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Effect of fat content on flavour release from sausages

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Abstract

The influence of fat content (5%, 10% and 15%) of sausage on the release of 10 volatile compounds with different physicochemical properties (log P and log ρL ranged between 1.01 and 4.23, and −0.66 and 1.69, respectively) was studied under static headspace (raw and cooked sausages) and in-mouth conditions (cooked sausages). Increasing fat content caused a general increase in the volatile compound concentrations of the sausages (fat acted as a reservoir) but a decrease in the compound concentration in the headspace and in the nosespace. The opposite effect was found for 3-methylbutanal and ethyl-2-methylbutanoate, which are more polar (low values for log P) and volatile (large values for log ρL) than the other compounds. Static headspace data revealed that the effect of fat content was larger in the raw samples than in the cooked sausages. The time to reach the maximum response for the compounds in the nosespace during mastication was not affected by fat content.

Keywords: Flavour release; Sausages; Fat content; APCI-MS; Nosespace; Cooking; Meat emulsion

1. Introduction

In recent years, health concerns about fat and changes in consumer preferences have led to extensive research on low-fat foods. Decreasing fat content of finely ground meat products modifies chemical composition and nutritive value, but also affects sensory characteristics and processing parameters (e.g. cooking loss, emulsion stability, yield) (Jiménez-Colmenero, 1996). Formulations with fat replacers provide low-fat meat products with acceptable processing parameters and sensory characteristics, but flavour is still a concern in these products and, in practice, a reformulation of flavourings and spices is required (Jiménez-Colmenero, 2000). The effect of decreasing fat content in sausage flavour is not clear: a decrease in sensory flavour scores was found by some authors (Jiménez-Colmenero, 2000), but others reported the opposite effect (Crehan, Hughes, Troy, & Buckley, 2000; Hughes, Cofrades, & Troy, 1997; Hughes, Mullen, & Troy, 1998). Varying fat content could influence sausage flavour by different mechanisms. Changes in the water/fat ratio modify the concentration in each phase of compounds such as salt (which is related to the ionic strength of the medium) and emulsifying proteins but also the concentrations of odour and taste active compounds. In addition, varying fat content influences emulsion stability (Jiménez-Colmenero, 1996), which could modify the interactions among some components involved in emulsion stability (e.g. proteins) and the odorants.

With regard to the odorants, the effect of fat content on their release from emulsions has been widely reported (Roberts, Pollien, Antille, Lindinger, & Yeretzian, 2003; Roberts, Pollien, & Watzke, 2003), but little attention has been paid to meat-based foods (Chevance & Farmer, 1999) and no data about flavour release from these products during mastication is available. Changes in fat content affect the release from emulsions as a function of the physicochemical parameters of each compound (Linforth, Friel, & Taylor, 1999). Among the thermodynamic parameters that affect flavour release, log P (indicator of hydrophobicity and therefore polarity) and log ρL (indicator of vapour pressure and therefore volatility) are key parameters describing odorant behaviour during eating of hydrocol-

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loid solutions (Linforth & Taylor, 2000) and gelatin/sucrose gels (Linforth et al., 1999), but up to now there are no data showing whether these parameters are related to odorant behaviour in meat emulsions.

Sausage odorants come from raw materials (e.g. spices and flavourings) or are generated through chemical reactions during cooking. With regard to sausage flavour, cooking is an important step of processing. Apart from compound generation, losses of odorants can occur through volatilization or reaction with other components, and also changes in sausage matrix (such as a reduction in moisture and occasionally fat, emulsion stability or protein denaturation) could modify odorant interaction and release. For compounds generated during cooking, it is difficult to study how a particular factor (e.g. cooking, fat content) influences flavour release without the interference of flavour generation. In addition, the usual low concentration of the odorants and the large number of volatile compounds (both odorants and odourless compounds) present in meat products make the study of in-mouth flavour release difficult because time-consuming concentration and separation procedures are not feasible. To overcome these drawbacks, the alternative approach of adding selected compounds at concentrations which can be monitored adequately by atmospheric pressure chemical ionization-mass spectroscopy (APCI-MS) has been successfully applied to dairy products (Brauss, Linforth, Cayeux, Harvey, & Taylor, 1999; Pionnier, Chabanet, Mioche, Le Quere, & Salles, 2004). The aim of this study was to study the influence of fat content on the release of odorants with different physicochemical properties under static headspace and in-mouth conditions.

2. Materials and methods

2.1. Materials

Ten volatile compounds (Table 1) with different physicochemical characteristics were chosen, taking into account log P (as an estimate of lipophilicity), log ρL (as an estimate of vapour pressure) and feasibility of monitoring by APCI-MS after mixing with the other compounds. Compounds were obtained from Sigma-Aldrich (Poole, Dorset, UK), except ethyl-2-methylbutanoate (Firmenich SA, Geneva, Switzerland). Log P and log ρL were calculated using the chemical modelling programme Molecular Operating Environment (MOE, Chemical Computing Group Inc, Quebec).

2.2. Preparation of sausages

The medium-fat content formulation (Table 2) was used to check whether the added volatile compounds had any effect on sausage properties. Two batches were prepared on the same day from the same raw materials, one containing the volatile compounds (500 mg of each compound/kg sausage) and the other with no added compounds.

