

QUALITATIVE AND QUANTITATIVE ASPECTS OF TRACE VOLATILE COMPONENTS IN IRRADIATED FOODS AND FOOD SUBSTANCES

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I. INTRODUCTION

The irradiation of foods and food substances has been shown to result in the formation of trace amounts of a large number of volatile compounds. When the production of these compounds, especially in meats¹⁻⁷, was first discovered several years ago, the chemist was concerned primarily with the effect these components might have on the flavor of the product. More recently, interest has shifted to the role that such trace components may play in the wholesomeness of irradiated foods.

Irradiation is not the only process that results in the formation of trace volatile compounds, however, and a large number of studies (see appended bibliography) of the volatile components in foods that may be related to flavor, have shown that oxidation, pyrolysis, and enzymatic action likewise result in the formation of hundreds of components that may be found in p.p.m. quantities or less. Current results provide greatly improved quantitative data. A detailed consideration of both the qualitative and quantitative aspects of these volatile compounds found within a wide spectrum of foods and food substances has been undertaken to try to correlate the great mass of analytical data which has become available in the last decade, to see if any comparisons may be adduced which relate the composition of trace volatile components in irradiated products to those found in more familiar foods.

II. TECHNIQUES

The great bulk of data now at our disposal has been derived mainly from analyses employing combined gas chromatographic and mass spectrometric methods. A schematic diagram of the analysis system employed to determine the composition of the trace volatile compounds in a food is shown in Fig. 1. The

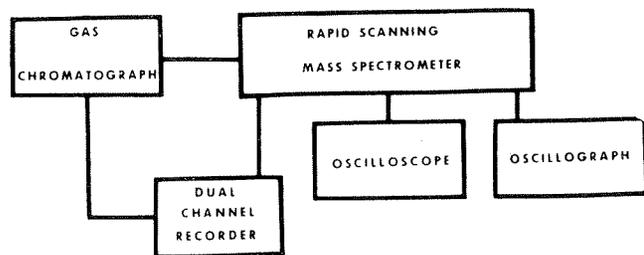


Fig. 1. Block diagram of combined gas chromatograph/mass spectrometer analysis system.

system has been used to study not only irradiated meat and other irradiated meat substances such as the fat, protein, triglycerides, polypeptides and so forth, but also a wide variety of other foods such as coffee, cheese, fish, cocoa, onion, cabbage, and eggs. Many other workers⁸⁻¹⁶ have likewise used combined gas chromatography/mass spectrometry techniques to study the volatile compounds in a host of other foods. Most of these studies have been primarily qualitative, however, and have utilized the system only to separate and identify the components isolated from the food.

It is also important to have quantitative information, and if properly contrived, the analysis system can provide data on how much of each component is present. This capability is indicated in the bottom line on the system diagram which shows some of the output devices of the mass spectrometer. The oscilloscope and oscillograph are used to display the mass spectrum. It is this output, of course, which is used to identify the eluates from the gas chromatograph. Most modern mass spectrometers can also display the total ion current and if this output is recorded on a strip chart recorder, or preferably on a digital integrator, it will provide a quantitative analysis.

The analyst has the alternative in a system of this kind to use an auxiliary gas chromatographic detector such as a flame ionization detector, but the variability in response of the FID may create some difficult calibration problems when dealing with mixtures of unknown compounds. The problem is illustrated in Fig. 2, which shows a comparison of a chromatogram obtained with a flame detector with that of the mass spectrometer total ion current. Although there are many similarities, a careful examination reveals that there are several compounds whose apparent response in the flame is quite different from the total ion current output.

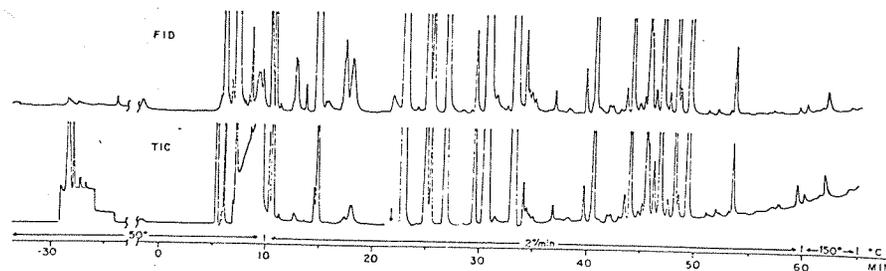


Fig. 2. Comparison of total ion current output from mass spectrometer with flame ionization detector of gas chromatograph (from ref. 24).

