OFF-FLAVORS IN FOODS : 1. ENVIRONMENTAL CONTAMINATION

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Abstract

Off-flavor in food may be defined as any flavor which is not normally associated with that food in question. This flavor may be unacceptable in any food, since it is completely alien to the palate, or it may be simply a flavor which is not present in that particular food. Basically an off-flavor in a food can either be derived from reactions within foodstuff or it may be due to incidental contamination of the food from environmental sources. The air is an excellent carrier for a wide range of compounds which can be deposited on a sensitive food product. Water which is used in the factory may carry undesirable compounds which can be absorbed onto food during preparation and processing. Water pollution is frequently linked with various off-flavors in fish and fishery products. Packaging materials, disinfectants, pesticides, detergents, preservatives, and other additives are also frequent sources of taints in foods.

Introduction

Flavor is one of the most importat quality attributes of foods. Flavors of food can be changed during preparation, processing, and storage and they can be desirable, undesirable, of questionable consequence, or a combination thereof. These off-flavors (OFs) may be due to incidental contamination of the food from environmental sources or may arise from the food itself. Genetics, diets of plants and animals, and microorganisms also play very important roles in food off-flavors.

Attention here will be given mainly to those flavors categorized as undesirable due to environmental contamination. The main sources of taints giving rise to OF due to environmental contamination will be discussed including air, water, packaging materials, and other sources such as disinfectants, pesticides and detergents.

Airborne Sources

The air can be a very effective means of conveying an OF to a food product. Airborne contamination often is exceedingly difficult to identify as the source of product contamination due to the fact that the OF cannot be reproduced in the product for studying. This is contrasted with an OF arising from lipid oxidation. The oxidized OF can be reproduced and subjected to analysis and eventual correction. The airborne OF may occur randomly, depending on the production of the offending source of OF, wind direction and speed, production schedule of the food processing plant, etc. The offending chemicals also typically have a very low sensory threshold so they are difficult to isolate and identify by established analytical techniques (Heath and Reineccius, 1986).

Baked products are generally found to be susceptible to the OF of the airborne sources. The products are baked and then cooled open to the air environment. While the OF may enter the products during cooling, it may also be a problem once packaged. Goldenberg and Matheson (1975) complied the OF they observed in the products of Marks and Spencer (Department Store in London) due to airborne contamination as shown in Table 1. There is a variety of sources that may be involved in the production of OF. The most common source appears to be a chemi-

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Table 1. Off-flavors due to airborne contamination.

Food	Contaminant	Method of Transmission
Biscuits	Herbicides	Carried by wind from near by herbicide (chlorophenols) factory (3-5 miles).
Biscuits	Tar	Tar boiler gave off smell through gaps left in wall.
Chocolates	"Aniseed taste"	"Aniseed-type" odors airborne from adjacent factory.
Cake	"Catty off-flavor"	Airborne contaminant produced by interaction of ketones and sulfur compounds in chemical factory in another town 20 miles away.
Wrapped bakery	Diesel oil fumes	May occur in depots, warehouses and loading bays. Diesel oil fumes can penetrate some types of wrapping materials and be absorbed by foods, especially "fatty" foods. May also be caused by forklift trucks driven by diesel oil.
Wrapped bakery and confectionary	Petrol vapors	May occur in depots, warehouses and loading bays, where petrol has been spilled.
Cakes, biscuits, meat pies, chocolate		Off-flavors due to paints used in loading stock meat pies, chocolate rooms and production areas.
Biscuits	Oxidized oil	Oil used for spraying savory biscuits and other products overheated through failure of heater thermostat. Oil oxidized in metal tank with "fishy" off-flavor. Products uneatable.

Source : *Goldenberg and Matheson (1975).*

cal manufacturing facility. The chemical plant may be producing offensive odorants (e.g., chlorophenols) or may be contributing compounds which undergo secondary reaction in foods to produce the OF.