Sausages with different fat contents were prepared by adjusting the amount of pork shoulder (20.7% protein content, 7.1% fat content, 71.5% water content), belly (15.3% protein content, 35.5% fat content and 48.7% water content) and water to give nominal fat contents of 5%, 10%, and 15% and a similar amount of protein (15%) (Table 2). The three batches were prepared on the same day and with the same raw materials. The volatile compounds (Table 1) were dissolved in propylene glycol (4.5 ml), added to water (450 ml) with vigorous mixing and divided into three aliquots, one for each sausage formulation. The pork shoulder was placed in a Hobart bowl chopper and was chopped with the rusk, the seasoning (a commercial mix including salt and additives), the volatile compound solution, the water, and then the chopped pork belly. The total chopping time was 9 min. The batter was stuffed into 30 mm diameter cellulose casings. Batter samples and sausages were vacuum-packaged and kept at −80 °C. When required, they were thawed at 4 °C, and grilled on individual tinfoil containers for 10 min using an electric grill. When cooking, sausages from the three formulations

Table 2
Sausage formulations (expressed as w/w percentage) for the 5%, 10% and 15% fat content sausages

	5% Fat	10% Fat	15% Fat
Shoulder	72	61	48
Belly	–	16	33
Compound solution	10	10	10
Water	9.6	5.4	1.1
Rusk	6.2	6.2	6.2
Seasoning	1.8	1.8	1.8

Table 1
Quantity, selected m/z values and physicochemical parameters of the volatile compounds added

Compounds added	mg/kg sausage	GC–MS m/z	APCI-MS m/z (cone voltage)	log P	log ρL
3-Methylbutanal	127	41	87 (15)	1.45	1.69
Hexanal	125	57	99 (15)	1.97	1.21
Octanal	251	41	111 (30)	2.86	0.27
Nonanal	251	41	143 (18)	3.30	−0.19
Decanal	504	41	157 (18)	3.74	−0.66
Octan-2-one	51	58	129 (21)	2.34	0.27
Ethyl-2-methylbutanoate	501	55	131 (21)	1.81	0.61
α-Pinene	253	93	92 (33)	3.94	−0.16
Myrcene	250	93	110 (27)	4.23	−0.60
Carvone	502	39	151 (24)	1.01	−0.42

(5%, 10% and 15% fat content) were grilled at the same time. The casings were removed prior to analysis.

2.3. Moisture determination and cooking losses

Moisture (AOCS, 1994) was determined on both raw batter and cooked sausages. Three replicates per treatment were performed.

Cooking losses were calculated by weight difference (with three replicates per treatment):

Water loss: (container with sausage before cooking-container with sausage after cooking) × 100/raw sausage.

Fat loss: (container after removing the cooked sausage and drying-container before placing on it the raw sausage) × 100/raw sausage.

2.4. Gas chromatography–mass spectrometry (GC–MS)

The samples were frozen with liquid nitrogen and blended to a powder. Two grams of the powder and 6 ml of dichloromethane solution containing 1-octanol (73 mg/l, m/z 41) were placed in a flask, capped and shaken for 3 h. One ml of the solution was vacuum-distilled by injection into a system which consisted of two round bottom flasks (one heated on a water bath 90 °C and the other cold on ice/water) pumped down and sealed at 690 mm Hg for 10 min. Then, the extract was analysed by GC–MS (Fisons GC800, MD800 Mass Spectrometer) using a DB5 column (30 m × 0.25 mm i.d. and 1 μm film thickness, J & W Scientific, Folsom, CA) and reference compounds for mass calibration. The 10 added volatile compounds were analysed in both raw batter and cooked sausages, with three replicates per treatment. Data were expressed relative to the largest value within the means for each compound to allow for easy comparison across fat levels.

2.5. Static headspace-atmospheric chemical pressure ionization-mass spectrometry (static headspace-APCI-MS)

A Platform quadrupole mass spectrometer (Micromass, Altrincham, UK) operating in the APCI positive ion mode and fitted with a custom-built air-sampling interface at Nottingham University (Linforth & Taylor, 1998) was used. After screening the headspace of aqueous solutions with individual compounds, the cone voltage was adjusted to give maximum sensitivity and minimize interferences for the selected m/z values to monitor each compound; m/z values and cone voltages for each compound are shown in Table 1.

Blended samples (5 g) were placed in 100 ml glass bottles, which were sealed and allowed to equilibrate to room temperature for 1 h. The headspace was sampled from the bottle directly into the APCI-MS via a heated (60 °C) deactivated fused silica line at a flow of 10 ml/min. The headspace was analysed on both raw batter and cooked sausages. Three replicates per treatment were performed in a random order. Data were expressed relative to the largest value within the means for each compound.

