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Release of Volatile Odor Compounds from Full-Fat and Reduced-Fat Frankfurters

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The effect of fat content on the release of volatile aroma compounds from frankfurters has been investigated. Although the release of most *n*-alkanals, alcohols, ketones, and furans was little affected by changes in the fat content of frankfurters, that of monoterpene hydrocarbons, sesquiterpene hydrocarbons, terpenes containing oxygen, cyclopentenones, phenyl propanoids, and phenols was greatly increased when the fat content was decreased. Some odors were also detected more frequently in the low-fat than in the full-fat sausages. These included smoky odors, due to phenols, spicy, synthetic, and floral odors due to terpenes, and meaty, roasted odors caused by sulfur-containing heterocyclic compounds. The release of aroma compounds from frankfurters appears to be closely related to the solvation of these compounds in the lipid phase.

Keywords: *Flavor; odor; volatiles; odor compounds; low-fat; frankfurters*

INTRODUCTION

Over the past 10 years, consumers' increased awareness of the role of dietary lipids in health issues such as cardiovascular diseases and obesity has induced the expansion of the market for foods with a reduced content of triglyceride lipids. "Low-fat" frankfurters and other processed meats have been developed to supply this market. The textural aspects of low-fat frankfurters have been well documented, and a major problem associated with producing such products is an increase in toughness and rubberiness (Hand et al., 1987; Wirth, 1988; Barbut and Mittal, 1989; Marquez et al., 1989; Park et al., 1989). The influence of fat on the sensory perception of the flavor of frankfurters has also been investigated, but conflicting results have been reported. For example, Park et al. (1989) showed a tendency for higher fat content to give greater scores for overall flavor intensity, whereas Marquez et al. (1989) reported the opposite effect. Recent studies (Solheim, 1992; Hughes et al., 1997; Chevance and Farmer, 1998) have shown that low-fat sausages or frankfurters have increased intensity for certain flavor attributes (e.g., smokiness, spiciness, saltiness) and reduced overall acceptability of the flavor compared with their full-fat counterparts.

The human perception of flavor is closely related to the nature and amount of odor and taste components available to the sensory system (Overbosch et al., 1991). The availability of flavor components to the sensory system is largely dependent on the release of these compounds from the food. Limited information is available on the release of flavor components from full- and low-fat meat products. El-Magoli et al. (1996) investigated the effect of fat content on the release of some volatile compounds from beefburgers, but the results were inconclusive. Recent studies on other types of low-fat foods, such as biscuits (Ingham et al., 1996) or cheese (Piraprez et al., 1998), suggested that flavor changes were caused by the retention of selected flavor volatiles by fat in these food matrices. Numerous studies on oil–water models, designed to mimic foods, have also shown that increased concentrations of oil decreased the release of flavor compounds in the headspace as a result of the solubility of these components in lipids (Buttery et al., 1973; Land, 1979; De Roos and Wolswinkel, 1994; Salvador et al., 1994; Schirle-Keller et al., 1994; Landy et al., 1996).

The volatile aroma compounds detected in frankfurter sausages have been identified and reported in a previous paper (Chevance and Farmer, 1999). The present study was designed to evaluate the effect of fat content on the release of these aroma compounds.

MATERIALS AND METHODS

Materials. Low-fat, medium-fat, and full-fat frankfurters were prepared at the National Food Centre (Dublin, Ireland) by adjusting the amount of pork adipose tissue (back fat) included in the composition to give nominal fat contents of 5, 12, and 30%. In this paper, the term "fat" refers to the mixture of triglyceride lipids from this source. In the reduced-fat products, water was added to replace the fat to ensure the same protein content in all formulations. Smoke was included as a liquid smoke flavoring (0.05%; hickory smoke, D402V, Dalgety Food Ingredients, Dublin, Ireland) to ensure homogeneity of the smoke components from batch to batch. The other ingredients, preparation, and proximate analysis of these frankfurters have been reported previously (Hughes et al., 1997).

Comparison of Total Volatiles. The relative quantities of total volatiles present in the different frankfurters were determined using a steam distillation extraction method (Nickerson and Likens, 1966) followed by GC/MS. The volatile compounds from frankfurters were extracted into 20 mL of pentane (A.R., Rhone Poulenc Ltd., Manchester, U.K.) over a period of 2 h. Bromobenzene (Aldrich Chemical Co. Ltd., Dorset, U.K.) was added to the solvent as an internal standard (10 μL, 2980 ng μL^{-1}) prior to collection. Full experimental details have been given in a previous paper (Chevance and Farmer, 1998). Three replicate extractions were conducted on the frankfurters containing 5 and 30% fat, and the volatile

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compounds collected were analyzed using an HP 5890 Series 2 gas chromatograph (Hewlett-Packard, Wokingham, Berks, U.K.) connected to an HP 5971 mass selective detector, operated at 70 eV in the EI mode over the range 35−450 amu. After desorption (5 min) onto the front of the column (CPWax52CB, 50 m × 0.32 mm i.d., Chrompack Ltd., London, U.K.), which was immersed in liquid nitrogen, the volatile components were analyzed using an oven program starting at 40 °C for 5 min, increased to 220 °C at 4 °C min^{-1}, and maintained at 220 °C for 30 min. Peak areas were determined by dividing the area of a selected ion of the compound by its relative abundance in the mass spectrum. Peak areas were expressed relative to the area given by 1 ng of bromobenzene (internal standard), and means of relative peak areas were calculated and analyzed by analysis of variance using a Genstat statistical software package (Genstat V, release 3.1, Lawes Agricultural Trust, Rothamsted Experimental Station). Where the effect of treatment was significant, a Fisher's least significant difference test was applied to the mean scores.