There are some components as seen on the left in the early part of the chromatogram which do not respond at all. Problems in recording the total ion current due to the presence of large amounts of diluent such as helium or air, or of large peaks due to solvent, water or carbon dioxide, or of baseline drift due to column bleed, are, in most cases, easily overcome in the mass spectrometer by adjusting various operational parameters or employing special gating techniques to select or remove the contribution of certain ions from the output signal.

The most important consideration for using the mass spectrometer total ion current output for measuring the quantitative distribution of components in the gas chromatographic eluate, is the uniformity of response factors within an homologous series and among various compound types. The relationship of the total ionization of an organic compound (under conditions of electron bombardment in a mass spectrometer ion source) to its size and type is shown in Fig. 3. The total ion current per microgram of component is plotted as a function of carbon number for the members of several commonly encountered types of compounds. In general, there is only a small variation on a relative basis from com-

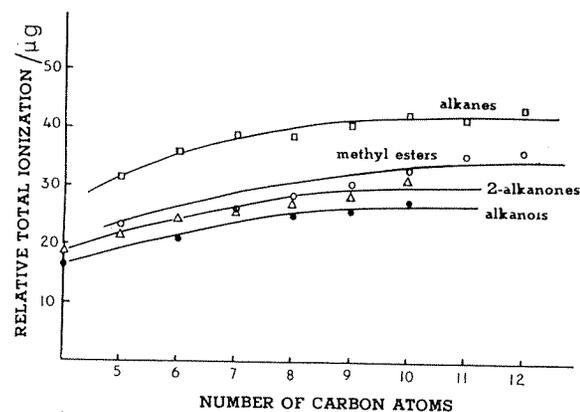


Fig. 3. Total ionization of various homologous series of organic compounds as a function of carbon number.

pound type to compound type, and within the homologous series, only the lower molecular weight members show a slight deviation. The corresponding calibration graphs for one such series, namely, the alkanes, is seen in Fig. 4.

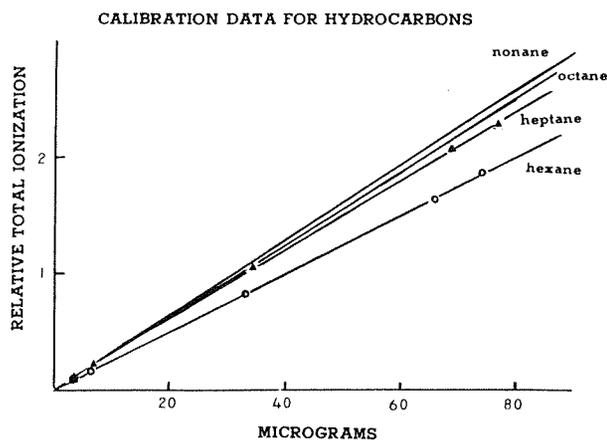


Fig. 4. Calibration graph for the amount of various alkanes as a function of their mass spectrometer total ionization current.

The details of the quantitative aspects of combined gas chromatographic/mass spectrometric analysis, including the application of correction factors where necessary, as well as all the other important parameters such as isolation and recovery of components in the sampling procedures, the selection and operation of the chromatographic columns, the interfacing with the mass spectrometer, and so on, have been the subject of current reports^{17,18} and a recent review¹⁹. A typical analysis is illustrated in Fig. 5 which shows a mass spectrometer total ion current chromatogram of the trace volatile compounds isolated from irradiated chicken. On the left is the corresponding print out of the peak areas from the digital integrator. The most abundant peak is No. 33 (which is the second highest, but has the largest area) corresponding to 350,000 counts. The smallest is No. 49 which can hardly be seen on the strip chart recording, but which registered 70 counts on the integrator. The range of component concentration in this analysis was therefore about 5,000 to 1. The overall range of linear response in the mass spectrometer is about 10,000 to 1 and the nominal sensitivity for detection, that is, to provide a usable mass spectrum, is less than a microgram.

