Effect of Some Fat Replacers on the Release of Volatile Aroma Compounds from Low-Fat Meat Products

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The effect of fat content and carbohydrate fat-replacers on the release of volatile odor compounds from beefburger, salami, and frankfurter has been investigated. The reduction in fat content in any of the three meat products studied resulted in a tendency toward an increase in the quantities of volatiles released in the headspace. Tapioca starch and maltodextrin appear to delay the release of certain classes of compounds selectively; for instance, tapioca starch appears to slow the release of some Maillard products while maltodextrin has a similar effect on terpenes. In contrast, oat fiber decreases the release of most of the compounds analyzed. Thus, the addition of carbohydrate fat-replacers to low-fat meat products could assist the flavor qualities of low-fat meat products by slowing down the release of odor compounds.

Keywords: *Flavor; odor; volatiles; odor compounds; low fat; meat products; beefburgers; salami; frankfurters; fat-replacers; oat fiber; tapioca starch; maltodextrin*

INTRODUCTION

Processed meats such as ground beef, coarse ground sausages, and emulsified sausages typically contain more triglyceride lipids than whole-muscle products, and therefore, they have been a subject of concern regarding their contribution to a healthy diet. The formulation of these products can be modified in order to produce "low-fat" or "reduced-fat" versions of meat products. However, the reduction of fat usually alters the textural and the flavor characteristics of such products. Low-fat minced beef produced by decreasing only the fat content from the full-fat product is known to have decreased product palatability, flavor intensity, juiciness, and tenderness compared to the full-fat product (Cross et al., 1980; Egbert et al., 1991; Berry, 1992; Millar et al., 1993; Troutt et al., 1992b). Sausages or frankfurters with reduced quantities of fat become tougher and more rubbery in texture (Hand et al., 1987; Wirth, 1988; Barbut and Mittal, 1989; Marquez et al., 1989; Park et al., 1989), have increased intensity of certain flavor attributes (e.g., smokiness, spiciness, saltiness), and reduced overall acceptability of the flavor (Solheim, 1992; Hughes et al., 1997; Chevance and Farmer, 1998), in comparison with their full-fat counterparts. For frankfurters, this increase in flavor intensity has been shown to coincide with a greater release of volatile flavor compounds from the low-fat sausage in comparison with the full-fat equivalent (Chevance and Farmer, 1999b). It is likely that fat acts as a solvent for these volatile flavor compounds and thus delays their release (Chevance and Farmer, 1999b).

Studies on interactions between flavor compounds and macromolecules in model systems have indicated that carbohydrates and proteins can bind, adsorb, entrap, complex, or encapsulate flavor compounds and may also undergo chemical reactions with them (Solms, 1986; Kinsella, 1990; Matheis, 1993; Plug and Haring, 1994; O'Neill, 1996). It has been suggested that interactions between volatile flavor compounds and carbohydrates or proteins are mainly reversible, thus, in principle, allowing the release of flavor compounds in the oral cavity during the eating process (Kinsella, 1990; Matheis, 1993). Therefore, it is possible that fat-replacers could facilitate the gradual release of flavor in low-fat products.

Plant or animal proteins, carbohydrates, fibers, and gums have been incorporated into low-fat meat products primarily to improve the textural and structural characteristics of low-fat meat products (Keeton, 1994; Mandigo and Eilert, 1994). Very little information is available on the effects of these fat-replacers on the release of volatile aroma compounds from meat products; El-Magoli et al. (1996) investigated the effect of adding whey protein concentrate to beef patties, with or without lactose, on a limited number of volatile compounds. They concluded that both treatments decreased the relative concentrations of hexanal and certain hydrocarbons (pentane, hexane, and heptane) but increased the concentration of other compounds (tentatively identified as 2-methylbutanal and 4,4-diethyl-2-oxetanone). More information is available on

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the effect of such ingredients on the sensory perception of flavor, with conflicting results, depending on the nature and quantity of the fat-replacers, and on the meat product studied. Soy protein, for example, has been reported to introduce "cereal-like" or "beany" off-flavors in beef patties (Brewer et al., 1992; Park et al., 1993) and frankfurters (Matulis et al., 1995), while corn starch has been shown to enhance "organ-meat/metallic" flavor in reduced-fat turkey frankfurters at high concentrations (Beggs et al., 1997). However, other experiments have shown a decrease in the intensity of some flavor attributes on addition of fat-replacers. For example, the addition of soy products to beef patties results in a decrease in beefy flavor or overall flavor, compared with controls (Drake et al., 1975; Kotula et al., 1976; Berry and Leddy, 1988; Brewer et al., 1992). Drake et al. (1975) also showed that increasing the soy protein level in the product resulted in further significant decreases in flavor ratings. Whey protein concentrate appears to reduce the intensity of meat flavor in frankfurters (Hung and Zayas, 1992), while recent studies (Mansour and Khalil, 1999) have shown that the addition of wheat fiber to low-fat beefburgers does not affect beef flavor intensity compared with full-fat beefburgers. Combinations of several fat-replacers have been used to improve the overall acceptability of low-fat beefburgers but cause a slight reduction of beef intensity scores compared with the full-fat products without fat-replacer (El-Magoli et al., 1996; Troutt et al., 1992a). In contrast, a recent study has indicated that certain blends of fat-replacers can be used to replace fat without alteration of the flavor characteristics (Troy et al., 1999).

This paper presents the results of three short preliminary studies whose aim was to investigate the effect of fat-replacers on the release of flavor compounds in low-fat meat products. These three studies formed part of an EU-funded project on low-fat meat products and were conducted on salami (Parma, Italy), beefburgers (Dublin, Ireland), and frankfurters (Belfast, U.K., and Dublin, Ireland). The fat-replacers (oat fiber, maltodextrin, and tapioca starch) were chosen for their ability to improve the structural and textural characteristics of the low-fat meat products being studied (Hughes et al., 1997; Troy et al., 1999). The meat products, with and without fat replacers, were produced by methodologies appropriate to the different products and studies on the release of flavor from these products were conducted at The Queen's University of Belfast as three separate investigations. While the differences in methodologies limit the direct comparisons that can be made, the three studies, nevertheless, gave consistent and complementary results. These have been drawn together in this paper.