Comparison of Volatiles Released into the Headspace. The relative quantities of volatiles released from the different frankfurters were obtained using a dynamic headspace collection method, followed by GC/MS. A stream of nitrogen (50 mL/min for 30 min) swept the volatiles released from frankfurters (50 g), held at 70 °C, onto a conditioned glass-lined stainless steel trap (2.6 mg Tenax GC; Scientific Glass Engineering Ltd., Milton Keynes, U.K.). An internal standard (0.5 μL; 74.5 ng μL^{-1} bromobenzene in ethanol) was added to the conditioned trap prior to the collection. A flow of nitrogen (50 mL min^{-1}) was used to remove excess solvent from the trap after addition of standard and residual water after collection of volatiles. Three collections of this type were performed on each of the frankfurters, and the volatiles collected were analyzed using an HP 5890A gas chromatograph connected to an HP 5970 mass selective detector, operated at 70 eV in the EI mode over the range 35−450 amu. The volatile compounds were chromatographed as described above, except that the oven program was maintained at 60 °C for 5 min before increasing at 4 °C min^{-1} to 220 °C (30 min). Relative peak areas were calculated and analyzed as described above.

Comparison of Odors. A static headspace collection method was used to collect odor compounds from frankfurters prior to GC/odor assessment. The method, which has been described previously (Chevance and Farmer, 1999), involved the displacement of the volatiles onto a Tenax trap using the pressure of air (10 mL) injected by a syringe into a sealed bottle (100 mL) containing frankfurters (20 g) held at 70 °C. Six collections of this type were conducted on each type of frankfurter (5, 12, and 30% fat). GC was performed in an HP 5890 Series II gas chromatograph fitted with a Unijector (Scientific Glass Engineering Ltd.), using the same oven program as for the volatiles collected by dynamic headspace collection. The effluent from the column was split between a flame ionization detector and an odor port (Chevance and Farmer, 1999). GC/odor assessments were conducted in duplicate by three assessors on each of the frankfurters.

RESULTS AND DISCUSSION

Seventy compounds in the headspace and 66 volatile compounds extracted by simultaneous distillation extraction (SDE), in three types of frankfurters, have been subjected to semiquantitative analysis (Tables 1 and 2). In each case the relative peak area for each compound is given, together with the total relative peak area for each compound class. Most compound classes were released in greater quantities from the low-fat frankfurters than from the medium- or full-fat frankfurters. However, some differences were also detected in the quantities of volatiles extracted by SDE. These data are compared to determine the effect of reduced fat content on the individual compounds listed.

The intensities and frequencies of detection of the key odors for the three types of frankfurters are compared in Table 3. Most of the individual odors were detected more often in the low-fat than in the full-fat frankfurters.

The volatile odor compounds in frankfurters include aliphatic compounds, mainly from lipid oxidation, sulfur-containing compounds and other products from the Maillard reaction, terpenes from the added spices, and phenols from the smoke (Chevance and Farmer, 1999). The effect of fat content will be discussed for each of these compound groups in turn.

Aliphatic Compounds. A comparison of the relative quantities of *n*-alkanals, alcohols, ketones, and furans released (Table 1) or present (Table 2) in the frankfurters suggests that these compounds were little affected by changes in the fat content of frankfurters. For example, the tendency of *n*-alkanals to be released in greater quantities from the low-fat frankfurters (Table 1) was in fact due to the differences in original quantities of volatiles present in the frankfurters (Table 2) and not the effect of flavor release. Similar quantities of furans were released from the three types of frankfurters (Table 1), and the original quantities of compounds available were also similar in all frankfurters (Table 2). The same observations may be made about four of the ketones. Studies investigating the effect of fat content on the flavor release from other types of foods showed different results for some of the above classes of compounds. For example, Ingham et al. (1996) observed larger amounts of benzaldehyde released from low-fat biscuits in comparison to full-fat biscuits, and Piraprez et al. (1998) found that the release of aldehydes and methyl ketones was increased in a low-fat cheese matrix in comparison to the full-fat matrix. In these studies, the quantities of volatile compounds originally present in the food matrix were not reported, which may account for the different results. The effect of fat on the perception of key odor compounds belonging to this class of compound varied (Table 3). The odor due to 1-octen-3-one ("mushroom") was not detected in the full-fat product by any of the assessors, whereas it was always detected in the low-fat product. It was not possible to monitor the release of this compound by GC/MS due to its small quantity. An unidentified alcohol could be responsible for the "metallic, geranium, stale" odor at LRI 1203 (Table 3), which showed little change. Sensory studies conducted on these frankfurters showed that the perception of "fatty" flavors was not affected by the fat content (Chevance and Farmer, 1998). Thus, in most cases, the release of lipid oxidation-derived odor compounds is not affected by fat content, although the quantities present in the product may alter.