2.6. Breath-by-breath (nosespace)

Six subjects (4 females and 2 males) chewed a piece of cooked sausage (4 g) for 1 min while sampling volatile compounds from the nose into the APCI-MS (flow: 30 ml/min). Panellists were instructed to inhale and chew normally while their breath was sampled and to not swallow the samples (to avoid uncontrolled losses and get uniform conditions during mastication). Acetone (m/z: 59)(a measure for exhalation) was measured simultaneously to ensure that normal breathing patterns were maintained during eating. The breath of the panellists was also analysed prior to the consumption of each sample to check for carry over of compounds from previous samples. Each subject consumed three replicates of each sausage type (5%, 10%, 15% fat) in a different order. Data for maximum response were expressed relative to the largest value within the means for each compound.

2.7. Data analysis

A two-way analysis of variance (ANOVA) with interaction by the GLM (General Linear Model) procedure was used to compare means. When a significant effect ($p < 0.05$) was found by applying the ANOVA, the Duncan's multiple range test was used to check which sample groups were different from the others. Statistical analyses were performed by means of SPSS version 11.0.

3. Results and discussion

3.1. Sausage formulations

When varying the levels of a component in a food, it is necessary to decide which of the other components should be adjusted to make up for the changes and which components should remain the same. A pragmatic approach to study the effect of varying fat content on flavour release is replacing fat by water (modifying the proportion of shoulder, belly and water) while keeping the nominal content of rusk (6.2%), seasoning (1.8%) and proteins (15%) constant (Table 2) as any significant changes in their content would have important effects on the integrity of the products. However, small differences could be expected in the content of the emulsifying (myofibrillar) proteins, since shoulder has a larger relative content of them and a lower content of collagen than has belly. Therefore, the three groups are clearly different, not only in fat content, but also in water content, and it could be assumed that the content of other components is similar.

3.2. Effect of adding compounds

The effect of the added volatile compounds on sausage integrity was checked by measuring cooking losses. No significant differences between the control and the treated samples were found ($p = 0.896$ for fat loss, $p = 0.828$ for

water loss). Therefore, compound addition did not modify matrix characteristics significantly, and sausages with added compounds could be expected to behave like normal sausages. Sausages (raw and cooked) were also monitored for the presence of the added volatile compounds. GC–MS analysis of extracts from the sausages without added compounds showed that most of them were absent or, when detected, they were less than 0.5% of the compound detected in the sausages with added compounds. Static headspace-APCI-MS analysis of sausages again revealed that most compounds were absent or at trace quantities (at least 10^4-fold smaller) when they were not added. After checking the effect of compound addition, the initial quantities of added compounds (500 mg/kg sausage) were decreased for further experiments to the quantities shown in Table 1 to yield m/z intensities between $4\times10^6 - 6\times10^7$ ion counts in the static headspace-APCI-MS.

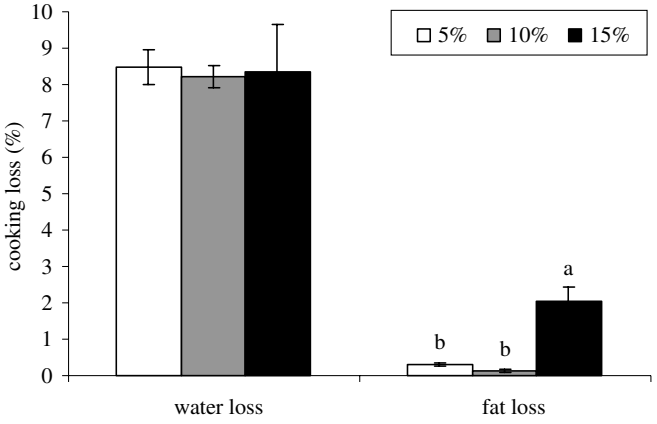

Fig. 1. Cooking losses measured by weighing (mean ± standard deviation) of sausages with varying fat content (5%, 10%, 15%). Different letters indicate significant differences ($p < 0.05$) in the Duncan's multiple range test.

3.3. Moisture changes and water loss after cooking

Results from the ANOVA in Table 3 show a significant effect of cooking on moisture content ($p = 0.006$), significant differences appearing only in the low fat content formulation.

Water losses after cooking were found in the range 7.8–8.9% (95% confidence intervals) and were larger than the values that could be expected from moisture decrease data. This could be related to the fact that sausages were cooked with the casings, which tend to trap water, whereas the other measurements (including moisture determination) were performed after removing the casings. Apparently, a similar difference between cooking loss and change in moisture content appeared in other studies (Crehan et al., 2000). As shown in Fig. 1, water loss was not significantly different among the three fat level sausages, and another ANOVA confirmed that there were no significant differences among the three groups for moisture decrease ($p = 0.342$).