MATERIALS AND METHODS

Trial 1: Effect of Tapioca Starch and Oat Fiber on Release of Flavor Volatiles from Low-Fat Beefburgers. Full-fat and low-fat beefburgers, together with low-fat beefburgers containing tapioca starch or oat fiber, were prepared at the National Food Centre, Dublin, as described by Desmond et al. (1998). The full-fat and low-fat beefburgers were formulated to contain nominal fat contents of 23% and 10% fat in the raw burgers. The main constituents were lean beef forequarter and fat trimming (Hereford cross heifers; 18−24 months old) together with water and encapsulated salt (0.5%, Balchem Corp, PO Box 175, Slate Hill, NY). Low-fat beefburgers were also prepared which incorporated tapioca starch (2.5%, Tapiocaline EX533, Tipiak, London, U.K.) or oat fiber (1.0%, OPTA Oat fiber 780, Williamson Fiber Products, Cork, Ireland). Beefburgers (113 g) were formed using a Manca burger press (Manca Butcher Equipment, Barcelona, Spain). Burgers were stacked four high and frozen overnight in plastic lined boxes at −20 °C. Once frozen, burgers were then vacuum-packed and stored at −20 °C until required.

Flavor analyses were conducted at The Queen's University of Belfast. A sample of beefburger (50 g), cut into four pieces, was placed in an Erlenmeyer flask loosely covered with aluminum foil and cooked in a water-bath at 100 °C for 30 min. The flask was then immediately fitted with a Dreschel head and conditioned trap (containing 2.6 mg Tenax GC, Scientific Glass Engineering Ltd, Milton Keynes, U.K.), placed in a water bath at 60 °C, and the volatiles collected for 30 min by dynamic headspace concentration as described previously (Chevance and Farmer, 1999a,b). An internal standard (37.3 ng bromobenzene) was added to the trap prior to collection (Chevance and Farmer, 1999b). Triplicate collections were conducted for each beefburger type. The collected volatiles were analyzed using a Carlo Erba MFC 500 gas chromatograph connected to a Kratos MS25 RFA mass spectrometer (Kratos Analytical Ltd., Manchester, U.K.) fitted with a CPWAX 52CB capillary column (50 m × 0.32 mm I.D., Chrompak, London, U.K.) as described previously (Chevance and Farmer, 1999a). In this preliminary study, 24 compounds were selected for analysis; these included the most abundant headspace volatile compounds, together with any compounds which demonstrated clear differences between the four types of beefburgers. The relative ion area for each compound was expressed as the area of the ion listed in Table 1 relative to the area of ion m/z 156 for bromobenzene divided by the mass of bromobenzene injected (37.5 ng), and subjected to one way analysis of variance (Genstat 1994) to compare the means for the four treatments. When significant overall differences were found, Fisher's least significant difference test was used to compare individual treatments.

Trial 2. Effect of Maltodextrin and Tapioca Starch on the Release of Odor Compounds from Salami. The production of four types of salami Milano was arranged by the University of Parma: one full-fat (28% nominal fat content) and three low-fat (15% nominal fat content). The precise formulations were as shown in Table 2. Low-fat batches were prepared by replacing part of the shoulder and the belly meat with trimmings obtained from fresh hams. The latter, compared with shoulder muscle, are characterized by very lean muscles with little intramuscular fat while the intermuscular fat can be reduced by manual trimming. In two of the low-fat batches, part of the belly meat was also substituted with tapioca starch (Tapiocaline CR521, Tipiak, Nantes, France) or with maltodextrin (C*Pur 01915, D.E. 18 ± 2, Cerestar, Milano, Italy). Meat and fat cuts were all obtained fresh (unfrozen) from a local slaughterhouse.

Additives (salts, spices, etc.) and processing technology were as described by Novelli et al. (1998), with the only adjustment regarding the dehydration step which was slowed by controlling the humidity in the drying rooms; the salami was held at 23 °C for 12 h with no control of relative humidity (RH), then at 20 °C for 18 h (RH = 75%), and at 11−12 °C (RH = 85−90%) until matured (up to 110 days).

The volatile odor compounds released from the four formulations of salami were collected by the static headspace collection method described previously (Chevance and Farmer, 1998). Slices of salami (20 g) were homogenized in a small food processor (Mini Chopper, model CH100, Kenwood Ltd., Hants, U.K.) and placed in a glass bottle (100 mL, Duran, Davidson and Hardy Ltd., Belfast, U.K.) into which a Tenax trap and a gastight syringe (10 mL; Series II, Scientific Glass Engineering Ltd.) could be fitted. After 15 min at 40 °C, the headspace volatiles (10 mL) were displaced on to the trap (Chevance and Farmer, 1999a). Gas chromatography was performed using a HP 5890 Series II gas chromatograph (Hewlett-Packard, Wokingham, Berks, U.K.), fitted with a sniffing port and a CPSil8CB capillary column (50 m × 0.32 mm i.d., Chrompack Ltd, London, U.K.). The odors of the separated volatiles were