Sulfur-Containing Compounds. Several furanthiols and sulfur-containing compounds have also been identified as key odor compounds in frankfurters (Chevance and Farmer, 1999). These compounds are formed by Maillard pathways involving cysteine, or possibly from the thermal degradation of thiamine (Mottram, 1991). It was not possible to monitor the effect of fat on the release of these compounds by GC/MS, due to the small quantities, but GC/odor assessment (Table 3) indicated a tendency for certain odors, such as "meaty, cereal" (due to 2-methyl-3-furanthiol; LRI 1321), "roasty, meaty" (2-furanmethanethiol; LRI 1430), "meaty, biscuity, roasty, popcorn" (2-acetylthiazoline; LRI 1751),

Table 1. Effect of Fat on Relative Peak Areas[a] for Selected Components Released from Frankfurters

LRI CBWax	compound	selected ions	frankfurters 30% fat mean	 30% fat SD	 12% fat mean	 12% fat SD	 5% fat mean	 5% fat SD	signif[b]	SEM[c]
	aldehydes									
1070	hexanal	72	18500	*6740*	16400	*3390*	20100	*4310*	NS	3000
1181	heptanal	81	6530	*2570*	6510	*600*	11000	*4320*	NS	1620
1280	octanal	84	2410	*1250*	2430	*466*	6430	*3100*	NS	1150
1383	nonanal	82	8880	*4580*	9130	*2340*	24200	*12900*	NS	4600
1216	2-hexenal	98	175	*12*	810^{e}		223^{e}			
1313	2-heptenal	83	1450	*705*	915	*67*	689	*482*	NS	300
1508	benzaldehyde	105	1840^{r}	*992*	2070^{rs}	*317*	3990^{s}	*999*	*	490
		subtotal:	**39785**		**38265**		**66632**			
	alcohols									
1241	1-pentanol	70	1963	*760*	1140	123	*1190*	*103*	NS	250
1395	2-butoxyethanol	75	790	*398*	718	174	*1890*	*804*	NS	200
		subtotal:	**2753**		**1858**		**3080**			
	ketones									
1328	6-methyl-5-hepten-2-one	108	820^{r}	*381*	1250^{rs}	*158*	5170^{s}	*2580*	*	850
1280	cyclohexanone	83	4050^{s}	*1440*	1600^{r}	*144*	2260^{r}	*304*	*	530
1341	2-cyclopenten-1-one	82	534	*278*	435	*77*	559	*157*	NS	100
1353	2-methyl-2-cyclopenten-1-one	67	2870	*1410*	2780	*333*	3930	*1300*	NS	650
1432	a dimethyl-2-cyclopenten-1-one	110	375^{r}	*146*	513^{rs}	*42*	852^{s}	*242*	*	90
1521	2,3-dimethyl-2-cyclopenten-1-one	110	1180	*660*	1330	*372*	2290	*878*	NS	390
1611	2(3*H*)-dihydrofuranone	42	235	*99*	174	*64*	388	*288*	NS	95
		subtotal:	**10064**		**8082**		**15449**			
	furans									
1224	2-pentylfuran	138	119	*99*	75	*10*	201	*55*	NS	46
1455	2-furfural	96	5490	*2470*	4560	*637*	5310	*1230*	NS	940
1493	2-acetylfuran	110	2820	*1320*	2880	*210*	4620	*1560*	NS	670
1560	5-methyl-2-furfural	110	1970	*943*	1340	*302*	1870	*620*	NS	390
		subtotal:	**10399**		**8855**		**12002**			
	benzenes									
1024	methylbenzene	92	970	*173*	913	*226*	910	*142*	NS	110
1115	ethylbenzene	91	2680	*1420*	2410	*1000*	2290	*1710*	NS	810
1123	1,4-dimethylbenzene	91	1170	*318*	1510	*369*	1560	*544*	NS	250
1129	1,3-dimethylbenzene	105	1890	*716*	2520	*392*	3080	*1060*	NS	420
1216	1-ethyl-1-methylbenzene	120	230	*18*	235	*57*	428	*322*	NS	100
1239	styrene	104	284^{r}	*120*	367^{r}	*32*	673^{s}	*173*	*	60
1324	1,2,3-trimethylbenzene	120	93	*13*	112	*32*	171	*109*	NS	30
1425	a methyl (1-methylethyl) benzene	117	2740^{r}	*2540*	6640^{r}	*2760*	13600^{s}	*3920*	*	1800
1898	BHT	205	246	*187*	134	*78*	853	*1120*	NS	380
		subtotal:	**10303**		**14842**		**23564**			
	monoterpene hydrocarbons									
1014	α-pinene	136	1480	*201*	1690	*383*	2300	*799*	NS	300
1018	α-thujene	136	2630	*913*	3170	*1440*	3890	*803*	NS	660
1102	*β*-pinene	79	3330	*382*	3570	*1040*	5060	*1510*	NS	580
1110	sabinene	77	17400^{r}	*3660*	17300^{r}	*1620*	36500^{s}	*12900*	*	4480
1136	3-carene	121	3580	*709*	3420	*748*	4340	*2340*	NS	850
1157	*β*-myrcene	69	52300^{r}	*16700*	61900^{rs}	*14800*	107000^{s}	*30400*	*	12600
1168	α-terpinene	136	17900	*14700*	16300	*6830*	24800	*3240*	NS	5500
1192	limonene	121	106000^{r}	*20800*	126000^{r}	*6460*	217000^{s}	*38100*	**	14600
1205	*β*-phellandrene	136	8070^{r}	*1660*	9700^{r}	*1540*	15400^{s}	*2870*	*	1180
1237	*γ*-terpinene	121	31000^{r}	*8410*	39500^{r}	*4460*	68000^{s}	*14000*	**	5650
1239	*β*-ocimene	121	7310^{r}	*3070*	12100^{r}	*4780*	21600^{s}	*3310*	**	2120
1261	*p*-cymene	119	27210	*11000*	31000	*14100*	48700	*18900*	NS	8660
1273	α-terpinolene	105	19500^{r}	*11900*	32800^{r}	*1320*	67900^{s}	*13500*	**	6020
		subtotal:	**297710**		**358450**		**622490**			
	sesquiterpene hydrocarbons									
1479	α-copaene	161	2580	*2340*	4260	*1090*	6730	*1470*	NS	990
1564	*β*-caryophyllene	204	22000^{r}	*12100*	28800^{r}	*8670*	54200^{s}	*1990*	**	5260
1652	α-caryophyllene	147	1770^{r}	*903*	3170^{r}	*948*	12700^{s}	*5620*	*	1890
1713	α-zingibirene	119	1770^{r}	*1210*	4290^{r}	*1610*	19500^{s}	*8000*	*	2980
1745	*δ*-cadinene	161	940^{r}	*480*	1630^{r}	*385*	5370^{s}	*898*	***	350
1756	α-farnesene	119	14800^{r}	*6220*	29900^{r}	*8430*	91900^{s}	*17700*	***	6780
1764	*ar*-curcumene	145	3400^{r}	*1780*	6750^{r}	*2470*	20000^{s}	*2140*	***	1190
		subtotal:	**47260**		**78800**		**210400**			

