982).

Flavor deterioration can occur in oils and fats even when there is little outward evidence of oxidation. In the case of soybean oil the characteristic "green-beany" flavor of the crude oil can be removed during neutralization, bleaching, and deodorization, but this flavor can return during storage. This "reversion flavor" is due to the presence of non-volatile oxidation products; not being removed during the refining process but continued to decompose in the finished oil (Rossell, 1984). A related problem is the so-called "hydrogenation taint", or "hardening flavor". Unsaturated oils such as soybean or rapeseed are frequently hydrogenated in order to lower the level of a rapid flavor release, giving a saturation and thus increase their resistance to oxidation. Under some conditions double bond isomerization and migration can occur, leading to the presence in the hydrogenated oil of isomerized polyunsaturated fatty acids. Some of these can be oxidized to intermediates which decompose into troublesome aldehydes. For instance, 9,15-octadecadienoic acid reacts to form the aldehyde 6-trans-nonenal which has an extremely potent "green-melon" OF characteristic, detectable on the palate even when present in an oil at a level as low as 0.0003 ppm (Rossell, 1984).

Oxidative rancidity in fatty products usually appears in the form of OFs which may be variously described as "tallowy", "fishy", "metallic" and often are not readily identified as being associated with the fat ingredient (Richardson, 1985). These can be no doubt that oxidizing polyunsaturated fatty acids of fish oils result in characteristic "rancid" odors. The odor of oxidized fish oils is similar, but is not identical, to the rancid odors of other oils, such as linseed. The rancid odor of fish oil includes other components that make it easily distinguishable. However, the "spoilage" odors of fish may be due, at least in part, to degradation of fish-oil fatty acids, and that, on the other hand, odors of fish oils may be due, at least in part, to products of protein decomposition (Stansby, 1962).

Soybeans are potentially the most abundant and economical source of food proteins. The uses of soy proteins for food items have been associated with their objectionable flavors. The OF of soybean protein products may be due to the incomplete removal of lipids in soy flour. Autoxidative decomposition products in soy flour have been identified, including alcohols, aldehydes, ketones, and 2-pentyl furan. Among these compounds, 2-pentyl furan and ethyl vinyl ketone are said to cause "beany", "grassy", and "green" odors of the soy flour (Hsieh et al., 1981).

Jeon and Bassette (1984) reported that oxidative products n-pentanal and n-hexanal were related to the development of OF in potato chips. Using a gas chromatographic method, they found that potato chips contained a relatively large amount of n-hexanal immediately after processing. The amount of n-hexanal formed was greater than n-pentanal formed. The concentration of both compounds significantly increased when potato chips were exposed to fluorescent light up to 60 hrs. When held at 120 °C, consistent increases in both n-pentanal and n-hexanal were found during 31/2 hrs and sharp increases after 4 hrs.

Analysis of n-hexanal is also used to evaluate the OF of stored brown rice. Shin et al. (1986) employed a gas chromatographic method using modified direct vapor injection and reported that the amount of n-hexanal was found to be linearly proportional to the amount of oxidized linoleic acid with the correlation coefficient of 0.99.

Off-flavors due to oxidative changes in meats can be divided into two categories: one involving oxidation which occurs in meats following cooking, the other in frozen raw meats. The OF which occurs following the cooking of meats is generally called "warmed over flavor" (WOF). This OF is generally accepted as being due to oxidation of the intramuscular phospholipid fatty acids. Oxidation proceeds at a very rapid rate following heating of the meat due to denaturation of the heme proteins and destruction of cellular structure thereby permitting intimate mixing of cellular constituents. The reaction is catalyzed by both heme and nonheme iron. The nonheme iron is of substantially greater importance to WOF development in most meat products than the heme catalysts (Reineccius, 1979; Bailey et al., 1980; Min and Stasinopoulos, 1985). The compounds responsible for WOF are n-hexanal and 2-pentyl furan since they are associated with fatty acid oxidation and undesirable flavor of many lipid-containing foods (Bailey et al., 1980).