Table 1. Effect of Fat Content, Tapioca Starch, and Oat Fiber on the Release of Selected Volatile Compounds from Beefburgers

			mean relative ion area[b] beefburger types[e]					
compd	ion	LRI[a]	FF	LF	LF + OF	LF + TS	SEM[c]	method of ID[d]
aldehydes								
hexanal	56	1092	3.02	3.42	2.64	3.36	0.546	MS + LRI
heptanal	70	1179	2.70^{ab}	3.28^{b}	2.26^{a}	3.52^{b}	0.435	MS + LRI
octanal	84	1280	0.69	0.96	0.71	1.31	0.322	MS + LRI
nonanal	57	1382	1.56	2.11	2.09	2.93	0.778	MS + LRI
2-hexenal	69	1220	0.14^{ab}	0.12^{ab}	0.06^{a}	0.16^{b}	0.035	MS + LRI
2-heptenal	83	1321	0.22^{ab}	0.27^{ab}	0.15^{a}	0.36^{b}	0.081	MS + LRI
2-octenal	41	1413	0.19^{a}	0.29^{ab}	0.15^{a}	0.39^{b}	0.071	MS + LRI
2-nonenal	70	1524	0.22^{ab}	0.22^{ab}	0.13^{a}	0.44^{b}	0.123	MS + LRI
2-decenal	70	1631	0.10	0.12	0.07	0.25	0.081	MS
4-heptenal	68	1243	0.23^{ab}	0.30^{ab}	0.10^{a}	0.41^{b}	0.096	MS
2,4-heptadienal	81	1491	0.11^{ab}	0.15^{ab}	0.05^{a}	0.17^{b}	0.046	MS
alcohols								
1-pentanol	70	1251	1.57	1.35	1.37	1.31	0.268	MS + LRI
1-hexanol	31	1353	0.83^{ab}	1.12^{ab}	0.68^{a}	1.24^{b}	0.195	MS + LRI
1-heptanol	56	1460	0.82^{a}	1.19^{ab}	0.72^{a}	1.50^{b}	0.264	MS + LRI
1-octanol	41	1555	0.56^{a}	0.99^{ab}	0.76^{ab}	1.27^{b}	0.236	MS + LRI
1-octen-3-ol	72	1446	0.98^{a}	1.71^{b}	1.00^{a}	1.76^{b}	0.288	MS + LRI
trans-1-oct-2-enol	67	1609	0.08^{a}	0.16^{ab}	0.10^{a}	0.19^{b}	0.041	MS
2-ethyl-1-hexanol	83	1494	0.27^{a}	1.59^{b}	0.73^{a}	2.43^{c}	0.255	MS + LRI
ketones								
2-heptanone	58	1189	1.01^{a}	1.66^{ab}	1.05^{ab}	1.70^{b}	0.285	MS + LRI
2-octanone	58	1278	0.18	0.32	0.15	0.33	0.088	MS + LRI
cyclic compounds								
benzaldehyde	105	1505	2.13	2.95	2.72	3.13	0.508	MS + LRI
2-pentylfuran	81	1226	1.06^{a}	2.15^{c}	1.34^{ab}	1.80^{bc}	0.298	MS
sulfur compounds								
dimethyl trisulfide	126	1356	0.10	0.18	0.09	0.09	0.054	MS + LRI
2-acetylthiazole	112	1634	0.05	0.07	0.05	0.09	0.023	MS + LRI

[a] Linear retention indices (LRI) are given for a CPWax52CB column. [b] Mean ion area relative to internal standard bromobenzene (ion 156). [c] SEM = standard error of means. [d] MS = mass spectrum agrees with literature spectrum; MS + LRI = mass spectrum and LRI agrees with that of authentic compound. [e] Beefburger types: FF = full fat (23% fat); LF = low fat (10% fat); LF + OF = low-fat beefburgers with oat fiber (1%); LF + TS= low-fat beefburgers with tapioca starch (2.5%). [a−c] Mean relative ion areas which do not share a common superscript are significantly different ($P < 0.05$).

Table 2. Formulation (%) of Salami Types

	salami types[a]			
ingredients	FF	LF	LF + TS	LF + MD
shoulder	45	25		
ham trimmings	25	65	88	90
belly	30	10		
skimmed milk			2	2
tapioca starch			2.5	
water			7.5	
maltodextrin				8

[a] Salami types: FF = full fat (28% fat); LF = low fat (15% fat); LF + TS = low fat + tapioca starch; LF + MD = low fat + maltodextrin.

described and scored on a five point scale (1 = very weak, 2 = weak, 3 = medium, 4 = strong, 5 = very strong) by two assessors as described previously (Chevance and Farmer, 1998). The peak areas of the major volatile compounds detected by flame ionization detector were integrated and subjected to analysis of variance and Fisher's least significance test, as described for trial 1.

Dynamic headspace collections followed by GC−MS analyses, conducted as described for beefburgers, enabled identification of the major volatile compounds. Positive identification of volatile compounds was confirmed by matching the linear retention index (LRI) and mass spectral data with that of the authentic compound. The identities of the key odor compounds were confirmed, whenever possible, by comparing the odor description obtained by GC-odor assessment of the salami headspace with that of a similar concentration of the authentic compound analyzed in the same way.

Trial 3. Effect of Maltodextrin and Oat Fiber on the Release of Volatile Odor Compounds from Frankfurters. 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%, as previously described (Hughes et al., 1997; Chevance and Farmer, 1999a). In the reduced-fat products, water was added to replace the fat. Low-fat frankfurters were also prepared containing oat fiber (OPTA Oat fiber 780, Williamson Fiber Products, Cork, Ireland) or maltodextrin (C*Pur 01915, D.E. 18 ± 2, Cerestar, Manchester, UK), both at 2.0% total weight. A static headspace method similar to that described for salami and as described previously (Chevance and Farmer, 1998) was used to collect volatile odor compounds from frankfurters. Duplicate GC-odor assessments were performed by 3 different assessors (Chevance and Farmer, 1998) for each of the frankfurter formulations. Odor compounds were identified as described for odor compounds from salami. Peak areas of the major volatile compounds detected by flame ionization detector (FID) were integrated and subjected to analysis of variance and Fisher's least significance test, as described for Trial 1. The identification of these compounds by GC-MS has been described previously (Chevance and Farmer 1999a).