Chloroanisoles have been found to be responsible for musty OF in eggs and boilers (Bemelmans and Noever de Brauw, 1974; Curtis et al., 1974). These chemicals generally have been transferred to the food product via air contamination. Engel et al. (1966) showed that certain batches of wood shaving used as bedding in cages gave rise to a musty taint in both eggs and boiler meats. The active substances responsible, which was isolated and identified as 2, 3, 4, 6-tetrachloroanisole, was not present in all batches of shavings and was confined to the superficial layers of wood. When feeding trials were conducted with the tetrachloroanisoles, the musty taint resulted in both eggs and boiler meat. Bemelmans and Noever de Brauw (1974) reported that the tainted eggs and boilers were found to contain tri- and tetrachloroanisoles, while the eggs also contained pentachlorophenol.

The chloroanisoles were formed by microbial methylation of chlorophenol (antisapstain agent) present as a wood preservative on shavings used as litter. Curtis et al. (1974) reported that at least three of the fungi found in poultry litter could effect this methylation. These fungi were *Scopulariopsis brevicaulis*, *Aspergillus sydowi*, and *Penicillium crustosum*. The chloroanisoles are very volatile and thus birds can absorb the compounds via lungs and ventral skin surfaces when roosting on the litter.

Transmitted flavors due to air contamination are also found in milk. The flavors are discribed as "cowy flavor" and "barny flavor" (Bassette et al., 1986; Shipe et al., 1978). Cows flavor is usually associated with barn odors and poor ventilation. Cows suffering from ketosis or acetocemia produce milk with a "cowy like" odor. The odor or the breath of the affected cow was found to be similar to that of its

milk. In severe cases, the odor was so strong that it was transmitted to the milk of neighboring cows when there was inadequate ventilation. Barny flavor is also associated with an inadequate ventilation. Cows inhale odors from damp, dirty barns and transmit the odors to milk. However, the nature of barny flavor has not been characterized or distinguished clearly from cowy flavor.

Waterborne sources

Chlorine is used extensively for germicidal treatment of water used in food processing plants and in water sprays applied to food processing and handling equipment. The amount of chlorine used in water could have a significant detrimental effect on flavor of food products. A second means by which OF may enter food supply from tainted water is via absorption of OF by fish and shellfish.

Goldenberg and Matheson (1975) summarized OF due to waterborne contamination as shown in Table 2.

The major cause of OF in food products was found to be chlorophenol which was derived from the chlorinated water used for cooling lithographed cans and phenol-based lithographic paint. The chlorophenol was also formed from chlorine in the main water and chemicals used for boiler water treatment.

Chlorinated water has been used in preparation of fruits and vegetables, such as washing, trimming, cutting, size grading, and dicing. Residual chlorine may cause "chlorine" off-odor in the products. Weckel et al. (1977) employed various amounts of chlorine to raw, cut, whole kernel sweet corn before heat processing. Sensory evaluation of canned sweet corn samples showed that experienced panelists could detect OF in corn treated with 25 ppm chlorine. A laboratory sensory panel was less critical, and found OF noticeable between 35 and 45 ppm chlorine.

Off-flavors have been found in fish and shellfish due to water contamination. Fish are very susceptible to absorbing chemicals from their environment resulting in objectionable OF. The OF may come from water pollution or bacterial growth in the water (Heath and Reineccius, 1986; Reineccius, 1979). Off-flavors may also occur due to the injection of pollutants from the land. Vale et al. (1970) and Shipton et al. (1970) reported a "kerosene-like" taint in mullet due to water pollution. Areas where tainted fish were caught generally had docks, sewage outlets or heavy industry. The "kerosene" taint was found to be associated with hydrocarbons form polluted water. The close compositional relationship between the tainted fish oil and the kerosene was completely established by mass spectrometric analyses. Identical hydrocarbons in both tainted fish oil and kerosene were n-tetradecane, naphthalene, 2-methylnaphthalene and 1-methylnaphthalene.