3.4. Fat loss during cooking

Fig. 1 shows that fat losses during cooking did depend on the fat content of the sausages, full-fat sausages having the greatest losses. Data from other studies are limited (usually only total cooking loss is reported), but data about fat emulsion stability show no significant differences between 5% and 12% fat content sausages (Crehan et al., 2000; Hughes et al., 1997; Hughes et al., 1998). For a wider range of fat content or a larger fat content, contradictory results have been reported: a decrease of stability was found when increasing fat content (Andersson, Andersson, & Tornberg, 2000), but also when decreasing fat content (Crehan et al., 2000; Shackelford, Reagan, Haydon, Lyon, & Miller, 1991), which indicates that fat instability is not

Table 3
Moisture content and total volatile compound content (mean ± standard deviation) of raw and cooked sausages with different fat levels (5%, 10%, 15%) and statistical significance from a two way ANOVA (GLM) with interaction

	raw			cooked			p level		
	5% Fat	10% Fat	15% Fat	5% Fat	10% Fat	15% Fat	Cooking	Fat content	Interaction
Moisture[x]	71 ± 0.3^{a}	60 ± 1.9^{c}	50 ± 2.4^{d}	68 ± 0.6^{b}	58 ± 2.0^{c}	47 ± 1.0^{d}	0.006	<0.001	0.613
3-Methylbutanal[y]	3 ± 1.4^{c}	75 ± 5.9^{b}	100 ± 22.1^{a}	0 ± 0.0^{c}	0 ± 0.1^{c}	0 ± 0.1^{c}	<0.001	<0.001	<0.001
Hexanal[y]	13 ± 7.9^{b}	24 ± 12.0^{b}	83 ± 52.8^{a}	42 ± 7.5^{ab}	98 ± 31.7^{a}	100 ± 39.9^{a}	0.017	0.013	0.277
Octanal[y]	37 ± 10.9^{c}	55 ± 13.2^{bc}	77 ± 14.1^{ab}	74 ± 19.9^{ab}	100 ± 17.9^{a}	98 ± 15.3^{a}	<0.001	0.011	0.427
Nonanal[y]	49 ± 11.9^{c}	70 ± 9.8^{bc}	86 ± 16.7^{ab}	61 ± 14.0^{c}	87 ± 15.8^{ab}	100 ± 5.1^{a}	0.033	0.001	0.958
Decanal[y]	46 ± 11.1^{c}	80 ± 10.7^{ab}	95 ± 25.1^{ab}	71 ± 7.5^{bc}	100 ± 17.8^{a}	85 ± 3.6^{ab}	0.106	0.003	0.117
Octan-2-one[y]	34 ± 11.4^{b}	61 ± 28.6^{ab}	60 ± 14.7^{ab}	57 ± 29.5^{b}	52 ± 6.6^{b}	100 ± 25.7^{a}	0.099	0.044	0.170
Ethyl-2-methylbutanoate[y]	43 ± 3.2^{bc}	58 ± 34.8^{ab}	100 ± 52.5^{a}	1.1 ± 0.7^{c}	4.0 ± 0.4^{c}	0.90 ± 0.6^{c}	<0.001	0.189	0.169
α-Pinene[y]	35 ± 4.2^{b}	70 ± 9.2^{ab}	100 ± 28.8^{a}	55 ± 15.4^{b}	93 ± 10.2^{a}	100 ± 32.6^{a}	0.145	0.001	0.571
Myrcene[y]	41 ± 8.1^{b}	76 ± 10.0^{a}	87 ± 11.6^{a}	78 ± 26.3^{a}	93 ± 8.6^{a}	100 ± 22.3^{a}	0.013	0.009	0.434
Carvone[y]	64 ± 9.5	80 ± 10.5	100 ± 34.5	58 ± 5.5	83 ± 15.5	68 ± 8.0	0.161	0.070	0.224

Different letters in the same row indicate significant differences ($p < 0.05$) in the Duncan's multiple range test.
[x] g water/100g product.
[y] % of the highest mean value for each compound.

only influenced by fat content. In fact, other factors, such as processing conditions, play an important role (Jiménez-Colmenero, 1996).

3.5. Concentration of added compounds

The total concentration of added compounds was measured in raw and cooked sausages to determine the effect of both cooking and fat content on the retention or loss of the added volatile compounds.

With regard to compound concentration, Table 3 shows that cooking had a significant effect on some compounds, the most remarkable being a drastic decrease in 3-methylbutanal and ethyl-2-methylbutanoate (both compounds had low log P and large log ρL, as indicated in Table 1). Conversely, hexanal, octanal, nonanal and myrcene increased after cooking. The increase could be related to the general concentration process caused by moisture reduction in cooked samples or to an increase in compound extractability, because compound generation could be ruled out (as mentioned above).

Results from the ANOVA in Table 3 show that fat content significantly influenced the total concentration of most compounds, except for ethyl-2-methylbutanoate and carvone (both compounds had low log P values and therefore low lipophilicities). Differences among the three fat content sausages were more evident in the raw samples (8 compounds were different according to Duncan's multiple range test); in fact, in cooked sausages, differences among the three groups appeared only for four compounds. Otherwise, as it is shown in Table 3, affected compounds were most abundant as fat content increased, which confirms that fat acts as a reservoir of lipophilic odorants.

3.6. Release of volatile compounds into the headspace

The effect of cooking and fat content on the release, in vitro was studied by using static headspace measurements. Results from the ANOVA indicated that cooking caused a significant effect on the release of seven compounds measured in the sample headspace (at the $p < 0.001$ level for 3-methylbutanal, octanal, nonanal, decanal, myrcene and carvone and $p = 0.001$ for octan-2-one). As shown in Fig. 2, the release decreased for most compounds after cooking. A previous study on a very different product (biscuits) also found a decrease in headspace concentration for trans-2-hexenyl acetate during baking (Brauss, Balders, Linforth, Avison, & Taylor, 1999). The decrease in the release from sausages could be related to an increased retention rather than to compound loss during cooking, because, in fact, cooking did not cause a general decrease in concentration, as mentioned above.