III. QUALITATIVE COMPARISONS

The elegance of the combined gas chromatographic and mass spectrometric analysis method is well appreciated and it is unnecessary to elaborate upon its

QUALITATIVE COMPARISONS

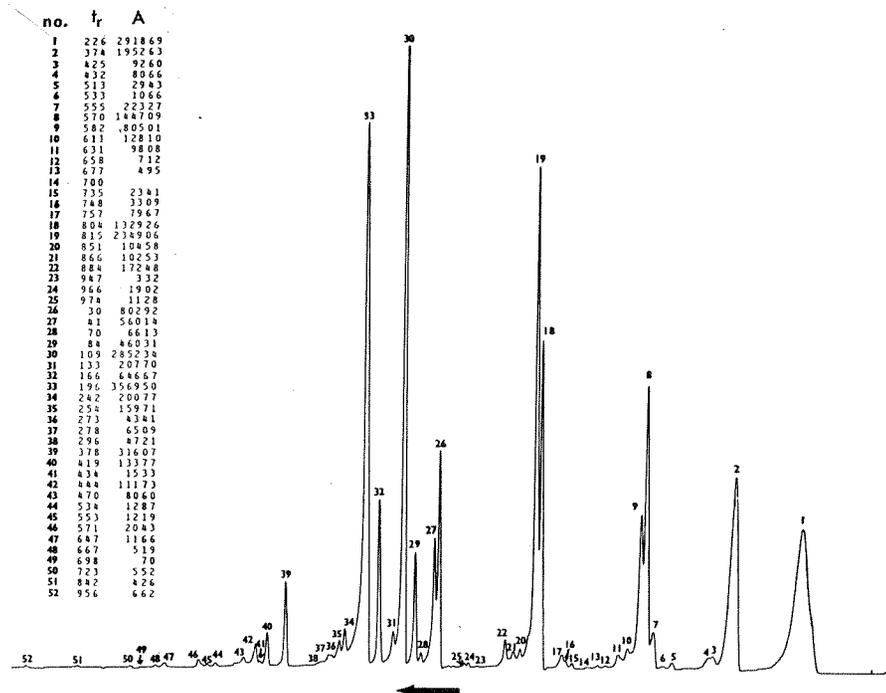


Fig. 5. Total ion current chromatogram from mass spectrometer of volatiles from irradiated chicken. Inset shows reproduction of paper tape output from printer of GC digitizer (ref. 19).

efficacy as an analytical tool. It is extremely important, however, to appreciate the wealth of information it has provided over the years, and in particular to compare the nature of the trace volatile compounds found in irradiated foods with those found in other foods.

A rather extensive compilation of the trace volatile compounds found in irradiated meats was presented before this division on the occasion of the symposium in 1965 on the radiation preservation of foods. Actually there were two papers^{5,6} that were concerned with volatile compounds, both of which are published in the proceedings of the symposium which have appeared in the ACS Advances in Chemistry Series as No. 65. Subsequently, Nawar has published several papers^{7,20,21} contributing still further to the list of compounds to be formed in beef and pork fats and in triglycerides, and Angelini and co-workers have recently presented two papers^{26,27} before the IFT dealing with the irradiation-induced volatile compounds in chicken and in haddock.

This work is summarized in Table 1. The compounds found are indicative of the components that are characteristically found in whole meats, such as beef, pork, mutton, lamb, veal, and chicken, and in general these compounds

TABLE 1

COMPOUNDS IDENTIFIED IN VARIOUS IRRADIATED MEATS AND ASSOCIATED SUBSTANCES
(Data from refs. 4, 5, 7, 25-27)