RESULTS

Trial 1. Effect of Tapioca Starch and Oat Fiber on Flavor Volatiles from Beefburgers. Table 1 lists the most abundant volatile compounds in beefburgers, together with any compounds that demonstrated clear differences between the four types of beefburgers. The headspace of all four types of beefburgers was dominated by saturated straight-chain aldehydes and alcohols. There were significant differences in relative ion areas between the low- and full-fat beefburgers for only three compounds, 1-octen-3-ol, 2-ethyl-1-hexanol, and

Table 3. Effect of Fat Content, Tapioca Starch, and Maltodextrin on the Release of Selected Volatile Compounds from Salami

		mean peak area[c] salami types[e]				
compd[a]	LRI[b]	FF	LF	LF + TS	LF + MD	SEM[d]
α-thujene	926	29^{a}	261^{b}	296^{b}	52^{a}	49.3
α-pinene	934	41^{a}	359^{b}	369^{b}	79^{a}	35.4
sabinene	973	35^{a}	299^{c}	420^{d}	130^{b}	21.2
β-myrcene	989	0^{a}	116^{b}	92^{b}	29^{a}	15.7
α-phellandrene	1004	7^{ab}	158^{b}	136^{b}	39^{a}	13.6
3-carene	1010	154^{a}	681^{b}	464^{b}	166^{a}	86.4
α-terpinene	1016	47^{a}	138^{b}	154^{b}	20^{a}	13.1
p-cymene	1023	135^{a}	465^{b}	569^{b}	141^{a}	79.1
limonene	1028	151^{a}	810^{b}	774^{b}	194^{a}	74.3
γ-terpinene	1058	44^{a}	207^{b}	216^{b}	35^{a}	20.2
terpinolene	1088	0^{a}	94^{c}	119^{c}	39^{b}	7.9

[a] Compounds were identified by comparison with their mass spectrum and LRI value obtained for the corresponding authentic compound, except for α-thujene, whose mass spectrum corresponded to that given by the mass spectral library. [b] Linear retention indices (LRI) are given on a CPSil8CB column. [c] Mean peak area given for three replicate analyses (static headspace). [d] SEM = standard error of means. [e] Salami types: FF = full fat (28% fat); LF = low fat (15% fat); LF + TS = low-fat salami with tapioca starch (2.5%); LF + MD = low-fat salami with maltodextrin (8%). [a−c] Mean peak areas which do not share a common superscript are significantly different ($P < 0.05$).

2-pentylfuran (Table 1). However, although most of the individual differences were not significant, most of the compounds from low-fat beefburgers were detected in greater quantities than from the full-fat beefburgers (Table 1).

The addition of tapioca starch to the low-fat beefburgers resulted in a tendency toward an increase in headspace volatiles released (Table 1). In contrast, the addition of oat fiber resulted in consistent decreases in the quantities of volatile compounds released, such that the overall quantities released were more similar to the full-fat beefburgers than to the low-fat beefburgers (Table 1). While most of the significant differences observed were between the beefburgers containing tapioca starch and oat fiber, significant differences in volatile concentrations between the low-fat control beefburgers and those containing oat fiber were observed for heptanal, 1-octen-3-ol, 2-ethyl-1-hexanol and 2-pentylfuran.

Trial 2. Effect of Maltodextrin and Tapioca Starch on the Release of Volatile Compounds from Salami. The major volatile compounds from salami collected by static headspace method and detectable by FID are listed in Table 3, together with their peak areas. These compounds were shown by GC-MS to be monoterpene hydrocarbons. A comparison of the full-fat and low-fat salamis showed that the release of these compounds was significantly increased by the reduction in fat content (Table 3). The inclusion of tapioca starch did not seem to greatly affect the release of monoterpenes from the low-fat salami, but adding maltodextrin resulted in a pronounced reduction in the quantities of volatiles released, giving quantities more similar to those obtained for the full-fat salami (Table 3).

The effect of fat replacers in salami is, to some extent, confounded by the presence of milk proteins in these salamis, but not the low-fat salami without fat replacers. It is possible, therefore, that the milk protein itself could exhibit some effect on flavor binding and release. However, it is clear that tapioca starch (with milk proteins) has very little effect on the major volatiles compared with the low fat salami (without milk proteins), while maltodextrin (with milk proteins) has a clear effect on the quantities of volatile compounds released (Table 3). It is likely, therefore, that maltodextrin is responsible for this effect.

Table 4. Effect of Fat Content, Maltodextrin, and Oat Fiber on the Release of Selected Volatile Compounds from Frankfurters

		peak area[c] frankfurter types[e]					
compd[a]	LRI[b]	FF	MF	LF	LF + OF	LF + MD	SEM[d]
α-pinene	1025	419^{b}	1028^{cd}	1214^{d}	650^{a}	971^{c}	75.9
β-pinene	1069	189^{a}	430^{c}	478^{c}	313^{b}	428^{c}	36.5
3-carene	1150	1699^{a}	4977^{c}	6570^{d}	2979^{b}	4753^{c}	349.4
β-myrcene	1161	258^{a}	1208^{c}	1700^{d}	836^{b}	1312^{c}	90.8
α-terpinene	1177	447^{a}	1594^{bc}	2378^{d}	1415^{b}	1941^{c}	123.7
limonene	1197	1158^{a}	3921^{c}	5770^{d}	2947^{b}	4465^{c}	299.2
1,8-cineole	1206	687^{a}	2017^{b}	3082^{c}	2321^{b}	2260^{b}	130.5
γ-terpinene	1242	662^{a}	2312^{c}	3587^{d}	1997^{b}	2771^{c}	215.2
p-cymene	1267	1126^{a}	2936^{bc}	3348^{c}	2346^{b}	3286^{c}	214.8
α-terpinolene	1278	235^{a}	883^{bc}	1385^{d}	802^{b}	1069^{c}	78.3
linalool	1540	135^{a}	388^{ab}	1002^{c}	888^{c}	779^{c}	116.6
β-caryophyllene	1588	108^{a}	223^{a}	572^{b}	441^{b}	445^{b}	57.5
4-terpineol	1599	172^{a}	486^{b}	965^{c}	926^{c}	840^{c}	73.1

[a] Compounds were identified by comparison with mass spectrum and LRI value obtained for the corresponding authentic compound. [b] Linear retention indices (LRI) is given on a CBWax52CB column. [c] Mean peak area given for four replicate analysis (static headspace). [d] SEM = standard error of means. [e] Frankfurter types: FF = full fat (30% fat); MF = medium fat (12%); LF = low fat (5% fat); LF + OF = low-fat frankfurter with oat fiber (2%); LF + MD = low-fat frankfurter with maltodextrin (2%). [a−d] Mean peak areas which do not share a common superscript are significantly different ($P < 0.05$).