The 2-thiobarbituric acid (TBA) test is often used to measure oxidative deterioration of meat fats. An increase in the TBA numbers is found to correlate with sensory scores for WOF and with a decrease in phospholipid and phospholipid polyunsaturated fatty acids (Willemot et al., 1985; Poste et al., 1986). Phospholipids are the main source of polyunsaturated fatty acid oxidation during WOF development.

Warmed over flavor can be inhibited by the same methods that are used for lipid oxidation. This includes the use of metal chelators, primary and secondary antioxidants and vacuum packaging (Heath and Reineccius, 1986). The use of browning products as an tioxidants has been found effective in reducing WOF in meats (Reineccius, 1979). Nitrite is one of the most effective compounds used to inhibit the development of WOF in meat products (Bailey, 1980). Igene et al. (1985) suggested the mechanisms that nitrite functions as an antioxidant in three possible ways: (1) by the formation of strong complex with heme pigments thereby preventing the release of nonheme iron and its subsequent catalysis of lipid oxidation; (2) by interacting directly with the liberated nonheme iron (Fe^{2+}) from denatured heme pigments and (3) to a lesser extent, by stabilization of the unsaturated lipids within the membranes. Stabilization of the porphyrin ring, preventing release of Fe^{2+} during the cooking process, appears to be the most important mechanism.

Terms most commonly used to describe the oxidized flavors in milk are "cabby", "cardboard", "metallic", "oily", "oxidized", and "tallowy". The polyunsaturated fatty acids in the phosphatides at the interface of the milk fat globules are considered the precursors of the flavors (Bassette et al., 1986). Several carbonyl compounds have been isolated from oxidized milk fats or phospholipids. The characteristic OFs and associated compounds are presented in Table 1. The OF develops upon storage and is more prevalent in pasteurized, unhomogenized milk and fluid cream products than in honogenized milk. Homogenization inhibits the development of oxidized flovor, but there is an agreement regarding the mechanism. Oxidized flavor development can be inhibited by the addition of certain phenolic antioxidants which inhibit free radical oxidations; however, the addition of such compounds to milk is not legal in the United States (Shipe et al., 1978).

Photo-induced Off-flavors

Off-flavors may be produced via photocatalyzed reactions in foods. "Skunky" or "sunstruck" flavor in beer and "burnt feathers" in dairy products are two of the more unique example of OFs in foods due to light exposure.

Milk exposed to various forms of radiant energy develops OF. Factors which contribute to the intensity of "sunlight flavor" are wavelength and intensity of light, exposure time, translucence of the container, levels of ascorbic acid, and riboflavin (Shipe et al., 1978; Bassette et al., 1986).

The light-induced or activated flavor has two distinct components - one a burnt activated, or sunlight flavor which develops rapidly and has been attributed to degradation of serum protein components. The second component is similar to oxidized flavor. The latter flavor, attributed to lipid oxidation, seems to develop more slowly. The lipid-oxidation component of the light-induced flavor undoubtedly contains some of the same volatile carbonyl compounds that are in typical oxidized flavors. Presumably, because of the difference in the rate of development of the two flavor components, the flavor of milk exposed to radiation changes with time. Initially, the "burnt" note predominates, and after 2 or 3 days the "oxidized" note becomes more pronounced; therefore, the OF that developed several days after light exposure may be difficult to differentiate from oxidized flavor (Shipe et al., 1978;

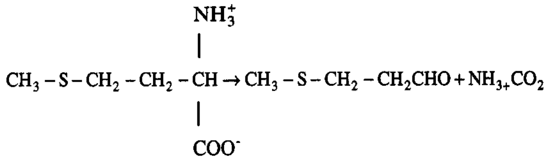
Table 1. Characteristic off-flavors and associated compounds in milk.