	Beef ^a	Veal ^a	Mutton ^a	Lamb ^a	Pork ^a	Chicken ^b	Haddock ^c
<i>n-Alkanes</i>							
Methane	S	S	S	S	S	S	
Ethane	M	M	M	M	M	T	
Propane	M	M	M	M	M	-	
Butane	M	M	M	M	M	-	S
Pentane	M	M	M	M	M	S	M
Hexane	M	M	M	M	M	S	S
Heptane	M	M	M	M	M	S	S
Octane	M	M	M	M	M	S	T
Nonane	M	M	M	M	M	T	
Decane	M	M	M	M	M		
Undecane	M	M	M	M	M		
Dodecane	M	M	M	M	M		
Tridecane	M	M	M	M	M		
Tetradecane	M	M	M	M	M		
Pentadecane	L	L	L	L	L		
Hexadecane	M	M	M	M	M		
Heptadecane	L	L	L	L	L		
<i>1-Alkenes</i>							
Ethene	S	S	S	S	S		
Propene	S	S	S	S	S		
Butene	S	S	S	S	S		T
Pentene	S	S	S	S	S	T	T
Hexene	S	S	S	S	S	T	T
Heptene	S	S	S	S	S	S	T
Octene	S	S	S	S	S	T	
Nonene	S	S	S	S	S		
Decene	S	S	S	S	S		
Undecene	S	S	S	S	S		
Dodecene	M	M	M	M	M		
Tridecene	S	S	S	S	S		
Tetradecene	L	L	L	L	L		
Pentadecene	M	M	M	M	M		
Hexadecene	L	L	L	L	L		
Heptadecene	L	L	L	L	L		
<i>1-Alkynes</i>							
Decyne	T	-	T	-	T		
Undecyne	T						
<i>Dienes</i>							
Tridecadiene	T	-	-	-	T		
Tetradecadiene	S	-	-	-	M		
Pentadecadiene	S	-	-	-	S		
Hexadecadiene	S	-	-	-	L		
Heptadecadiene	M	-	-	-	L		

QUALITATIVE COMPARISONS

TABLE 1 (continued)

	Beef ^a	Veal ^a	Mutton ^a	Lamb ^a	Pork ^a	Chicken ^b	Haddock ^c
<i>Aromatic hydrocarbons</i>							
Benzene	T	T	T	T	T	T	S
Toluene	T	T	T	T	T	S	S
Ethylbenzene	T	T	T	T	T	T	
Propylbenzene	T	T	T	T	T		
<i>Alcohols</i>							
Ethanol	M	M	M	M	T	S	S
Propanol	S	S	S	M	S		
Butanol	S	S	T	S	T		
Pentanol	S	S	S	S	-		
Hexanol	T	-	-	-	-		
<i>Ketones</i>							
Acetone	S	T	S	M	M	T	S
Butanone	T	S	S	M	M		S
Acetone	-	T	T	T	T		
<i>Aldehydes</i>							
Butanal							S
Pentanal	S	-	-	-	-		T
Hexanal	S	T	T	T	S		T
Heptanal	T	-	-	-	-		
Octanal	T	-	-	-	-		
<i>Esters</i>							
Ethyl acetate	T	T	T	T	T		
<i>Sulfur compounds</i>							
Methanethial						T	
Ethanethial							T
2-Thiapropane	T	T	T	T	T		M
2-Thiabutane	-	-	-	-	T		
2, 3-Dithiabutane	S	S	T	T	S		S
3, 4-Dithiahexane	T	T	S	T	T		
3-Thiaheptane	T	T	T	-	T		
Methional	T	-	T	-	T		

L = large (> 1 p.p.m.); M = moderate (> 0.1 p.p.m.); S = small (> 0.01 p.p.m.); T = trace (< 0.01 p.p.m.). Quantities estimated from gas chromatographic data.

^a 6.0 Mrad.

^b 0.5 Mrad.

^c 5.6 Mrad.

are always found in about the same proportions in all these meats whenever they are analyzed. The separation into protein and lipid fractions and the analyses of triglycerides, fatty acid methyl esters, etc., were performed to elucidate the source of some of the components with respect to their precursors and the mechanisms

for their formation. These topics have been discussed fully in the original papers and there is no need of detailed treatment here. There are one or two facts that relate to these data, however. For example, if the volatile compounds in haddock are tabulated, they correspond to the components found in meat protein as expected, and if the compounds in an irradiated bean, such as cocoa, are tabulated, they correspond to the products in a lipoprotein. Likewise, irradiation products in meat fats correspond to the products found in triglycerides, and the products in irradiated meat protein are also found in irradiated amino acids, polypeptides and pure proteins.