To assess the effect of fat content and fat-replacers on the release of the key odors, GC-odor assessments were conducted on each of the four types of salami. Figure 1 shows the frequencies of detection of these odors, together with an indication of the odor scores obtained. The identities of the compounds responsible for these odors, where identified, are listed in the footnote to Figure 1. Some of the key odors detected in this study were different to those reported previously for salami (Meynier et al., 1999). Both studies found important and similar odors at approximate LRI values of 700, 920, and 1220. However, the retention index and descriptors of other odors differed. These differences are likely to be due to differences in the salami and method of volatile collection. The reduction in fat content of salami increased the number and sometimes the intensity of odors detected (Figure 1). The addition of maltodextrin or tapioca starch to low-fat salami caused a number of alterations to the odor profile.

Trial 3. Effect of Maltodextrin and Oat Fiber on the Release of Volatile Odor Compounds from Frankfurters. The relative peak areas of those volatiles collected by static headspace and detected by FID are listed in Table 4. The release of these compounds (mostly terpene hydrocarbons and alcohols) was greatly increased as the fat in frankfurters was decreased. This agrees with previous observations for the volatiles from these frankfurters collected by dynamic headspace concentration (Chevance and Farmer, 1999b). The addition of oat fiber and, to a lesser extent, maltodextrin, to the low-fat frankfurters reduced the quantities released of monoterpene hydrocarbons (Table 4). Terpene alcohols, such as linalool and 4-terpineol, and