While water pollution is not a main problem, the growth of bacteria or tainted algae in the water may cause OF problems. Actinomyces in water has been found to cause "earthy" taint in water. This "earthy" taint in water containing odor-causing algae is found to develop an objectionable "muddy" taints. Some algae are known to emit characteristic odors and tastes. Such algae are Anabaena, Ceratium and Pediastrum. The muddy taint is found to associated with 2-pentanone and dimethyl sulfide (Reineccius, 1979). Blue green algae, *Symploca muscorum* and *Oscillatoria tenuis* are reported to produce "earthy-musty" OF by producing mainly geosmin (1,10-trans-dimethyl-trans-(9)-decalol) in water causing OF in fish (Lovell and Sackey, 1973).

Packaging sources

The materials used to manufacture packages has found to be the principal source of OFs in packaged foods. Glass is the only food packaging material that will not potentially contribute an OF to foods. Since food is not sold in glass ampoules, its needs a closure of some type which could contribute an OF to food. Some occurrences of food contamination by packaging materials and resulting in OF as compiled by Heath and Reineccius (1986) are presented in Table 3. Most often the OFs may be related to the production of packaging materials (e.g., styrene monomer), trace contaminants in the packaging materials (e.g., ethylbenzene in plastics or residual inks in recycled papers), solvents used in inks to print on food package or solvents in adhesives.

Plastic materials used for food packaging has posed problems of OFs in foods. Most plastic materials in food packaging are inert. Nevertheless, polymerization causes the formation of low molecular weight constituents capable of migrating into foods

Table 2. Off-flavors due to waterborne contamination.

Food	Contaminant	Method of Transmission
Canned fruits and canned vegetables	Chlorophenols	Chlorinated water used for cooling lithographed cans sub sequently used as boiler feed water. Chlorine reacted with phenol-based lithographic print. Resulting chlorophenols volatized in steam, subsequently used for heating brines and syrups by direct steam injection.
Canned products	Compounds used in boiler-water treatments	Can cause "off-flavors" if live steam is used for heating.
Spray-dried cheese powder	Disinfectant ?	Source of "off-flavor" water borne. Problem solved by use of activated carbon water filter.

Source : *Goldenberg and Matheson (1975).*

(Anonymous, 1988). Plastic films used in food packaging normally have characteristic odors. For example, polyester films may have terephthalic acid which has a paper-like odor; polyethylene films, a burnt and phenolic odor (Bassette et al., 1986). Styrene has shown to be present in packaging polymer as unreacted residual monomer, migrates into foodstuff during storage. Styrene has a characteristic flavor of plastic-like chemical odor or taste with threshold concentration as low as 0.005 ppm (Ramshaw, 1984). Large number of additives used in the polymer industry may also be transferred to food forming OFs. Processing of polymers at considerably high temperatures may lead to their partial degradation and to the appearance of oxidative products capable of further decomposition. Small amounts of solvents used during lamination, coating, or lacquer application may remain in the material (Peled and Mannheim, 1977).

Goldenberg and Matheson (1975) reported OF of orange and lemon drinks due to plastic stabilizer containing mercaptide group. When the plastic resin mix containing this stabilizer was mold by heat into bottles, the mercaptide group present would apparently split off by the nascent HCI formed before it could be neutralized by the metal stabilizer and thus caused the OF .

Polyethylene bag and cardboard box are found to produce noticeable OF in UHT milk. It is possible that the sizing glues and components in the carboard are absorbed through the polyethylene film (Bassette et al., 1986). Prize in cereal industry is used in the form of multi-colored graphics on plastic-foil constructions and various coupons and premiums as packaging inserts. The volatiles in these inserts, if not controlled, can import undesirable flavors to packaged foods. Heydanek, Jr. et al. (1979) investigated the transmission of simulated volatile compounds (styrene, toluene, n-pentanal and 2-butanone) through overwrap films; conventional polyethylene, polypropylene, or polyvinylidene chloride (PVDC) coated cellophane, which were used to prevent flavor alterations from occurring when various toys and coupons were inserted in the ready-to-eat cereals. A polyester/PVDC/polyester film was found to be the most absolute barrier to the premium and coupon volatiles.