Accordingly, the components occurring among the volatiles in irradiated foods can be listed as consisting primarily of an homologous series of *n*-alkanes from C₁ to C₁₇, of an homologous series of 1-alkenes, having the same range of carbon number and some assorted alkadienes, or alkynes in very low concentration. All the hydrocarbon compounds have been shown to arise from cleavage reactions in fat^{4,5,7,21}. Irradiation of protein and proteinaceous substances tends to yield, primarily, various sulfur compounds and some alkyl benzenes⁵. When water and air are present, other compounds such as alcohols and certain aldehydes and ketones are also produced by irradiation of meat and other fatty foods^{5,6,22,23}.

The composition of trace volatile components in unirradiated foods has also been studied extensively. When one compares the trace volatile compounds found in other foods, the conclusion is inescapable that there is nothing unique about the components found in irradiated foods.

Table 2 shows a tabulation of the volatile compounds isolated from samples

TABLE 2
COMPOUNDS IDENTIFIED AMONG THE VOLATILE COMPONENTS ISOLATED FROM STORED, FREEZE-DRIED EGGS*

Hydrocarbons	Carbonyls	Sulfur compounds
13 Alkanes C ₂ -C ₁₁	Acetaldehyde	Carbonyl sulfide
9 Alkenes C ₂ -C ₁₀	Benzaldehyde	Methyl mercaptan
7 Aromatic C ₆ -C ₁₀	7 Methyl ketones C ₃ -C ₅ , C ₇ -C ₁₀	Dimethyl sulfide
		Dimethyl disulfide
Esters	Alcohols	
Methyl hexanoate	Ethanol	
Hexyl acetate	Pentanol-1	

* Ref. 32.

of freeze-dried eggs held in storage for a period of 3 to 6 months. The nature of the compounds found is quite similar to that observed for irradiated meat. Typically are seen the homologous series of saturated and unsaturated hydrocarbons, the carbonyls, the sulfur compounds, the esters and alcohols, all formed not from

TABLE 3
COMPOSITE COMPOSITION (3 VARIETIES^a) OF VOLATILE COMPOUNDS ISOLATED FROM GROUND COFFEE BEANS*

Green	Roasted ^b	Green	Roasted
<i>Hydrocarbons</i>		<i>Esters</i>	
Ethane	Ethane	Methyl formate	Methyl formate
Ethene	<i>n</i> -Butane	Methyl acetate	Methyl acetate
<i>i</i> -Butane	<i>i</i> -Butane	Methyl propanoate	Methyl propanoate
	Butene		Methyl butanoate
<i>n</i> -Pentane	<i>n</i> -Pentane	Methyl pentanoate	
<i>i</i> -Pentane	<i>i</i> -Pentane	Methyl hexanoate	Methyl hexanoate
	<i>i</i> -Pentene		
<i>i</i> -Hexane	<i>i</i> -Hexane	Ethyl acetate	
	<i>i</i> -Hexene	Ethyl butanoate ^c	
<i>i</i> -Heptane	<i>i</i> -Heptane	Ethyl pentanoate ^c	
<i>i</i> -Octane	<i>i</i> -Octane	Propyl propanoate ^c	
<i>i</i> -Octene	<i>i</i> -Octene	Hexyl acetate ^c	2-Furfuryl acetate
<i>i</i> -Nonane			
<i>i</i> -Nonene		<i>Sulfur compounds</i>	
<i>i</i> -Decane	<i>n</i> -Decane	Sulfur dioxide	Sulfur dioxide
<i>i</i> -Decene		Carbon disulfide	Carbon disulfide
<i>i</i> -Undecane	2-Methyl-1,3-butadiene	2-Thiapropane	2-Thiapropane
			2-Thiabutane
			2,3-Dithiabutane
			Thiophene
			Methylthiophene
<i>Aldehydes</i>		<i>Heterocyclic compounds</i>	
Ethanal	Ethanal	Furan	Furan
	Propanal	2-Methylfuran	2 Methylfuran
	Butanal	2,5-Dimethylfuran	2,5-Dimethylfuran
2-Methyl propanal	2-Methyl propanal		
	2-Methyl 2-propen-1-al		
Pentanal	Pentanal		
2-Methyl butanal	2-Methyl butanal		Pyrrole
2-Methyl 2-buten-1-al	2-Methyl 2-buten-1-al	<i>N</i> -Methylpyrrole	<i>N</i> -Methylpyrrole
	2-Methyl pentanal		<i>N</i> -Ethylpyrrole
	Furfural		2-Methylpyrrole
	5-Methyl 2-furfural		<i>N</i> -Methyl-2-methylpyrrole
			Pyrazine
	Benzaldehyde		2-Methylpyrazine
<i>Ketones</i>		<i>Aromatic compounds</i>	
2-Propanone	2-Propanone	Benzene	Benzene
2-Butanone	2-Butanone	Toluene	Toluene
	3-Pentanone	Xylene	Xylene
	2-Heptanone	Ethylbenzene	Ethylbenzene
2,3-Butanedione	2,3-Butanedione	C ₉ aromatic	
	2,3-Pentanedione	C ₁₀ aromatic	
	2,3-Hexanedione		
	3,4-Hexanedione		
	Cyclopentanone		
	2-Furylmethylketone		