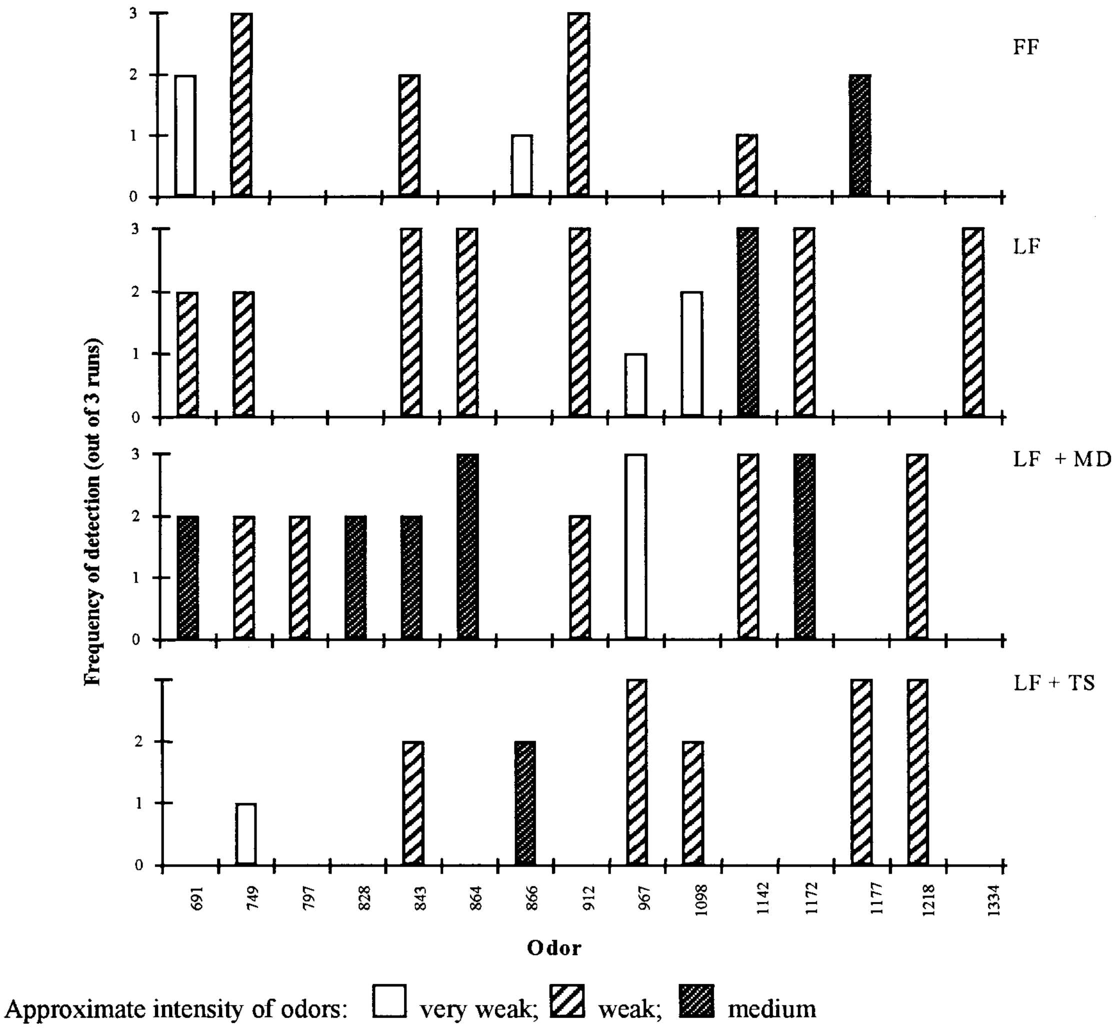

Figure 1. Effect of fat and fat-replacers on main odors detected in salami. Odors: The numbers correspond to LRI values of the odors on a CPSil 8CB capillary column. Descriptions of these odors are as follows: **691** = "salami, gas, sulfur"; **749** = "salami, spice"; **797** = "sweet"; **828** = "banana, sweet"; **843** = "salami, vanilla"'; **864** = "roasted meat" (2-methyl-3-furanthiol); **866** = "sweet"; **912** = "biscuity, pop corn"; **967** = "cabbage, sulfur, unpleasant" (dimethyltrisulfide); **1098** = "fresh, floral" (linalool); **1142** = "meaty, sulfur" **1172** = "roasty, meaty" (2-methyl-3-methyldithiofuran); **1177** = "sweet, vanilla"; **1218** = "grilled fat, sulfur"; **1334** = "meaty, caramel".

sesquiterpenes, such as β-caryophyllene, were less affected by the addition of oat fiber or maltodextrin.

Figure 2 compares the frequencies of detection and odor scores obtained for low-fat frankfurters containing oat fiber or maltodextrin with those obtained for the full, medium and low-fat frankfurters without fat-replacers. The identities of the compounds responsible for these odors, where known, are listed in the footnote to Figure 2. The values for low-fat, medium fat, and full-fat frankfurters have been reported elsewhere (Chevance and Farmer, 1999b), but are illustrated here for comparison; many of the odors were detected more frequently and scored more highly for the low-fat than the full-fat frankfurters, with medium-fat frankfurters usually receiving intermediate scores. The addition of oat fiber or maltodextrin to the low-fat product tended to reduce the frequency of detection of these odors. In the case of maltodextrin, 10 of the 24 odors show a clear reduction in the frequency of detection and/or intensity of the odors, while for oat fiber, eight odors are similarly reduced.

DISCUSSION

Reducing the fat content in any of three meat products studied showed a similar tendency toward an increase in quantities of volatiles released in the headspace (Tables 1, 3, and 4). This effect is believed to be due to the lipids acting as a solvent for aroma compounds; volatile compounds with a greater affinity for the lipid phase appear to show a greater increase in flavor release in reduced fat frankfurters (Chevance and Farmer, 1999b).

The effects of the fat-replacers appear to be dependent on the type of fat-replacer and on the particular flavor compound class. The following examines the effect of each fat-replacer on the release of different compound classes.

Tapioca Starch. Low-fat beefburgers containing tapioca starch released volatiles in similar quantities to the low-fat product without fat-replacers (Table 1). There was no evidence of any decrease in flavor release; indeed, for one compound (2-ethyl-1-hexanol) increased quantities were found in the presence of tapioca starch. Similar results were obtained for salami; there were no significant differences in the volatiles released, except for an increase in the quantity of sabinene detected (Table 3). However, changes were observed in the odors detected by GC−OA. Fewer odors were detected in the low-fat salami with tapioca starch than in the equivalent salami without fat-replacer. Odors described as