Oxidized Flavor	Responsible Compound
Cardboardy (from copper-induced)	Acetone, ethanal, n-hexanal, and C4-C11 monounsaturated aldehydes.
Oily	n-Hexanal, n-heptanal, hex-2-enal, and heptan-2-one
Tallowy	n-Heptanal, n-octanal, n-nonanal, n-heptan-2-one, n-hept-2-enal, and n-non-2- enal.
Painty (butter)	n-pentanal and C_5-C_{10} alk-2-enals.
Cucumber	Non-2-enal.
Metallic	Oct-1-en-3-one
Mushroom	Oct-1-en-3-o1.

Compiled from *Bassette et al. (1986).*

Bassette et al., 1986).

Methional is found to be the major compound responsible for an activated flavor in milk. Strecker degradation plays a role in converting methionine into methional, ammonia, and carbon dioxide:



$$\underset{COO^-}{\overset{NH_3^+}{CH_3-S-CH_2-CH_2-CH}} \rightarrow CH_3-S-CH_2-CH_2CHO+NH_3+CO_2$$

Methionine Methional

Riboflavin and oxygen are needed for this reaction, along with a free amino acid (Allen and Parks, 1975; Kochhar, 1993). Free radicals derived from methionine, methional, and cysteine are found to combine to form methanethiol, dimethyldisulfide and dimethylsulfide (Bassette et al., 1986):

$$CH_3-S.+H \rightarrow CH_3-SH$$

Methanethiol

$$2CH_2-S. \rightarrow CH_3-S-S-CH_3$$

Dimethyldisulfide

$$CH_3-S.+CH_3. \rightarrow CH_3-S-CH$$

Dimethylsulfide

Off-flavors due to light exposure have also been reported in beer. High sunlight intensities or high ultraviolet exposure on supermarket shelves cause "sunstruck" flavor in pale-colored or colorless glass bottled beers. Riboflavin, other flavin derivatives or melanoidines may act as photo-activators (Tressl et al., 1980).

Like dairy products, the photo-induced changes in beer flavor are complex involving photo-oxidation of lipids, photocatalyzed decarboxylation and deamination of amino acids and hydrolysis of the isohumulones. Unlike dairy products, however, beer will take on an initial OF often characterized as being "skunky" (Heath and Reineccius, 1986). This skunky OF is attributed to the photo-catalyzed degradation of the isohumulones in hops. In the presence of hydrogen sulfide from yeast fermentation, a photo-catalyzed reaction occurs at the carbon adjacent to the keto group of isohumulone (Lindsay, 1985). The compound responsible for the OF formed by Photo-degradation of isohumulones is identified as 3-methyl-2-butene-1-thiol (prenylmercaptan). Prenylmercaptan has a threshold of 0.05 ppb in beer. As shown in Figure 1, the 4-methyl-3-pentenoyl - side chain is released during photodegradation and component II (2, 7-dimethyl-2,6-octadiene) and III (4-methyl-2-pentanal) are formed as main constituents (Tressl et al., 1980).

Enzymatic Flavor Changes

Foods contain a variety of enzymes. While many are inactivated by processing or inactive due to inadequate conditions for functioning (e.g., low water activity, temperature, and pH), some foods do contain active enzymes which may cause OFs to develop in the food products. The enzymes most commonly associated with OFs in foods are lipoxygenase, lipase and various proteases (Heath and Reineccius, 1986).

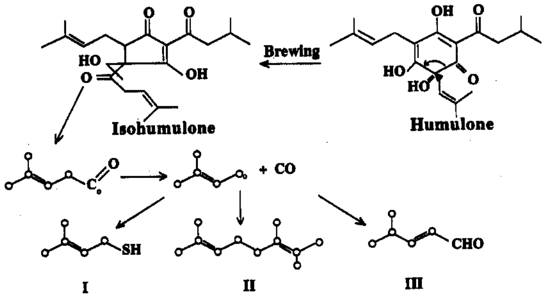


Fig. 1. Photo-degradation of isohumulones in a cysteine model system.