^a Robusta, Columbian, Santos.

^b 400-430° F.

^c Columbian beans only.

* Ref. 31.

irradiation, but from oxidation reactions during storage. Table 3 shows some of the components found in a typical analysis of the components of coffee aroma²⁸⁻³¹. Again many of the same components are found as in irradiated substances, but these compounds are formed as the result of pyrolysis of the coffee bean during roasting. Finally, a tabulation of the components isolated from apples held in storage is shown in Table 4. The pattern of component type is again familiar, i.e. homologous series of alkanes, alkenes, alcohols, esters, and aldehydes.

TABLE 4
COMPOUNDS IDENTIFIED FROM APPLES*

Hydrocarbons	Alcohols	Esters	Aldehydes
2-Methyl butane	2-Propanol	<i>n</i> -Butyl formate	2-Methyl propenal
<i>n</i> -Hexane	2-Methyl-1-propanol	<i>sec</i> -Butyl formate	Isovaleraldehyde
2-Methyl pentane	2-Methyl-2-propanol	Butyl acetate	Heptanal
Cyclohexane	2-Pentanol	Octyl acetate	Octanal
<i>n</i> -Heptane	3-Pentanol	Ethyl butyrate	Nonanal
<i>n</i> -Octane	2-Methyl-1-butanol	Butyl butyrate	Decanal
<i>n</i> -Nonane	3-Methyl-1-butanol	Hexyl butyrate	
Methyl octane	2-Methyl-2-butanol	Hexyl pentanoate	
<i>n</i> -Decane	3-Methyl-2-butanol		
Methyl nonane	1-Hexanol		
<i>n</i> -Undecane	3-Methyl-1-pentanol		
1-Heptene			
1-Octene			
1-Nonene			
1-Decene			
1-Undecene			
1-Octyne			
1-Nonyne			
1-Decyne			
Methyl benzene			
Ethyl benzene			
<i>n</i> -Propyl benzene			
1-Propyl benzene			
<i>n</i> -Butyl benzene			
<i>tert.</i> -Butyl benzene			
<i>n</i> -Pentyl-benzene			

* From ref. 12.

An overview of the qualitative distribution of compounds of various component types may be obtained by collating from the literature some typical distributions of the compounds found in irradiated food with those found in other foods; this is seen in Table 5. The data are taken from a most comprehensive survey compiled by Weurman and Van Straten²⁸, comprising more than 500 references.

The most abundant compounds in irradiated foods are the C₁-C₁₇ alkanes; these compounds are also found in abundance in coffee, cheese, apples, grapes,

TABLE 5
DISTRIBUTION OF VOLATILE COMPOUNDS AMONG VARIOUS FOODS*

Alkanes	Alkenes and alkadienes	Alcohols	Alkyl benzenes	Carbonyl compounds	Sulfur compounds	Esters
Coffee	Coffee	Apples	Coffee	Apples	Strawberries	Apples
Cheese	Cheese	Pears	Cheese	Pears	Cabbage	Pears
Apples	Citrus fruits	Bananas	Fish	Bananas	Onions	Bananas
Grapes		Grapes	Berries	Grapes	Potato	Grapes
Citrus fruits		Berries	Tea	Berries	Celery	Peaches
		Tomatoes		Tomatoes	Peas	Berries
		Peaches		Onions	Rutabaga	Citrus fruits
		Coffee		Coffee	Coffee	Coffee
		Cocoa		Cocoa	Cocoa	Cocoa
		Tea		Tea	Tea	Wine
		Bread		Bread	Bread	Beer
		Wine		Wine	Beer	Cheese
		Beer		Beer	Milk	
		Cheese		Milk	Cheese	
		Meat		Cheese	Meat	
				Meat	Fish	
				Fish		
				Citrus fruits		