In some cases the contamination responsible for the OF is a normal constituent of the packaging system but has not been adequately removed by the processing such as lubricants used in can manufacture. Rolling lubricants containing polyunsaturated and/or esters employed to produce two-piece cans have been found to cause OFs in beer packaged in the can. The OFs result when the fatty acids or esters are oxidized producing fatty aldehydes having carbon chains of C7-C9 some of which produce potent flavor influence on beer. Mineral oil has been found in some rolling lubes. It appears to be naphthenic in nature; its flavor impact is kerosene like, although it resembles the fatty aldehydes when it is present in beer at low concentrations. Its

Table 3. Off-flavors in foods due to packaging materials.

Food	Packaging Material	Source and Method of Transmission
	Paper	
Cakes, biscuits	Chipboard	Off-flavor due to either preservatives added to repulped waste paper or compounds in print in waste paper.
Doughnuts	Coated paper	Inadequate removal of hydrocarbon divider cellophane solvents used to apply divider coating overwrap
Gold cereals	Glassine liner coupons	Residual solvents in inks.
Chocolate cakes, yogurt containers confectionery	Coated paper-print on one side	Inadequate "curing" of inks used in printing
	Plastic	
Orange and lemon drinks	PVC bottle	Mercaptide stabilizer used in PVC split off in processing of beverage.
Chocolate and lemon cookies	Polystyrene trays wrapped in printed cellophane	Residual styrene monomer.
TV dinners	Polystyrene trays	Residual styrene monomer.
	Laminates	
Fruity soft drinks	Polyester/aluminum foil/polyethylene laminate	Residual toluene in laminate adhe- sive-faulty drying process.
	Metal-Paper	
Refrigerated doughs	Paper tube with metal caps	Residual hydrocarbon solvents in triglycerides used to lubricate metal caps to facilitate packaging operation.
	Metal	
Canned pork products	Lacquered can	"Catty" OF due to use of lacquer to cover side seam to prevent blackening. Solvent used contained mesityl oxide which reacted with sulfur compounds in food to cause OF.
Refrigerated milk beverage	Lacquered can	Trace contaminant (isophorone) in solvents used in lacquer which did not "flash off".
Beer	Can	Lubricants used in can manufacture.

Source : *Heath and Reineccius (1986).*

potency is close to that of 2-nonenal (Hardwick, 1985).

Stale-like flavor is also observed in beer contained in cans coated with an insufficient thickness of epoxy resin liner. Can coatings can act as membranes allowing the solutes in beer pass through them causing an oxidation of heavy metal of the tin plate of the can with the evidence of a few spots of oxidized metal appeared below the epoxy coating. An oxidized metal formed such as iron oxide may catalyze an undesirable reaction producing stale-like flavor. The anomalous beers also form little forth when poured into a glass (Cabezudo et al., 1986). Canned meats have been found to have a "catty flavor" (Goldenberg and Matheson, 1975). This flavor is apparently caused by the interaction between mesityl oxide present as an impurity in the solvent used to dissolve the lacquer with SH groups from proteins.

A variety of packaging materials made from cellulose fibers have been successfully used for the transportation and storage of nonhermetically sealed foods. As examples, in many countries, jute sacks are used for cereal grains and flours, multi-wall paper sacks for powdered milk products and cocoa powder, and fiberboard carbons for biscuits and dried fruits. These fibrous packaging materials are found to contain chlorophenols and chloroanisoles causing "disindectant" and "musty" OF in foods, respectively. Materials used in manufacturing of sacks and cartons contained 2, 6-dichlorophenol and 2, 4, 6-trichlorophenol below 1 mg/kg could produce unacceptable levels of "disinfectant" OF in some foods. At lower concentrations approaching 100 mg/kg, 2, 4, 6-trichlorophenol and 2, 3, 4, 6-tetrachlorophenol could produce even greater problems, for if the packaging materials absorb moisture from the surrounding environment these compounds could be converted into the very strongly flavored chloroanisoles which readily migrate into food stuffs (Whitfield and Last, 1986).