Source: *Tressl et al. (1980) and Lindsay (1985).*

Lipoxygenase (linoleate/oxygen oxidoreductase) catalyzes the hydroperoxidation of polyunsaturated fatty acids and esters containing a 1, 4-pentadiene system. This enzyme initiates lipid oxidation by abstracting a hydrogen radical from the fatty acids. The mechanism of lipoxygenase catalysis by which hydroperoxides are formed and then subsequently degraded to form a variety of secondary products leading to OF follows the typical autoxidation as has been previously described. This enzyme is widely distributed in great variety of plants and its presence in animal tissue has also been found (Rackis et al., 1979; Heath and Reineccius, 1986).

Legumes, especially soybeans, contain substantial amount of lipoxygenase enzyme. The beany flavor of soybeans is believed to be due to lipoxygenase activity in the bean once tissue damage has occurred (Heath and Reineccius, 1986). Determination the flavor of the hydroperoxides of linoleic and linolenic acids due to the activity of soybean lipoxygenase using trained sensory panels, Kalbrener et al. (1974) reported that linoleic acid hydroperoxide was described as predominantly grassy/beany, musty/stale, and bitter. Linolenic acid hydroperoxide was described with a variety of terms with the most predominant description being grassy/beany followed by bitter and astringent.

Lipoxygenase enzyme has been reported to be present in fish skin tisue (Hsieh and Kinsella, 1986). This enzyme can oxidize polyunsaturated fatty acids to produce specific hydroperoxides. These hydroperoxides may then decompose to produce short chain carbonyls to result in fish oxidative OF.

Off-flavors may arise from lipase activity in foods. Lipolyzed flavor is due to the hydrolysis of fatty acids from the triglycerides. Lipolysis can occur slowly by chemical reacitions but enzyme-catalyzed hydrolysis can be very rapid and devastating. Lipolysis may commonly occur in foods but the perception of free fatty acid in foods depends on the length of the fatty acids. Mid - to long-chain fatty acids (C > 12 carbons) are too large to make a significant contribution to either odor or taste. Therefore, the only foods where lipolysis produces significant OF are those which contain short chain fatty acids such as dairy, coconut oil and palm kernel oil products (Barnes and Galliard, 1982; Heath and Reineccius, 1986).

"Soapy" flavor of food products has been reported to be due to the coconut oil free fatty acids. Fritsch et al. (1971) reported that the amount of coconut oil free fatty acid to produce a "soapy" flavor was found to vary with the type of product and the sensitivity of the individual to this type of OF. Coconut oil free fatty acids produced a soapy flavor at a lower level in sweet foods than in salty ones. Soapy OFs were also found in a low moisture food containing coconut oil by the lipase activity of other ingredi ents such as cinnamon.

The milk lipase-catalyzed hydrolysis of milk fat triglycerides causes a common flavor defect described as "rancid", "goaty", "soapy", "butyric", and/or "bitter". Since these flavors are produced by lipase-catalyzed hydrolysis of triglycerides, "lipolyzed flavor" is recommended to denote the lipase induced flavor defects in milk (Shipe et al., 1978; Bassette et al., 1986). Volatile short-chain free fatty acid released by the action of lipase on milk glycerides are responsible for the lipolyzed flavor of milk. These free fatty acids include the C4 to C12 volatile free fatty acids (Bassette et al., 1986).

While food products may become lipolyzed due to indigenous enzymes, the lipase may also be from outside sources. Bacterial activity, spices and some fruits contain lipase which may attack the triglycerides of milk. Pina colada, an alcoholic drink consisting primarily of coconut and pineapple juice, is found to have "soapy" flavor which may be due to pineapple lipase. The pineapple is an excellent source of quite heat stable lipases (Heath and Reineccius, 1986).