* Data taken from ref. 28.

and citrus fruits. Their presence in coffee and cheese is due to oxidative reactions in the lipids; in the fruits, they are part of the wax cuticle which is a natural part of the protective coating on the skin. Alkenes and alkadienes found in irradiated food are likewise found in coffee, cheese, and citrus fruits. The origin of these compounds is similar to that of the alkenes. The alkyl benzenes, toluene through propyl benzene, which are formed in irradiated products from cleavage of phenylalanine, are likewise formed in coffee or cheese, fish and berries from cleavage due to pyrolysis or enzymatic action.

Carbonyl compounds are widespread and are formed in great abundance in fruits and vegetables, beverages, dairy products, and they occur naturally in meat and fish. The amounts occurring naturally in fruits and vegetables are usually much greater than those found in irradiated meat and similar products. The situation is very similar with alcohols and these are likewise found naturally in nearly all fruits and vegetables, beverages, and dairy products. Esters are not very significant among the compounds formed by irradiation, but they are, however, very commonly found in fruits, and like nearly all the other compound classes, are the result of microbial action in the production of cheese. Finally, the sulfur compounds found in irradiated foods are widely distributed naturally in other foods.

The large number of studies of flavor compounds made during the past decade has made it easy to demonstrate that all the trace volatile compounds

found in irradiated meats are also found widely distributed among a variety of other foods.

IV. QUANTITATIVE COMPARISONS

Although the presence of every compound found in irradiated foods can be established also in non-irradiated foods, it is more difficult to estimate the relative abundance of these compounds since very few of the investigators have attempted to obtain quantitative data. Some data are available, however, enabling at this time at least, a preliminary comparison of the quantitative levels at which products of irradiation are formed relative to the amounts of volatile compounds in un-irradiated food.

Table 6 shows the relative amounts of the various compounds found in

TABLE 6

RELATIVE ABUNDANCE OF VOLATILE COMPOUNDS IN IRRADIATED BEEF*

Volatile compound	p.p.m.
Alkanes	12
Alkenes	14
Aldehydes	1.5
Sulfur compounds	1.0
Alcohols	1.0
Ketones	<0.5
Alkyl benzenes	<0.1
Esters	<0.1

* Refs. 4, 5, 7.

irradiated meat. The data are for beef, but nearly the same relative distribution would be found for all the meats studied. With these data in mind, comparisons may be drawn to the amounts of these components found in other foods. Table 7 shows a comparison of the relative amounts of the sulfur and aromatic compounds found in irradiated and non-irradiated haddock after treatment and storage. Alkyl benzenes are formed in haddock upon irradiation in a reaction that is characteristic of the irradiation of protein. Benzene and toluene are also found to be produced during spoilage as the fish is stored under refrigeration. The quantity produced during storage increases with time, but as is seen here, at 14 days there is more benzene and toluene in the unirradiated fish than the amount found in the irradiated fish after irradiation and storage.

A similar situation is observed comparing the formation of sulfur compounds in refrigeration-stored haddock with those produced by irradiation treatment. Here the amounts of methyl mercaptan, dimethyl sulfide, and dimethyl disulfide are

QUANTITATIVE COMPARISONS

TABLE 7

RELATIVE AMOUNTS OF SULFUR AND AROMATIC COMPOUNDS IN HADDOCK*

	Irradiated (5.6 Mrad.), stored 30 days (mg/kg, p.p.m.)	Non-irradiated stored 14 days** (mg/kg, p.p.m.)
<i>Sulfur compounds</i>		
CH ₃ -SH	1	350
CH ₃ -S-CH ₃	1	200
CH ₃ -S-S-CH ₃	2	150
<i>Aromatic compounds</i>		
Benzene	0.1	0.2
Toluene	0.2	0.5

* Refs. 25, 26.