Chloroanisoles have also been found to cause an unpleasant, musty OF in wines bottle with cork closure. Buser et al. (1982) reported the investigation of 2, 4, 6-trichloroanisole as the main component responsible for the cork taint. Using high-resolution gas chromatography with direct odor characterization and combined with mass spectrometry, they found that part per trillion concentrations of this compound were responsible for the OF. At it has been mentioned above that chloroanisoles were identified as an OF component in eggs and chicken broilers (Bemelmans) and Noever de Brauw, 1974; Curtis et al., 1974; Engel et al., 1966). In that case, the chemical was traced to chlorophenols containing feed and litter with chloroanisoles formed through microbial action. In the wine case, the chloroanisoles were presumed to originate from the chlorination of lignin-related compounds during chlorine bleaching in the processing of the cork (Buser et al., 1982).

Corks contaminated with guaiacol, probably during shipping or storage before reaching the winery, have been found to be responsible for a taint in bottled wine (Simpson et al., 1986). Guaiacol is found to be a degradation of lignin. Microorganisms, Streptomyces species, are also capable of degrading vanillin and vanillic acid to guaiacol. Guaiacol has a sweet, burnt aroma and smokey taste. Simpson et al. (1986) reported its aroma threshold of 0.020 mg/l found in a dry white wine.

Miscellaneous sources

The miscellaneous sources of OFs due to environmental contamination include disinfectants, pesticides, detergents, preservatives, and additives. These categories occasionally contribute to OFs in foods due to inadequate care in their application. The summary of OFs observed at Marks and Spencer (Table 4) by Goldenberg and Matheson (1975) provides a useful illustration of how these chemicals may enter a food and produce an OF.

Off-flavors in milk caused by contaminatin of milk with chemicals associated with cleaners, sanitizers, and disinfectants are described as chemical flavors. The frequent contaminants are chlorine and iodine. Phenolic compounds from disinfectant and some weed killers also are found occasionally in milk and cause OFs. A chlorophenol flavor has been found in milk and has been attributed to the products of a reaction of chlorine sterilizing reagents with phenols which were in water supply. Chemical flavors may be transferred to milk from returnable plastic milk bottles which have been misused as containers for gasoline, disinfectants, pesticides, herbicides, etc. (Bassette et al., 1986; Shipe et al., 1978). Soapy flavors have been found in butters containing low concentrations of soapy-flavored free fatty acids, es-

Table 4. Off-flavors due to disinfectants, pesticides and detergents.

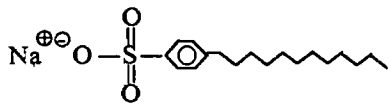
Food	Packaging Material	Source and Method of Transmission
Cake	Chlorophenol	Due to sultanas, contaminated on board ship by chlorophenol. On a previous voyage, holds had been used for cargo of herbicide containing 0.5% chlorophenol as impurity. Hold washed out but timber still impregnated. Finally timber parts had to be destroyed.
Spray-dried milk powder	Chlorophenol	"Off-flavor" of chlorophenol type: waterborne; use of activated carbon eliminated off-flavor.
Canned peas	Chlorophenol	Peas transported to cannery in open steel troughs on newly tarred road. Peas contaminated by tar covered stones flying up from road. Peas then blanched in chlorinated water and chlorophenol formed.
Canned raspberries	Pesticide	"Catty" off-flavor may have been due to mesityl oxide in ketonic solvent.
Pork	Disinfectant	Preservative spraying with disinfectant in slaughter house against spread of swine vesicular disease.
Tomatoes	Pesticide	"Off-flavor" of chlorophenol type
Smoked bacon	Disinfectant	Hypochlorite used as sterilizing agent: excess used and inadequately washed off Chlorine combined with phenolic compounds present in smoked bacon to give chlorophenol. Bacon uneatable. Sterilizing agents containing chlorine should not be used where handled, unless special precautions are taken.