Conversely to the general behaviour, 3-methylbutanal and hexanal ($p < 0.001$ and $p = 0.054$, respectively, for cooking effect in the ANOVA) had larger headspace values in the cooked samples than in the raw ones (Fig. 2). It should be noted that these compounds had the largest log ρL values (Table 1). Although the increased headspace values for hexanal could be related to the increase in concentration (Table 3), for 3-methylbutanal, the dominant

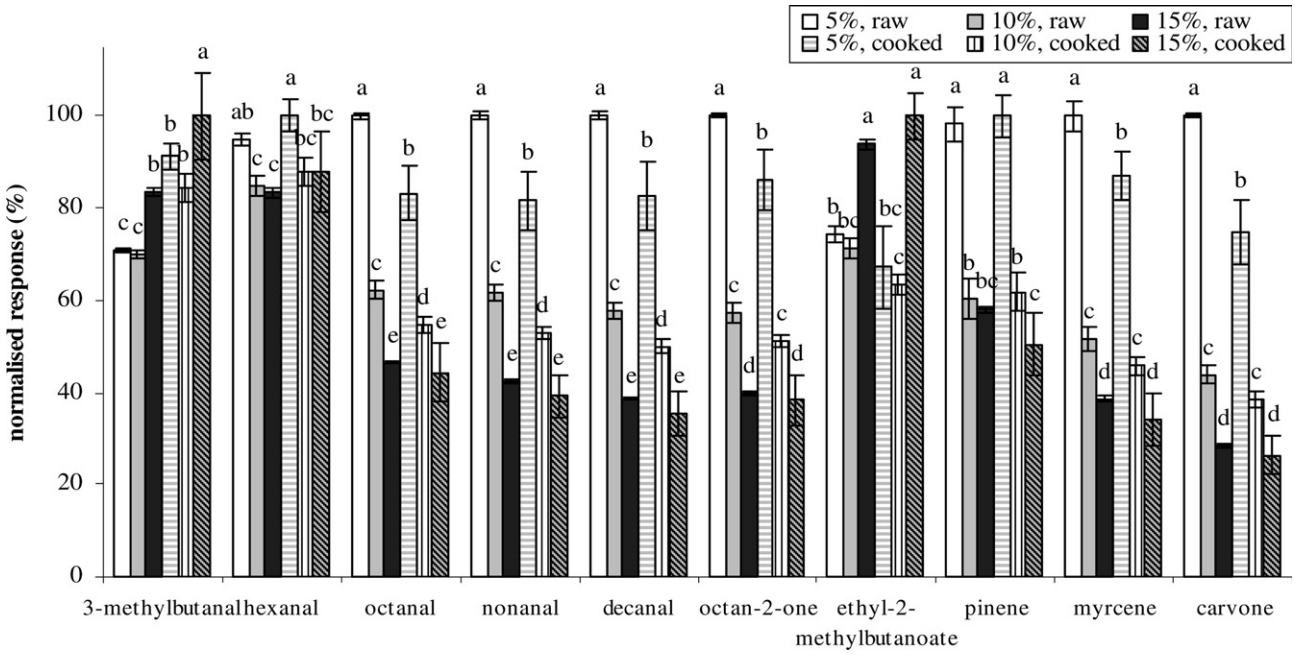

Fig. 2. Effect of cooking and fat content (5%, 10%, 15%) on the release of added volatile compounds into the static headspace. Values (means ± standard deviation from three replicates) are expressed relative to the largest value within the means for each compound. Different letters indicate significant differences ($p < 0.05$) in the Duncan's multiple range test.

cause is not an increase in concentration (because concentration decreased dramatically, as mentioned above) but a decrease in retention.

The effect of cooking was more evident as fat content decreased: the low-fat content sausages were the most affected (7 compounds), whereas the large-fat content sausages only had differences caused by cooking in one compound (3-methylbutanal) (Fig. 2). In fact, a significant interaction between cooking and fat content was found in most compounds affected by cooking (all except 3-methylbutanal and myrcene).

Results from the ANOVA indicated that fat content significantly influenced the headspace concentration of all the compounds ($p < 0.001$), and therefore fat content affected a larger number of compounds than did cooking. Values decreased as fat content increased, except for 3-methylbutanal and ethyl-2-methylbutanoate. The largest effect of fat content on release occurred in the most lipophilic compounds (Fig. 2), and when increasing fat above 5%. Results are consistent with the decrease in release generally reported when increasing fat content (Doyen, Carey, Linforth, Marin, & Taylor, 2001; Jo & Ahn, 1999) and are also consistent with the relationship between release from fat-containing samples and the physicochemical properties of each compound; the more lipophilic the compound, the lower is the amount of lipid needed to reduce its headspace concentration (Roberts et al., 2003). Some data from emulsions showed that the release of lipophilic compounds is dramatically decreased in the presence of small quantities of fat (below 1% for the most lipophilic compounds), and above this level compound release remains practically unaffected (Carey, Asquith, Linforth, & Taylor, 2002; Roberts et al., 2003). However, Miettinen, Hyvonen, and Tuorila (2003) reported that, even for the most lipophilic compounds, a decrease in release was evident when fat increased from 5% to 10%, and the release of ketones tended to decrease above 4% fat, and alcohols and aldehydes above 2% fat (Jo & Ahn, 1999), which indicates that some factors could modulate the effect of fat content on release. With regard to meat products, some studies on frankfurters showed that the release of terpene hydrocarbons, alcohols (Chevance et al., 2000) and some ketones and phenolic compounds (Chevance & Farmer, 1999) decreased significantly as fat content increased from 5% to 30%, which agrees with the effect found in most compounds (Fig. 2).