Table 1 (Continued)

			frankfurters							
			30% fat		12% fat		5% fat			
LRI CBWax	compound	selected ions	mean	SD	mean	SD	mean	SD	signif[b]	SEM[c]
	terpenes with oxygen									
1196	1,8-cineole	111	1290	*201*	1830	*868*	1870	*328*	NS	270
1538	sabinene hydrate isomer	121	249	*244*	334	*317*	555	*430*	NS	230
1548	linalool	121	32400^{r}	*12000*	46500^{r}	*2530*	79900^{s}	*14800*	**	6460
1559	isobornyl acetate	196	380	*73*	1330	*489*	1430	*776*	NS	360
1588	terpinen-4-ol	154	16900^{r}	*5500*	24200^{r}	*1020*	37200^{s}	*7020*	**	2900
1691	α-terpineol	136	34000	*27800*	37600	*24900*	104000	*59200*	NS	24500
1718	*l*-carvone	108	1840^{r}	*1060*	3000^{r}	*696*	8270^{s}	*2160*	**	820
		subtotal:	**87059**		**114794**		**233225**			
	terpenoid phenols									
1656	estragole	121	1970	*2470*	3460	*1100*	15000	*15100*	NS	6200
1854	safrole	131	7690^{r}	*4040*	14200^{r}	*3140*	42800^{s}	*8960*	***	7140
2008	*cis*-methylisoeugenol	178	489^{r}	*365*	1150^{r}	*456*	3800^{s}	*539*	***	300
2162	eugenol	149	5570^{r}	*4850*	10600^{r}	*4040*	28000^{s}	*7420*	**	3200
2228	elemicin	193	813^{r}	*863*	1790^{r}	*1310*	5770^{s}	*1760*	*	800
2262	myristicin	161	7840^{r}	*5510*	15700^{s}	*5580*	47800^{t}	*7560*	***	17100
		subtotal:	**24372**		**46900**		**143170**			
	phenols									
1850	2-methoxyphenol (guaiacol)	124	8030^{r}	*4740*	11600^{rs}	*2550*	22100^{s}	*7410*	*	3040
1949	4-methylguaiacol	138	4310^{r}	*2980*	7480^{r}	*2170*	16600^{s}	*5070*	*	2100
2000	2-methylphenol	108	635^{r}	*402*	1010^{r}	*177*	2120^{s}	*783*	*	300
2000	phenol	66	1660	*532*	1850	*164*	3940	*2620*	NS	900
2024	4-ethylguaiacol	137	710^{r}	*532*	1410^{r}	*484*	3800^{s}	*1140*	**	450
2076	dimethylphenol	107	760^{r}	*524*	1200^{rs}	*282*	2600^{s}	*1070*	*	420
2103	4-propylguaiacol	137	94^{r}	*76*	191^{rs}	*73*	612^{s}	*187*	**	70
2168	dimethylphenol	107	795^{r}	*549*	1260^{r}	*296*	2720^{s}	*1120*	*	290
		subtotal:	**16994**		**26001**		**54492**			

[a] Relative peak areas are expressed as the mean (three replicate analyses for each treatment) and standard deviation, relative to the peak area given by 1 ng of bromobenzene =100. Values >1000 are stated to three significant figures. Values in bold are the sum of relative peak area values for the given compound class. [b] Degree of significance among the three frankfurters (analysis of variance): NS, no significant difference; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$. [c] SEM, standard error of mean. [d] For each compound, values that do not share a common superscript (r, s, t) are significantly different ($P < 0.05$) according to Fisher's LSD test. [e] Single observation.

and "potatoes, biscuity, roasted meat" (methional plus an unknown meaty compound; LRI 1451), to be perceived more frequently and to give more intense odors in the low-fat frankfurters. However, the odors "meaty, roasty, metallic" (dimethyl trisulfide; LRI 1373) and "meaty, roasty, biscuity" [2-methyl-3-(methyldithio)-furan; LRI 1663] appeared to be unaffected or only slightly affected by the change in fat content in frankfurters, possibly due to their relatively intense odors even when static headspace techniques are used. In contrast, Piraprez et al. (1998) found that dimethyl trisulfide was largely retained in a full-fat cheese matrix in comparison to a low-fat one. Two compounds that may contribute to the perceived difference in flavor between the low-fat and full-fat frankfurters are those responsible for the "sweet, meaty, roasty" and "popcorn, biscuity" odors at LRI 1177 and 1613, which show a clear change in roasty−biscuity intensity and frequency of detection (Table 3). Unfortunately, these compounds are, as yet, unidentified, but, from the nature of their aromas, they may be derived from similar pathways to the above compounds. The fact that sensory studies showed that overall meaty flavor was largely unaffected by changes in fat content (Chevance and Farmer, 1998) suggests that these small changes in aroma intensity had a minor effect on the overall flavor.