Bitterness in foods is an OF that may occur due to enzyme activity. This OF is caused frequently by proteolysis since some peptides and amino acids elicit bitter flavors (Health and Reineccius, 1986). Bitter peptides have been found to produce OF in soy products, zein, casein and cheddar cheese. Bitter peptides in these products are shown in Table 2. Bitter peptides in cultured dairy products are formed by the action of rennet and bacterial proteinases on casein, predominantly β-casein. Bitterness formed is generally dependent upon the total proteinase activity of the starter cultures which is a product of the proteinase activity of the starter strain, and the total starter cell population in the cheese.

Thermally Induced Off-flavor

Many flavor compounds found in cooked or processed foods occur as the result of reactions common to all types of foods regardless of whether they are of animal, plant or microbial origin. These reactions take place when suitable reactants are present and appropriate conditions (heat, pH, and light) exist. The flavors derived from thermally induced reactions may or may not be desirable.

Nonenzymatic Browning

While nonenzymatic browning is very important to the production of desirable flavor, it is also a pri-

Table 2. Bitter peptides identified in protein hydrolysated and cheese products.

Soy globulin hydrolyzed with pepsin:
Arg-Leu, Gly-Leu, Leu-Lys, Phe- Leu, Gln-Tyr-Phe-Leu, Ser-Lys-Gly-Leu.

Zein hydrolyzed with pepsin:
Ala-Ile-Ala, Gly-Ala-Leu, Leu-Val-Leu, Leu-Pro-Phe-Ser-Gln-Leu.

Casein hydrolyzed with trypsin:
Gly-Pro-Phe-Pro-Ile-Ile-Val, Phe-Ala-Leu-Pro-Gln-Tyr-Leu-Lys.

Cheddar cheese:
Pro-Phe-Pro-Gly-Ile-Pro.
Pro-Phe-Pro-Gly-Pro-Ile-Pro-Asn-Ser.
Leu-Val-Tyr-Pro-Phe-Pro-Gly-Pro-Ile-Pro.

Source: *Heath and Reineccius (1986).*

mary source of undesirable flavors in foods.

When food preparations are heat processed or stored for long periods of time, a number of chemical reactions occur. Among these is the Maillard reaction (nonenzymatic browning). The Maillard reaction involves the reaction of an aldehyde (usually a reducing sugar) and an amine (usually a protein or amino acid) in its initial stages. As a result of the initial interaction of sugars and amines, volatile food flavors and aromas ultraviolet (UV) absorbing compounds are produced, and dark-colored polymeric materials arise. The distribution of individual compounds does, however, depend on such factors as availability of precursors, temperature, time, and water activity (Feather, 1985; Lindsay, 1985).

Lane and Nursten (1983) investigated the variety of odors produced in Maillard model systems in the range of 100-200 °C. Glucose was heated with the following amino acids: alanine (ala), leucine (leu), asparagine (asn), aspartic acid (asp), cystine (cys), cysteine (cys_2), glutamic acid (glu), glutamine (gln), glycine (gly), histidine (his), and lysine (lys) being in the form of their monohydrochlorides. Generally, they found that the aroma become stronger and more unpleasant, aldehydic, andburnt within creased temperature and time. The aromas obtained from some amino acids were reported to possess a consistent note throughout the temperature range investigated, as shown in Table 3.

Generally, flavor volatiles are formed in browning reactions from the interaction of α-dicarbonyl compounds (intermediate products in the Maillard reaction) with amino acids through the Strecker degradation reaction. Although some flavor compounds are acyclic, many are heterocyclic, with nitrogen, sulfur, or oxygen substituents in common. Some heterocyclic compounds found commonly in flavor compounds associated with heating or browning of foods are pyrazine, pyridine, trithiane, γ-pyrone, thiophene, furan, thiazole, trithiolane, pyrrole, oxazole, 3-thiazoline and tetrahydrothiophene (Lindsay, 1985). Some of these heterocyclic compounds are responsible for OFs in foods. For example, 2, 5-diethylthiazole and 2, 5-dimethylthiazole responsible for musty, earthy flavor, and 4-methyl-5-ethylthiazole responsible for nutty, green earthy flavor (Taranishi and Buttery, 1985).