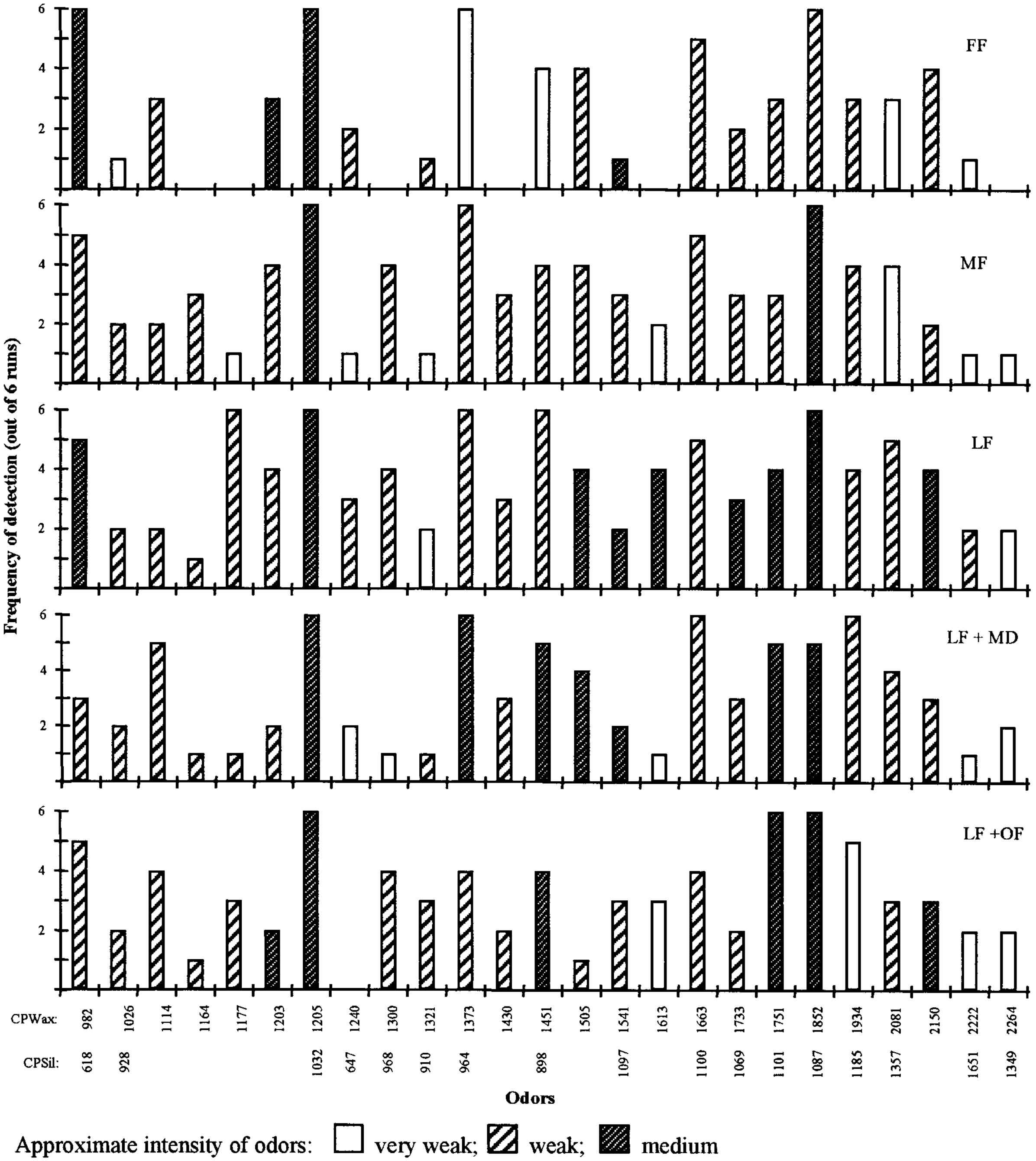

Figure 2. Effect of fat and fat-replacers on main odors detected in frankfurters Odors: The numbers correspond to LRI values on two capillary columns, whenever possible. The following descriptions are given in reference to CPWax52CB values: **982** = "caramel, fudge, vanilla" (2,3-butanedione); **1026** = "spices, green, pine needles" (α-pinene); **1114** = "stale, sulfurous, vegetation" (unknown); **1164** = "vegetable, grassy, green" (unknown); **1177** = "sweet, meaty, roasty" (unknown); **1203** = "metallic, geranium, stale" (an unsaturated alcohol); **1205** = "medicinal, cough syrup" (1,8-cineole); **1240** = "stale, damp, green" (unknown); **1300** = "mushroom" (1-octen-3-one); **1321** = "meaty, cereal" (2-methyl-3-furanthiol); **1373** = "meaty, roasty, metallic" (dimethyltrisulfide); **1430** = "roasty, meaty" (2-furanmethanethiol); **1451** = "potatoes, biscuity, roasty" (methional + unknown); **1505** = "raw potato, stale, metallic" (2-acetylfuran + unknown); **1541** = "floral" (linalool); **1613** = "popcorn, biscuity" (unknown); **1663** = "meaty, roasty, biscuity" (2-methyl-3-(methyldithio)furan; **1733** = "medicinal, slightly fecal" (unknown); **1751** = "meaty, biscuity, popcorn" (2-acetylthiazoline); **1852** = "smoky, frankurter" (guaiacol); **1934** = "smoky, frankurter" (4-methylguaiacol); **2081** = "burning, plastic, stale, gassy" (4-propylguaiacol); **2150** = "sausage meat, eucalyptus" (unknown); **2222** = "mushroom" (unknown); **2264** = "smoky, frankfurter, burnt" (syringol).

"salami, gas, sulfur" (LRI 691 on CPSil8CB column), "salami, spice" (LRI 749), "roasted meat" (LRI 864), "biscuity, popcorn" (LRI 912), "meaty, sulfur" (LRI 1142), "roasted, meaty" (LRI 1172), and "meaty, caramel" (LRI 1334) were reduced in the presence of tapioca starch (Figure 1). The compounds responsible for these odors, where identified (see footnote to Figure 1), are sulfur-containing furans and other Maillard-type products, generally possessing very low odor thresholds. It appears that tapioca starch may selectively bind these compounds, but not the terpenes listed in Table 3. Four odors were increased in frequency of detection or intensity by the presence of tapioca starch; these included "sweet" (LRI 866), "cabbage, sulfur" (LRI 967), "fresh, floral" (LRI 1098) and "sweet, vanilla" odors (LRI 1177). The odor profile did not mimic that of the full-fat salami.

The salami containing tapioca starch also contained skimmed milk, unlike the low-fat salami without fat replacers (Table 2), which raises the possibility that milk proteins caused or contributed to the changes described. However, with the exception of the decrease in "meaty, caramel" (LRI 1334) and an increase in "cabbage, sulfur" (LRI 1967) the same effects were not observed for low fat salami containing maltodextrin and skimmed milk. Thus, while further studies are needed to clarify the effects of these ingredients, it seems likely that tapioca starch is delaying the release of certain odor compounds.

Tapioca starch, in common with other native starches, comprises amylose and amylopectin fractions. Amylose, with glucose linked by α-(1−4) glucosidic bonds, has a helical structure which is capable of trapping flavor compounds (Solms, 1986; Matheis, 1993). In these helical structures, hydroxyl groups are orientated to the outside of the coil, forming hydrophobic regions inside the helices in which lipophilic flavor compounds can be retained (Godshall and Solms, 1992). Relatively low-molecular weight compounds (e.g., hexanol) can be entrapped in single helices where one turn consists of six glucose molecules. Higher molecular weight or cyclic compounds (e.g., monoterpene hydrocarbons) might be entrapped in helices of 7-D-glucosyl residues per turn (Matheis, 1993) or in the interhelical space outside helices formed of 6-D-glucosyl residues per turn (Nuessli et al., 1997). The outer branches of the amylopectin can also form helical structures and interact with flavor compounds (Rutschmann and Solms, 1990). However, starches with a low amylose content or waxy starches consisting only of amylopectin, have been reported to have a weak binding capacity (Matheis, 1993). Tapioca starch contains one of the lowest amylose contents of any of the native starches, with 17% amylose and 83% amylopectin content (Rapaille and Vanhemelrijck, 1992). This may be one reason tapioca starch did not have any effect on aldehydes, ketones and alcohols released from beefburgers, nor on monoterpene hydrocarbons from salami. However, some type of interaction occurred between tapioca starch and most meaty odor compounds in salami.