Source : *Goldenberg and Matheson (1975).*

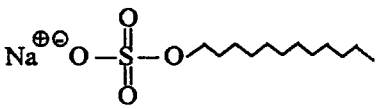
pecially decanoic acid (C10) and dodecanoic acid (C12). Woo and Lindsay (1982) reported the causes of this objectionable flavor in butters were anionic detergents. Alkylbenzene sulfonates are widely used as sanitizing agents for bathing mammary glands of the cows at milking and for sanitizing dairy equipment. Similarities in chemical features of some of the common anionic detergents and soapy-flavored free fatty acids are shown in Figure 1.

Sodium hypochlorite, a common sanitizing solution used to reduce number of microorganisms has been found to produce a taint flavor in maple syrup. Sodium hypochlorite is commonly used to flush tree tapholes, sap collection plastic lines, storage tanks, and vacuum reservoirs, followed by rinsing with water or with sap during the first sap flow. If the collection system is not properly used, sodium hypochlorite may accumulate in the maple sap. Morsilli et al. (1985) reported the salty OF detected in maple syrup due to the presence of high levels of sodium chloride. The OF was called undefined flavor.

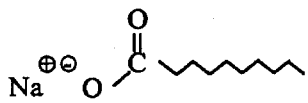
Food preservatives are commonly employed in food products to inhitit growth of microoganisms. The residues of food preservatives could possibly cause a taint in food products. Sulfur dioxide (SO_2) is frequently used to inhibit yeast and bacterial growth



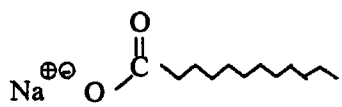
Sodium dodecylbenzene sulfonate



Sodium dodecyl sulfate



Sodium decanoate



Sodium dodecanoate

Fig. 1. Structures of anionic detergents and soapy flavored free fatty acids.

in food products. Ingestion in high levels of this substance, however, is suspected of being toxic. To reduce the quantities of SO_2 used in wine making, sorbic acid has been used in conjunction with SO_2 to reduce quantity of yeast. De Sosa et al. (1983) reported the treatments of sparkling wine with sorbic acid gave rise to the formation of ethyl sorbat that increased linearly during storage. This compound smelled of pineapple-celery and was responsible for an adverse flavor effect. The formation of products from bacterial metabolism of sorbic, particularly of 2-ethoxyhexa-3, 5-diene, which is responsible for the geranium-like OF, was not observed in their experimental conditions. The use of iodized salt and lemon cake mix has been found to cause a "medicinal" OF in cake. Sevenants and Sanders (1984) investigated the cause of this OF and found that iodocresol was responsible for this taint in the cake. Iodocresol was formed from the reaction of iodine in iodized salt used with *r*-cresol (a natural, approved flavor ingredient) in lemon flavor. This medicinal compound was found to anosmic, that is, it did not elicit a response for some people due to the lack of certain receptor sites in the olfactory system (Sevenants and Sanders, 1984).

Summary

In summary, flavors of foods could be regarded as either acceptable or unacceptable. Off-flavors usually are defined as unacceptable or in question. Environmental contamination is categorized as one of the sources that can cause off-flavor in food products. Environmental contamination is an intentional, incidental occurrenc in food preparation and processing. Taints from air, water, packaging materials, disinfectants, cleaning agent and pesticides may give rise to off-flavors to foods that could unfit for consumption.

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