** Fish is inedible after 14 days.

all seen to be much greater in the haddock which is undergoing spoilage. Comparable amounts could be found in other fish that are preserved by salting or smoking, and which are eaten without question.

Data are also available which allow sulfur compounds found in cheese to be compared with those produced in irradiated beef. This is seen in Table 8.

TABLE 8

RELATIVE AMOUNT OF SULFUR COMPOUNDS IN BEEF AND CHEESE

	Irradiated beef, 6 Mrad ^a (mg/kg, p.p.m.)	Cheddar cheese ^b (mg/kg, p.p.m.)
H ₂ S	< 1	50
CH ₃ SH	10	30
CH ₃ SCH ₃	5	1
CH ₃ SSCH ₃	20	70

^a Refs. 4, 5.

^b Ref. 33.

Again, microbial or enzymatic activity is seen to produce generally larger amounts of certain sulfur compounds than are produced by irradiation at sterilizing doses.

There are no data which can be used to compare the amounts of the esters, alcohols, or ketones formed by irradiation with their presence in other foods. However, a direct comparison has been made of the formation of aldehydes in butter fat due to copper-induced oxidation and irradiation²². The data are

depicted graphically in Fig. 6. In this study the irradiation dose was 6 Mrad and both the copper-oxidized and irradiated fat were exposed to O_2 . The oxidized fat was stored 1 week without refrigeration. In irradiated meat, the total aldehyde level is about 1.5 p.p.m. In this study, the total aldehyde content, C_3 through C_7 , in the oxidized fat was about 100 p.p.m.

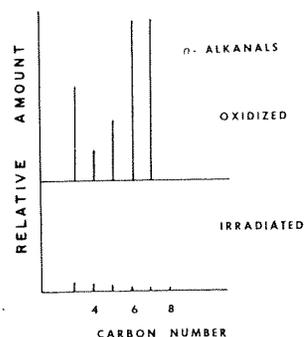


Fig. 6. Comparison of relative amounts of *n*-alkanes in oxidized and irradiated butter fat (ref. 22).

The most abundant compounds in irradiated meat are the hydrocarbons. The only data presently available for quantitative comparison of these components comes from a study by Meigh³⁴ of the alkane content in the wax cuticle of apples. The data are depicted graphically in Fig. 7. The distribution of hydrocarbons found in irradiated beef is shown in the lower graph and is seen to range from C_1 to C_{17} .

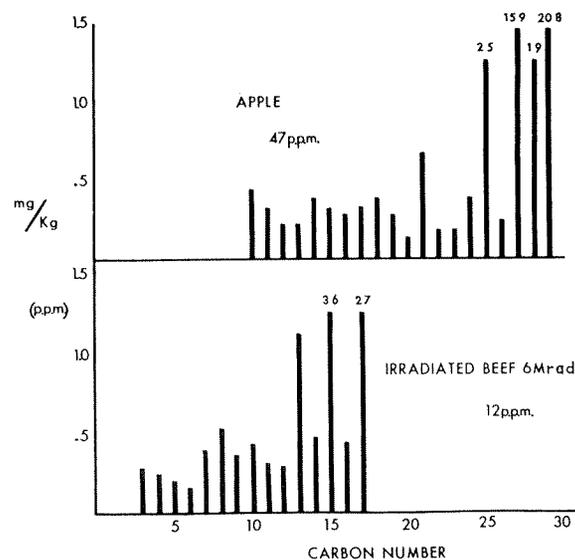


Fig. 7. Comparison of relative amounts of *n*-alkanes found in apples and irradiated beef.

The total is about 12 p.p.m., of which more than half is due to pentadecane and heptadecane. The distribution of hydrocarbons in apple shown in this figure is a little misleading. Although it appears that no members of the series below decane are present, this is simply because they were not determined. The lower molecular weight numbers of this series have also been found in rather large yield in stored apples by Angelini and Phlug¹², but they did not measure the amounts quantitatively. The 47 p.p.m. total hydrocarbon content is based on the weight of the whole apple. Since the compounds are largely concentrated on the skin, the figure could be correspondingly higher if skin alone is considered or less, if not nil, if the apple is peeled.

The conclusion arising from these comparisons is simple. No volatile compounds produced in foods by irradiation have been found that are not similarly found qualitatively and quantitatively in other products resulting naturally.

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