Terpenes and Phenols. The compounds most affected by fat content included the classes of monoterpene and sesquiterpene hydrocarbons, terpenes containing oxygen, cyclopentenones, phenyl propanoids, and phenols (Tables 1 and 2). These compounds have been found to be derived from the spices or smoke incorporated to these frankfurters (Chevance and Farmer, 1999). For a number of these compounds, significantly greater quantities were released from the low-fat frankfurters, and most of those compounds for which the difference was not significant showed the same trend (Table 1). Because the same amounts of spices and smoke were incorporated into the different frankfurters, it was not surprising to find that the relative quantities of these compounds extracted from 5 and 30% fat frankfurters were very similar (Table 2), confirming that the observed differences in headspace were due to differences in flavor release. Fat content also showed an effect on some key odor compounds belonging to these classes of compounds (Table 3). The frequency of detection and intensity of the odors at LRI 1026 and 1541 ("spices, green, pine needles" and "floral"), due to α-pinene and linalool, were slightly greater for the low-fat and/or the medium-fat frankfurters than for the full-fat frankfurters (Table 3). The intensity of odors was unaffected for 1,8-cineole, probably due to the fact that it was consistently detected by all assessors; at this concentration there was little discrimination between samples. The 2−5-fold increase in the release of these terpenes and the less distinct increase in frequency of odor detection explain the increased perception of "peppery", "spicy," and perhaps "synthetic" flavors detected by sensory profiling studies (Chevance and Farmer, 1998). Even among terpenes, the effect of fat varies among compound classes. For example, sesquiterpene hydrocarbons are more affected by fat content than monoterpene

Table 2. Effect of Fat on Relative Peak Areas[a] for Selected Components Extracted from Frankfurters

			frankfurters					
			30% fat		5% fat			
LRI CPWax	compound	selected ions	mean	SD	mean	SD	signif[b]	SEM[c]
	aldehydes							
1085	hexanal	72	20200	*3160*	49100	*35000*	NS	15600
1179	heptanal	96	8410	*1880*	16600	*7390*	NS	3400
1281	octanal	84	3270	*700*	6310	*2980*	NS	1380
1383	nonanal	98	8800	*2110*	24600	*8720*	*	3950
1506	benzaldehyde	105	8670	*1780*	8510	*1400*	NS	900
2109	hexadecanal	110	65900	*8290*	28100	*5450*	***	3800
		subtotal:	**115250**		**133220**			
	alcohols							
1353	1-hexanol	84	570	*540*	2750	*500*	*	380
	ketones							
1330	6-methyl-5-hepten-2-one	126	4770	*650*	2180	*226*	***	330
1354	2-methyl-2-cyclopenten-1-one	67	885	*300*	859	*330*	NS	180
1430	a dimethyl 2-cyclopenten-1-one	110	547	*119*	558	*202*	NS	93
1498	3-methyl-2-cyclopenten-1-one	67	4350	*1690*	4900	*772*	NS	707
1524	2,3-dimethyl-2-cyclopenten-1-one	95	5240	*4280*	3890	*939*	NS	1580
		subtotal:	**11022**		**10207**			
	fatty acids							
2680	tetradecanoic acid	129	75700	*27600*	20500	*3500*	**	10200
2922	hexadecanoic acid	185	96100	*17400*	75400	*14300*	NS	8910
		subtotal:	**171800**		**95900**			
	furans							
1498	2-acetylfuran	110	5690	*957*	4750	*733*	NS	460
1462	2-furfural	96	9050	*930*	9690	*1690*	NS	820
1567	5-methylfurfural	109	4670	*1680*	8720	*1640*	*	880
		subtotal:	**19410**		**23160**			
	monoterpene hydrocarbons							
1014	α-pinene	136	492000	*145000*	543000	*56400*	NS	58700
1047	camphene	136	70800	*28900*	86600	*7660*	NS	11120
1099	*β*-pinene	69	665000	*163000*	728000	*81400*	NS	69650
1107	sabinene	77	581000	*132000*	576000	*58100*	NS	54890
1130	3-carene	121	126000	*29300*	134000	*18500*	NS	13500
1157	*β*-mircene	69	82100	*24200*	41600	*10000*	*	9900
1163	α-terpinene	121	9170	*3090*	9400	*1770*	NS	1390
1188	limonene	121	436000	*114000*	427000	*49600*	NS	47200
1205	*β*-phellandrene	121	56900	*3880*	56900	*8820*	NS	4210
1236	*γ*-terpinene	121	183000	*37000*	151000	*18600*	NS	15900
1267	p-cymene	119	192000	*42600*	191000	*20900*	NS	18200
1281	α-terpinolene	105	69000	*16600*	56800	*6520*	NS	6700
		subtotal:	**2962970**		**3001300**			
	sesquiterpene hydrocarbons							
1476	α-copaene	161	15300	*5820*	27600	*3490*	*	2600
1581	*β*-caryophyllene	204	79900	*25400*	119000	*43300*	NS	21700
1637	α-caryophyllene	147	16300	*6200*	20900	*1980*	NS	2370
1710	α-zingibirene	119	3000	*1480*	6720	*687*	*	600
1745	*δ*-cadinene	161	9140	*3860*	13600	*1730*	NS	1600
1764	*ar*-curcumene	145	43200	*17900*	66600	*8890*	NS	7740
		subtotal:	**166840**		**254420**			
	terpenes with oxygen							
1191	1,8-cineole	111	212000	*17400*	194000	*26900*	NS	13600
1534	sabinene hydrate isomer	154	249000	*24700*	230000	*37100*	NS	18900
1546	linalool	121	433000	*33300*	324000	*46700*	*	24200
1551	*cis*-sabinene hydrate	154	86400	*31400*	43300	*9900*	*	12300
1568	isobornyl acetate	196	10400	*3550*	10400	*845*	NS	1400
1588	terpinen-4-ol	154	655000	*43000*	380000	*64300*	**	32800
1618	*p*-2-menthen-8-ol	154	39800	*4330*	17900	*1740*	***	1780
1687	α-terpinyl acetate	136	339000	*42100*	291000	*47900*	NS	26400
1709	piperitone	82	1940	*633*	2150	*345*	NS	300
1718	l-carvone	108	5000	*5610*	3030	*874*	NS	2090
1839	*p*-cymen-8-ol	135	9500	*1070*	5560	*830*	**	500
1842	*trans*-geraniol	69	15700	*13400*	10700	*859*	NS	4900
		subtotal:	**2056740**		**1512040**			