Heated flavors

The effect of heat treatment on food flavor is generally recognized. The kind and intensity of flavor depends on time and temperature of treatment.

In meat canning, number of volatile compounds are produced by aminoacid and protein degradation. Oxidative compounds are also formed from lipid oxidation and degradation. Sulfur compounds, carbonyls, alcohols, and substituted furans are found to be responsible for "retort" flavor in canned meat products (Bailey et al., 1980). "Catty" odor in canned meat is reported to be due to 4-methyl-4-mercaptopenta-2-one which is formed from the reac-

Table 3. Aromas obtained from some amino acids and glucose.

System	Aroma
Ala + glucose	caramel
Ala alone	burnt
Leu + glucose	aldehydic
Asn alone	ammoniacal
Cys + glucose	puffed wheat, sugar puffs
Cys_2 + glucose	puffed wheat, sugar puffs
Gln + glucose	chocolate
Gln alone	ammoniacal
Gly + glucose	caramel and burnt
Gly alone	burnt
Ile alone	fruity
Lys + glucose	bread, cakes, etc.
Met + glucose	potatoes
Phe + glucose	chocolate
Phe alone	floral
Pro + glucose	nutty
Ser alone	meaty
Thr + glucose	burnt
Thr alone	meaty
Tyr + glucose	chocolate
Val + glucose	aldehydic

Source: *Lane and Nursten (1983).*

tion of hydrogen sulfide, from meat protein, with mesityloxide, from acetone in lacquer (Bailey et al., 1980).

Off-flavors may be produced by heat processing of fluid milk, These heat-induced flavors have been classified into four types: cooked or sulfurous, heated, caramelized, and scorched (Shipe et al., 1978; Bassette et al., 1986). Hydrogen sulfide contributes significantly to the cooked flavor. A rich or heated note is perceptible after the sulfurous dissipates. Heat-induced diacetyl, lactones, methyl ketones, maltol, vanillin, benzaldehyde, and acetophenone are reported to be responsible for heated flavor in milk. Nonenzymatic browning causes caramelized flavor in retorted and autoclaved milk. A scorched flavor can result from exceptionally large amounts of "burnt on" in a heat exchanger. This flavor also occurs in dry milk powders subjected to abnormally high temperature processing (Shipe et al., 1978; Bassette et al., 1986).

In summary, the primary role of flavors in food processing is to make the food palatable. Many food products may become unattractive for consumption due to biochemical and chemical reactions of food products during preparation, processing and storage. Off-flavors of fat and oil products and food containing fat and oil normally described as "oxidized" and "rancid" flavors are caused by lipid oxidation reactions with the final products of aldehydes, ketones, acids, alcohols, hydrocarbons, lactones and esters being responsible for undesirable flavors. OFs of foods can occur via photo-catalyzed reactions. The two most commonly photo-induced OFs are found with beer and fresh milk products. Isohumulones derived from hops in brewing produce a compound, prenylmercaptan, upon sunlight exposure causing skunky flavor of beer bottled in pale-colored or colorless glass. "Burnt feather" flavor of fresh milk due to photo-degradation is significantly caused by methional from the Strecker degradation of methionine along with minor components such as methanethiol, dimethyldisulfide and dimethylsulfide.

After food processing, active enzymes in foods may remain and cause OFs to develop in food products. The enzymes most commonly associated with biochemical reactions in foods and cause OFs are lipoxygenase, lipase and various proteases producing oxidative, grassy/beany, fishy, soapy and bitter flavors to many food products. Processing conditions such as heat and pH applied to food products can also cause OFs. Thermal processing may cause both desirable and undesirable flavors. The latter flavors may cuase devastating effect to food products.

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