In contrast to the behaviour of most compounds, 3-methylbutanal and ethyl-2-methylbutanoate increased in the headspace as fat increased. The largest effect appeared when fat increased up to the large fat content, and no differences were found between the low and medium fat content sausages. As mentioned above, both compounds had low log P values, and therefore results for them are consistent with other studies, which reported that the release of polar compounds could be unaffected as oil content increased (Brauss et al., 1999; Miettinen et al., 2003; Roberts et al., 2003; Roberts et al., 2003) or could even increase, as was found for diacetyl and butanoic acid (Guyot et al., 1996). The increase was caused by a decreased retention when increasing fat content, at least in cooked sausages (differences in compound concentrations for 3-methylbutanal and ethyl-2-methylbutanoate in cooked sausages could be ruled out according to results in Table 3, and also generation of compounds, as mentioned above), and could be related to the quantitative differences in the aqueous phase (the larger fat content, the smaller water content and therefore the larger concentration of lipophilic compound at this phase) or to fat instability. In this way, a study on beef patties also showed an increase in both cooking loss and the release of some compounds when fat increased (El-Magoli, Laroia, & Hansen, 1996). Therefore, the dominant mechanisms that influence the release of polar (low value for log P) volatile compounds with large volatility (large value for log ρL) could be their concentrations in the aqueous phase and fat emulsion instability (estimated as fat loss) rather than fat retention.

3.7. Release of volatile compounds during mastication: maximum response and time to maximum response

The release of volatile compounds from the three fat content sausages was measured in the air flowing from the nostril whilst panellists masticated the samples. Results from the two-way (panellists, fat content) ANOVA with interaction showed a marked effect of panellists on both the maximum response measured (all the compounds were affected) and the time to maximum response (except for nonanal, all the compounds were affected), and in both cases the effect of panellists was significant for a larger number of compounds than the effect of fat content. This fact confirms panellists themselves as an important source of variation in the in-mouth flavour release, as was previously shown (Hodgson, Linforth, & Taylor, 2003; Weel et al., 2002).

Fat level influenced the release of volatile compounds during mastication. A significant effect of fat content on the maximum response was found for most compounds, and it was similar to the effect on the headspace compounds: the maximum response for most compounds significantly decreased as fat content increased, but 3-methylbutanal and ethyl-2-methylbutanoate showed the opposite tendency (Fig. 3). Breath-by-breath data were consistent with data from previous studies, which showed that increasing fat content caused a general decrease in the release of hydrophobic compounds during eating of yogurts (Brauss et al., 1999), biscuits (Brauss et al., 1999) and dairy emulsions (Roberts et al., 2003) but did not affect the release of more hydrophilic compounds (Brauss et al., 1999; Brauss et al., 1999).

Apart from fat-odorant interactions, fat content could affect flavour release during mastication by modifying sausage structure, although, in any case, the effect of structure on flavour release would be limited (Lethuaut, Weel, Boelrijk, & Brossard, 2004; Weel et al., 2002).