Table 2 (Continued)

LRI CPWax	compound	selected ions	frankfurters 30% fat mean	SD	frankfurters 5% fat mean	SD	signif[b]	SEM[c]
	terpenoid phenols							
1857	safrole	135	133000	*15100*	89800	*11300*	**	7500
2155	eugenol	149	321000	*4840*	129900	*24400*	***	11000
2228	elemicin	193	116000	*6470*	44300	*7380*	***	4050
2262	myristicin	161	355000	*20700*	158700	*21000*	***	12100
2399	isoelemicin	208	3460	*71*	670	*103*	***	60
		subtotal:	**928460**		**423370**			
	phenols							
1851	2-methoxyphenol (guaiacol)	124	28900	*4960*	16200	*4380*	*	2700
1933	a methylguaiacol	123	491	*175*	311	*36*	NS	60
1957	4-methylguaiacol	138	44900	*3170*	18600	*4590*	***	2350
2000	2-methylphenol	108	1340	*129*	799	*395*	NS	180
2000	phenol	94	351	*46*	511	*665*	NS	300
2020	4-ethylguaiacol	137	14100	*108*	4000	*789*	***	350
2068	2-ethylphenol	107	768	*153*	574	*136*	NS	80
2073	2,5- or 2,4-dimethylphenol	107	4450	*344*	2380	*407*	***	230
2088	a methylphenol	107	1270	*40*	716	*206*	*	100
2099	4-propylguaiacol	137	4050	*168*	923	*100*	***	80
2266	2,6-dimethoxyphenol (syringol)	154	877	*137*	504	*89*	**	60
2349	4-methylsyringol	168	232	*99*	116	*24*	NS	40
		subtotal:	**101729**		**45634**			
	other							
1357	dimethyl trisulfide	79	3390	*595*	4440	*823*	NS	430
2407	unknowns 182, 167	182	2890	*268*	533	*99*	***	100
		subtotal:	**6280**		**4973**			

[a] Relative peak areas are expressed as the mean (three replicate analyses for each treatment) and standard deviation, relative to the peak area given by 1 ng of bromobenzene = 100; values >1000 are stated to three significant figures. Values in bold are the sum of relative peak area values for the given compound class. [b] Degree of significance among the three frankfurters (analysis of variance): NS, no significant difference; *, $P < 0.05$; **, $P < 0.01$; ***, $P < 0.001$. [c] SEM, standard error of means.

Table 3. Effect of Fat on Main Individual Odors and Key Odor Compounds from Frankfurters

LRI[a]	odor	possible compound	frequency of detection of odor from frankfurters containing 5% fat	12% fat	30% fat
982	caramel, fudge, vanilla	2,3-butanedione	**5** (3)*m*[b]	**5** (2) *w*	**6** (3) *m*
1026	spices, green, pine needles	α-pinene	**2** (1) *w*	**2** (1) *w*	**1** (1) *vw*
1114	stale, sulfurous, vegetation	unknown	**2** (2) *w*	**2** (2) *w*	**3** (2) *w*
1164	vegetable, grassy, green	unknown	**1** (1) *w*	**3** (2) *w*	nd
1177	sweet, meaty, roasted	unknown	**6** (3) *w*	**1** (1) *vw*	nd
1203	metallic, geranium, stale	an unsaturated alcohol	**4** (3) *w*	**4** (3) *w*	**3** (2) *m*
1205	medicinal, cough syrup, eucalyptus, pine needles	1,8-cineole	**6** (3) *m*	**6** (3) *m*	**6** (3) *m*
1240	stale, damp, green, stagnant	unknown	**3** (3) *w*	**1** (1) *vw*	**2** (2) *w*
1300	mushrooms	1-octen-3-one	**4** (3) *w*	**4** (3) *w*	nd
1321	meaty, cereal	2-methyl-3-furanthiol	**2** (2) *vw*	**1** (1) *vw*	**1** (1) *w*
1373	meaty, roasty, metallic, geranium	dimethyltrisulfide	**6** (3) *w*	**6** (3) *w*	**6** (3) *vw*
1430	roasty, meaty	2-furanmethanethiol	**3** (2) *w*	**3** (2) *w*	nd
1451	potatoes, biscuity, roasted meat	methional	**6** (3) *w*	**4** (2) *w*	**4** (3) *vw*
1505	raw potatoes, stale, metallic	2-acetylfuran + unknown	**4** (2) *m*	**4** (2) *w*	**4** (3) *w*
1541	floral	linalool	**2** (1) *m*	**3** (2) *w*	**1** (1) *m*
1613	pop corn, biscuity	unknown	**4** (3) *m*	**2** (1) *vw*	nd
1663	meaty, roasty, biscuity	2-methyl-3-(methyldithio) furan	**5** (3) *w*	**5** (3) *w*	**5** (3) *w*
1733	medicinal, sl. faecal, plastic	unknown	**3** (2) *m*	**3** (2) *w*	**2** (1) *w*
1751	meaty, biscuity, roasted, popcorn	2-acetylthiazoline	**4** (2) *m*	**3** (2) *w*	**3** (2) *w*
1852	smoky, frankfurter	2-methoxyphenol	**6** (3) *m*	**6** (3) *m*	**6** (3) *w*
1934	smoky, frankfurter	2-methoxy-4-methylphenol	**4** (3) *w*	**4** (3) *w*	**3** (2) *w*
2081	burning, plastic, stale, gassy	2-methoxy-4-propylphenol	**5** (3) *w*	**4** (2) *vw*	**3** (2) *vw*
2150	sausage meat, eucalyptus, sweet	unknown	**4** (2) *m*	**2** (1) *w*	**4** (2) *w*
2222	mushrooms	unknown	**2** (1) *w*	**1** (1) *vw*	**1** (1) *vw*
2264	smoky, frankfurter, burnt	2,6-dimethoxyphenol	**2** (1) *vw*	**1** (1) *vw*	nd