Maltodextrin. The effect of maltodextrin on the major volatile compounds and odors was examined for both salami and frankfurters. In the case of salami, the addition of 8% maltodextrin caused a substantial decrease in the quantity of all the terpenes monitored while a lesser amount (2%) of maltodextrin in frankfurters caused smaller but consistent reductions in terpenes. The effect on odors was less consistent. In salami, two odors (LRI 1098 and 1334 on CPSil8CB) were reduced by maltodextrin compared with low fat salami without fat replacers (Figure 1), while the intensity of at least 7 of the 25 odors detected in the low-fat frankfurters decreased on adding maltodextrin (Figure 2). However, other odors were increased by adding 8% maltodextrin to salami (LRI, 797, 828, and 1218). The last of these may have arisen from the milk proteins as it was also present in low fat salami with tapioca starch.

Three of the odors listed for salami (Figure 1) were caused by compounds detected by GC-FID (Table 3; α-pinene, 1,8-cineole, and linalool) and reduced in the presence of maltodextrin. The odor impact of these compounds changed only slightly between treatments, suggesting that large changes in quantities of volatiles released are needed to give odor differences detectable by the human nose using GC−OA. Nevertheless, some odors do change in intensity and frequency of detection.

The odors which were more intense in the low-fat frankfurters than the full-fat frankfurters were "sweet, meaty, roasty" (LRI 1177), "mushroom" (LRI 1300), "roasty, meaty" (LRI 1430), "potatoes, biscuity, roasty" (LRI 1451), "popcorn, biscuity" (LRI 1613). The inclusion of maltodextrin reduced the intensity and the frequency of detection of three of these odors (LRI 1177, 1300, and 1613). However, additional odors contributed to the odor which were not major contributors to the odor of full-fat frankfurters.

Thus, it appears that monoterpene hydrocarbons and some aliphatic compounds are retained in the presence of maltodextrin in low fat meat products, but that other compounds, such as monoterpene alcohols and phenols are unaffected. These results partly agree with those obtained in model systems by other authors (Bredie et al., 1994), who found that maltodextrin increases the retention of limonene. However, these authors also reported that the retention of the terpene alcohol, menthol, by maltodextrin was greater than that of limonene. In the studies on frankfurters (Table 4), the terpene alcohols monitored (linalool and 4-terpineol) appeared less affected by maltodextrin than the monoterpene hydrocarbons.

Dextrins are derived from the hydrolysis of a starch that has been depolymerized in aqueous media using catalysts, enzymes or acids. If the degree of depolymerization has not been too extensive (≤20%, i.e., dextrose equivalent = 20 or less), the resulting dextrin is called maltodextrin (Rapaille and Vanhemelrijck, 1992). The degree of polymerization of the maltodextrin is known to influence the retention of volatile components; flavor volatile retention has been shown to be inversely related to the dextrose equivalent of the polymer (Bangs and Reineccius, 1981; Bredie et al., 1994; LeThanh et al. 1992). It has been suggested that these larger dextrins may confer a degree of order to the solution, which could facilitate entrapment of aroma compounds (Bredie et al. 1994). In the present studies, the same maltodextrin was used for salami and frankfurters (dextrose equivalent around 18); such dextrins have been reported to give best results for aroma molecule encapsulation (Raja et al., 1989).

The starch used to produce the dextrin in these studies was derived from corn, which is known for its high content of amylose, with 26% amylose and 74% amylopectin (Rapaille and Vanhemelrijck, 1992). This may be one of the reasons why the resulting dextrin was better than tapioca starch at binding monoterpenes in the present studies.

Oat Fiber. The effect of oat fiber was examined in beefburgers and frankfurters. In beefburgers, the oat fiber caused a significant reduction in the quantities of four volatile compounds (heptanal, 1-octen-3-ol, 2-ethyl-1-hexanol, and 2-pentylfuran) compared with the low-fat beefburgers without fat-replacer (Table 1). While the remaining compounds did not individually show significant reductions, all except one (1-pentanol) showed a small decrease in quantity released from beefburgers with oat fiber. A similar effect was observed for frankfurters. For most of the terpenes monitored by static headspace analysis, the quantities released from the frankfurters with oat fiber were significantly reduced compared with the low-fat frankfurters without oat fiber (Table 4).

GC-odor assessment of the volatile compounds in frankfurters (Figure 2) shows that, of the five compounds which most contribute to the increase in odor volatiles in the low-fat frankfurters, three are decreased by the inclusion of oat fiber. These are as follows: "sweet, meaty, roasty" (LRI 1177), "potatoes, biscuity, roasty" (LRI 1451; methional + unknown), "popcorn, biscuity" (LRI 1613). Other odors, "stale, damp, green" (LRI 1240), "meaty, roasty, metallic" (LRI 1373; dimethyltrisulfide), and "raw potato, stale, metallic" (LRI 1505; 2-acetylfuran + unknown) are also decreased in importance. Thus, oat fiber appears to delay the release of a range of volatile classes, including the aliphatic compounds which dominated in beefburgers, terpenes and the sulfur compounds and Maillard products probably responsible for the above-mentioned odors in frankfurters.

One characteristic of oat fiber is its high β-glucan content (Webster, 1986). The energetically preferred conformation of (1→3) β-D-glucans, has been proposed to comprise a wide and extended helix, or probably, a double or triple stranded helix (Bluhm and Sarko, 1977). This may confer on the oat fiber its capacity to bind a wide range of volatile flavor compounds. The process of retention of flavor compounds by oat fiber or β-glucans requires further investigation.

These studies provide preliminary evidence that certain carbohydrates, sometimes used to improve the texture of low-fat meat products, may also assist the flavor qualities by delaying the release of some odor compounds. Tapioca starch and maltodextrin appear to delay the release of certain compound classes selectively. However, oat fiber slows the release of most of the compounds studied. Further research is needed to establish how much of this effect is due to specific binding and how much is caused by structural changes in the meat products, and also to evaluate the potential benefits of these carbohydrates in the formulation of low-fat meat products with improved flavor release properties.

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