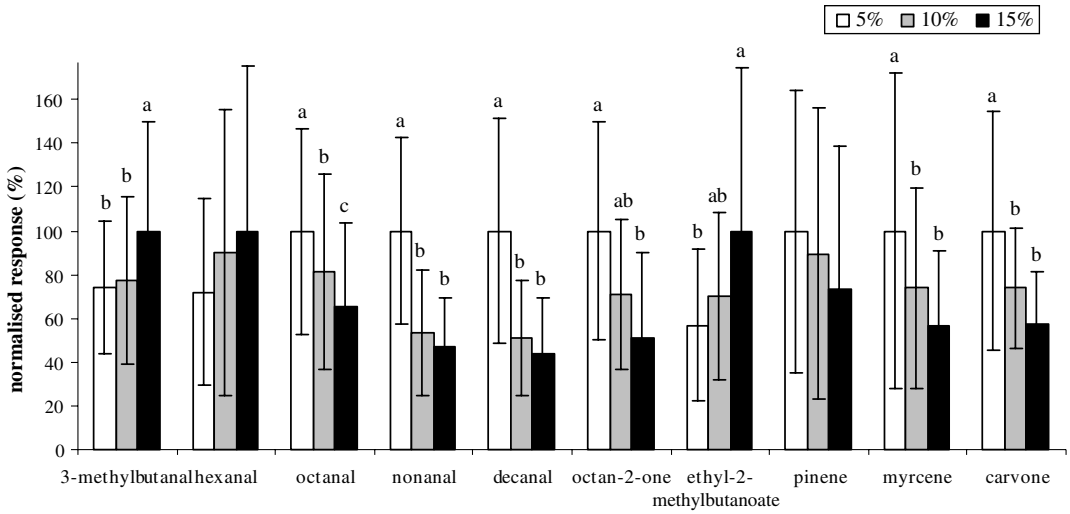

Fig. 3. Effect of fat content (5%, 10%, 15%) on the release of volatile compounds during mastication of sausages. Values (means ± standard deviation from 3 replicates × 6 panellists) represent the maximum response measured in the exhaled breath from the nose expressed relative to the largest value within the means for each compound. Different letters indicate significant differences ($p < 0.05$) in the Duncan's multiple range test.

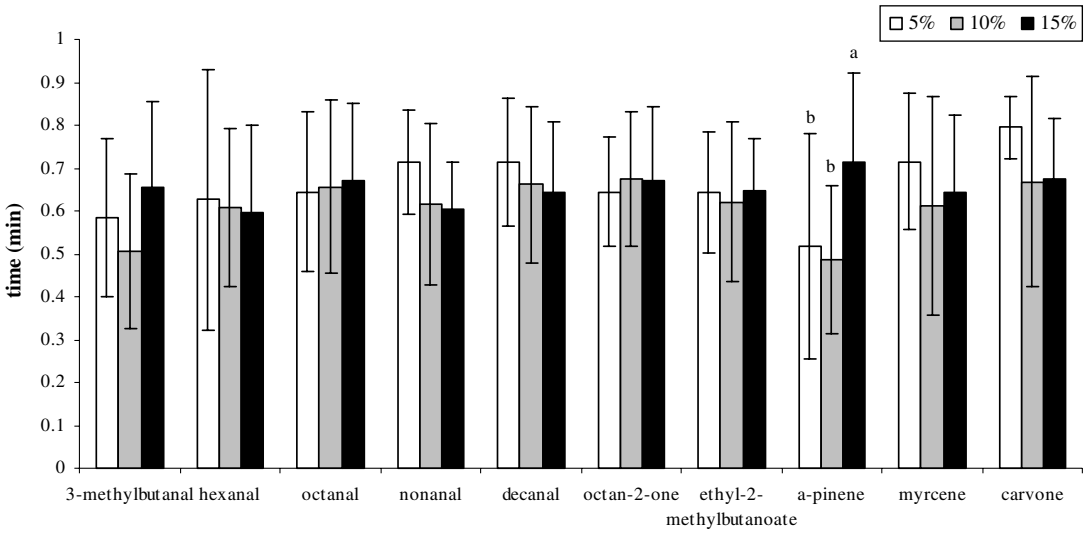

Fig. 4. Effect of fat content (5%, 10%, 15%) on the release of volatile compounds during mastication of sausages. Values represent the time taken to reach maximum response in the exhaled breath from the nose (means ± standard deviation from 3 replicates × 6 panellists). Different letters indicate significant differences ($p < 0.05$) in the Duncan's multiple range test.

Although varying fat content affected compounds in the headspace and nosespace in a similar way, the effect was significant for a larger number of compounds in the headspace (all the compounds) than in the nosespace (8 compounds), and variations caused by fat content were in fact larger in the headspace than in the nosespace (compare Figs. 2 and 3). This fact is in accordance with previous studies of products without meat (Doyen et al., 2001; Roberts et al., 2003; Weel et al., 2004).

Time to maximum response was barely influenced by fat content. As is shown in Fig. 4, only α-pinene (the second most lipophilic compound, log $P = 3.94$, Table 1) was affected, time to maximum response increasing as fat content increased. The effect of fat on the temporal release depends on the food system: in yogurt, a significant effect of fat content on the time to maximum response of the lipophilic compounds (anethole and terpinolene) was reported, showing a delay as fat content increased (Brauss et al., 1999) but, in emulsions, no such effect was observed for hydrophobic and hydrophilic compounds (Miettinen et al., 2003). In the case of sausages, it can be assumed that, under real eating conditions, there is no effect of fat content on the temporal release of volatile compounds, at least when mastication is short (around 1 min).

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References

Andersson, A., Andersson, K., & Tornberg, E. (2000). A comparison of fat-holding between beefburgers and emulsion sausages. *Journal of the Science of Food and Agriculture, 80*, 555–560.

Brauss, M. S., Balders, B., Linforth, R. S. T., Avison, S., & Taylor, A. J. (1999). Fat content, baking time, hydration and temperature affect flavour release from biscuits in model-mouth and real systems. *Flavour and Fragrance Journal, 14*, 351–357.

Brauss, M. S., Linforth, R. S., Cayeux, I., Harvey, B., & Taylor, A. J. (1999). Altering the fat content affects flavor release in a model yogurt system. *Journal of Agricultural and Food Chemistry, 47*, 2055–2059.

Carey, M. E., Asquith, T., Linforth, R. S. T., & Taylor, A. J. (2002). Modeling the partition of volatile aroma compounds from a cloud emulsion. *Journal of Agricultural and Food Chemistry, 50*, 1985–1990.