[a] Linear retention indices on a CPWax 52 CB capillary column. [b] nd, odor not detected. Numbers in bold correspond to frequency of detection out of six runs; numbers in parentheses correspond to the number of assessors having detected the odor out of three assessors; letters in italics indicate approximate intensity of odor when detected (vw, very weak; w, weak; m, medium; s, strong; vs, very strong).

hydrocarbons, and, within the same class of compounds, the compounds with higher molecular weight appear to be more affected by the variation of fat.

The "smoky" odors at LRI 1934, 2081, and 2264, due to 2-methoxy-4-methylphenol (4-methylguaiacol), 2-methoxy-4-propylphenol (4-propylguaiacol), and 2,6-

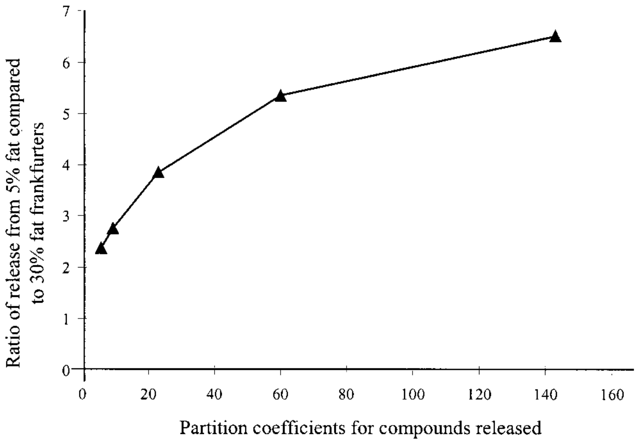

Figure 1. Plot of observed ratios of release between the low-fat and full-fat frankfurters against values of oil–water partition coefficients of phenols, as given in the literature (Doerr and Fiddler, 1970). Phenols include phenol, guaiacol, 4-methylguaiacol, 4-ethylguaiacol, and 4-propylguaiacol.

dimethoxyphenol (syringol), respectively, were also consistently detected more frequently in the low-fat frankfurters than in the other fat versions (Table 3). 2-Methoxyphenol was consistently detected by all assessors and was, therefore, probably too intense to allow discrimination among samples. These results agree with the increased perception of "smoky" flavor in low-fat frankfurters, as measured by sensory studies (Chevance and Farmer, 1998).

Studies conducted using simple emulsion-based model systems have shown that a reduction of oil increases the release of fat-soluble compounds (e.g., limonene, ethyl heptanoate, δ-decanolactone, *cis*-3-hexanol) and, hence, increases their sensory perception (Schirle-Keller et al., 1994; Guyot et al., 1996; Widder and Fischer, 1996). In contrast, the quantity and perception of diacetyl, a water-soluble compound, showed less change. Some authors have found that the effect of oil reduction is more pronounced as the chain length of a compound in a homologous series and, therefore, its hydrophobicity, increase (Buttery et al., 1973; Landy et al., 1996). A similar effect is observed with some of the data obtained in these studies. Figure 1 shows the ratio of volatile release between 5% fat and 30% fat frankfurters plotted against reported oil–water partition coefficients (Doerr and Fiddler, 1970) for a homologous series of phenols. The effect of fat on release appears to be greater for the higher molecular weight compounds, although the rate of increase in the ratio of volatile release between 5% fat and 30% fat frankfurters seems to decrease as the partition coefficient increases. It will be necessary to obtain reliable partition coefficients for a wider range of compounds to allow this relationship to be studied further. However, the above data are consistent with a hypothesis that fat is acting as a solvent for volatile flavor compounds, thus delaying the release of flavor in higher fat products.

LITERATURE CITED

Barbut, S.; Mittal, G. Influence of K^+ and Ca^{2+} on the rheological and gelation properties of reduced fat pork sausages containing carrageenans. *J. Food Sci. Technol.* **1989**, *22*, 124–132.

Buttery, R. G.; Guardagni, D. G.; Ling, L. C. Flavor compounds: Volatilities in vegetable oil and oil–water mixtures. Estimation of odor thresholds. *J. Agric. Food Chem.* **1973**, *21*, 198–201.

Chevance, F. F. V. Effect of fat on the release of volatile aroma compounds from frankfurters. Ph.D. Thesis, The Queen's University of Belfast, U.K., 1998.

Chevance, F. F. V.; Farmer, L. J. Influence of fat on the flavour of an emulsified meat product. In *Food Flavors: Formation, Analysis and Packaging Influences*; Contis, E., Ho, C. T., Mussinan, C., Parliment, T., Shahidi, F., Spanier, A., Eds.; Elsevier Science: Amsterdam, The Netherlands, 1998; pp 255–270.

Chevance, F. F. V.; Farmer, L. J. Identification of major volatile and volatile odor compounds from frankfurters. *J. Agric. Food Chem.* **1999**, *47*, 5151–5160.

Delahunty, C. M.; Piggott, J. R.; Conner, J. M.; Paterson, A. Low-fat cheddar cheese flavour: flavour release in the mouth. In *Trends in Flavour Research, 7th Weurman Flavour Research Symposium*; Maarse, H., van der Heij, D. G., Eds.; Elsevier Science: Amsterdam, The Netherlands, 1994; pp 47–52.

De Roos, K. B.; Wolswinkel, K. Nonequilibrium partition model for predicting flavour release in the mouth. In *Trends in Flavour Research, 7th Weurman Flavour Research Symposium*; Maarse, H., van der Heij, D. G., Eds.; Elsevier Science: Amsterdam, The Netherlands, 1994; pp 15–32.

Doerr, R. C.; Fiddler, W. Partition ratios of some wood smoke phenols in two oil: water systems. *J. Agric. Food Chem.* **1970**, *18*, 937–939.

El-Magoli, S. B.; Laroia, S.; Hansen, P. M. T. Flavor and texture characteristics of low fat ground beef patties formulated with whey protein concentrate. *Meat Sci.* **1996**, *42*, 179–193.

Guyot, C.; Bonnafont, C.; Lesschaeve, I.; Issanchou, S.; Voilley, A.; Spinnler, H. E. Relationships between odorous intensity and partition coefficients of δ-decalactone, diacetyl and butyric acid in model emulsions. In *Flavour Science: Recent Developments, 8th Weurman Flavour Research Symposium*; Taylor, A. J., Mottram, D. S., Eds.; The Royal Society of Chemistry: Cambridge, U.K., 1996; pp 380–385.

Hand, L. W.; Holligsworth, C. A.; Calkins, C. R.; Mandigo, R. W. Effects of preblending, reduced fat and salt levels on frankfurters characteristics. *J. Food Sci.* **1987**, *52*, 1149–1151.

Hughes, E.; Cofrades, S.; Troy, D. J. Effects of fat level, oat fibre and carrageenan on frankfurters formulated with 5, 12, and 30% fat. *Meat Sci.* **1997**, *45*, 273–281.

Ingham, K. E.; Taylor, A. J.; Chevance, F. F. V.; Farmer, L. J. Effect of fat content on volatile release from foods. In *Flavour Science: Recent Developments, 8th Weurman Flavour Research Symposium*; Taylor, A. J., Mottram, D. S., Eds.; The Royal Society of Chemistry: Cambridge, U.K., 1996; pp 386-391.

Land, D. G. Some factors influencing the perception of flavour contributing substances in food. In *Progress in Flavour Research, 2nd Weurman Flavour Research Symposium*; Land, D. G., Nursten, H., Eds.; Applied Science Publishers: London, U.K., 1979; pp 53–66.

Landy, P.; Courthaudon, J.-L.; Dubois, C.; Voilley, A. Effect of interface in model food emulsions on the volatility of aroma compounds. *J. Agric. Food Chem.* **1996**, *44*, 526–530.

Marquez, E. J.; Ahmed, E. M.; West, R. L.; Johnson, D. D. Emulsion stability and sensory quality of beef frankfurters produced at different fat or peanut oil levels. *J. Food Sci.* **1989**, *54*, 867–870, 873.

Mottram, D. S. Meat. In *Volatile Compounds in Foods and Beverages*; Maarse, H., Ed.; Dekker: New York, 1991; pp 107–177.

Nickerson, G. B.; Likens, S. T. Gas chromatographic evidence for the occurrence of hop oil components in beer. *J. Chromatogr.* **1966**, *21*, 1–5.

Overbosch, P.; Afterof, W. G. M.; Haring, P. G. M. Flavor release in the mouth. *Food Rev. Int.* **1991**, *7*, 137–184.

Park, J.; Rhee, K. S.; Keeton, J. T.; Rhee, K. C. Properties of low-fat frankfurters containing monounsaturated and omega-3 polyunsaturated oils. *J. Food Sci.* **1989**, *54*, 500–504.

Piraprez, G.; Hérent, M.-F.; Collin, S. Flavour retention by lipids measured in a fresh cheese matrix. *Food Chem*. **1998**, *61*, 119−125.

Salvador, D.; Bakker, J.; Langley, K. R.; Potjewijd, R.; Martin, A.; Elmore, J. S. Flavour release of diacetyl from water, sunflower oil and emulsions in model systems. *Food Qual. Pref.* **1994**, *5*, 103−107.

Schirle-Keller, J. P.; Reineccius, G. A.; Hatchwell, L. C. Flavor interactions with fat-replacers: Effect of oil level. *J. Food Sci*. **1994**, *59*, 813−815, 875.

Solheim, R. Consumer liking for sausages affected by sensory quality and information on fat content. *Appetite* **1992**, *19*, 285−292.

Widder, S.; Fischer, N. Measurement of the influence of food ingredients on flavour release by headspace gas chromatography-olfactometry. In *Flavour Science: Recent Developments, 8th Weurman Flavour Research Symposium*; Taylor, A. J., Mottram, D. S., Eds.; The Royal Society of Chemistry: Cambridge, U.K., 1996; pp 405−412.

Wirth, F. Technologies for making fat-reduced meat products. *Fleischwirtsch* **1988**, *68*, 1153−1156.

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