Chevance, F. F. V., & Farmer, L. J. (1999). Release of volatile odor compounds from full-fat and reduced- fat frankfurters. *Journal of Agricultural and Food Chemistry, 47*, 5161–5168.

Chevance, F. F., Farmer, L. J., Desmond, E. M., Novelli, E., Troy, D. J., & Chizzolini, R. (2000). Effect of some fat replacers on the release of volatile aroma compounds from low-fat meat products. *Journal of Agricultural and Food Chemistry, 48*, 3476–3484.

Crehan, C. M., Hughes, E., Troy, D. J., & Buckley, D. J. (2000). Effects of fat level and maltodextrin on the functional properties of frankfurters formulated with 5%, 12% and 30% fat. *Meat Science, 55*, 463–469.

Doyen, K., Carey, M., Linforth, R. S. T., Marin, M., & Taylor, A. J. (2001). Volatile release from an emulsion: headspace and in-mouth studies. *Journal of Agricultural and Food Chemistry, 49*, 804–810.

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

Guyot, C., Bonnafont, C., Lesschaeve, I., Issanchou, S., Voilley, A., & Spinnler, H. E. (1996). Effect of fat content on odor intensity of three aroma compounds in model emulsions: delta-decalactone, diacetyl, and butyric acid. *Journal of Agricultural and Food Chemistry, 44*, 2341–2348.

Hodgson, M., Linforth, R. S. T., & Taylor, A. J. (2003). Simultaneous real-time measurements of mastication, swallowing, nasal airflow, and aroma release. *Journal of Agricultural and Food Chemistry, 51*, 5052–5057.

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

Hughes, E., Mullen, A. M., & Troy, D. J. (1998). Effects of fat level, tapioca starch and whey protein on frankfurters formulated with 5% and 12% fat. *Meat Science, 48*, 169–180.

Jiménez-Colmenero, F. (1996). Technologies for developing low-fat meat products. *Trends in Food Science & Technology, 7*, 41–48.

Jiménez-Colmenero, F. (2000). Relevant factors in strategies for fat reduction in meat products. *Trends in Food Science & Technology, 11*, 56–66.

Jo, C., & Ahn, D. U. (1999). Fat reduces volatiles production in oil emulsion system analyzed by purge-and-trap dynamic headspace/gas chromatography. *Journal of Food Science, 64*, 641–643.

Lethuaut, L., Weel, K. G., Boelrijk, A. E., & Brossard, C. D. (2004). Flavor perception and aroma release from model dairy desserts. *Journal of Agricultural and Food Chemistry, 52*, 3478–3485.

Linforth, R., & Taylor, A. (1998). Apparatus and methods for the analysis of trace constituents of gases Patent Eur Patent EP 0819 937 A2 1998.

Linforth, R. S. T., Friel, E., & Taylor, A. J. (1999). Modeling aroma release from foods using physicochemical parameters. *Abstracts of Papers of the American Chemical Society, 218*, 71-AGFD.

Linforth, R., & Taylor, A. J. (2000). Persistence of volatile compounds in the breath after their consumption in aqueous solutions. *Journal of Agricultural and Food Chemistry, 48*, 5419–5423.

Miettinen, S. M., Hyvonen, L., & Tuorila, H. (2003). Timing of intensity perception of a polar vs nonpolar aroma compound in the presence of added vegetable fat in milk. *Journal of Agricultural and Food Chemistry, 51*, 5437–5443.

Pionnier, E., Chabanet, C., Mioche, L., Le Quere, J. L., & Salles, C. (2004). 1. In vivo aroma release during eating of a model cheese: Relationships with oral parameters. *Journal of Agricultural and Food Chemistry, 52*, 557–564.

Roberts, D. D., Pollien, P., Antille, N., Lindinger, C., & Yeretzian, C. (2003). Comparison of nosespace, headspace, and sensory intensity ratings for the evaluation of flavor absorption by fat. *Journal of Agricultural and Food Chemistry, 51*, 3636–3642.

Roberts, D. D., Pollien, P., & Watzke, B. (2003). Experimental and modeling studies showing the effect of lipid type and level on flavor release from milk-based liquid emulsions. *Journal of Agricultural and Food Chemistry, 51*, 189–195.

Shackelford, S. D., Reagan, J. O., Haydon, K. D., Lyon, C. E., & Miller, M. F. (1991). Acceptability of low-fat frankfurters as influenced by the feeding of elevated levels of monounsaturated fats to growing finishing swine. *Meat Science, 30*, 59–73.

Weel, K. G. C., Boelrijk, A. E. M., Alting, A. C., van Mil, P., Burger, J. J., Gruppen, H., et al. (2002). Flavor release and perception of flavored whey protein gels: Perception is determined by texture rather than by release. *Journal of Agricultural and Food Chemistry, 50*, 5149–5155.

Weel, K. G., Boelrijk, A. E., Burger, J. J., Jacobs, M. A., Gruppen, H., Voragen, A. G., et al. (2004). Effect of emulsion properties on release of esters under static headspace, in vivo, and artificial throat conditions in relation to sensory intensity. *Journal of Agricultural and Food Chemistry, 52*, 6572–6577.