Temporal changes of flavour and texture in cooked bologna type sausages as affected by fat and salt content

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A B S T R A C T

Temporal changes of flavour (mushroom-like and saltiness) and texture (juiciness) in cooked bologna type sausages with different fat and salt content and containing selected volatile compounds (100 mg kg⁻¹ of 1-octen-3-ol and 200 mg kg⁻¹ of 2,6-dimethylpyrazine) were evaluated using time-intensity (TI) method. Preceding the TI study, descriptive profiles of sausages were determined. Release of volatiles was analysed by solid-phase microextraction coupled to gas chromatography–mass spectrometry (SPME-GC–MS) and an instrumental texture analysis was also performed. Chromatographic results obtained for 1-octen-3-ol were strongly correlated with the intensity perception of the linked odour and flavour (mushroom). Modifications of sausages matrix in terms of fat and salt content differently affected the dynamic perception of mushroom flavour, saltiness and juiciness. NaCl contributed to increasing release of 1-octen-3-ol (salting-out effect) confirmed by SPME analysis as well as the intensity and duration of the related flavour (mushroom) evaluated by TI. Similarly, NaCl increased the temporal perception of both saltines and juiciness of sausages. Increase in fat content led to a higher retention of 1-octen-3-ol (lipophilic compound) and thus to a less intense and shorter duration of mushroom flavour. Moreover, fat contributed to a more intense and a longer juiciness of sausages. These results highlight the feasibility of TI technique to evaluate changes in the temporal flavour and texture perception of sausages caused by modification of matrix composition.

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1. Introduction

Sensory characteristics are of a great importance for consumer preferences and satisfaction with foods (Tuorila & Monteleone, 2009). Among the food components, fat is a critical part of the food matrix for both flavour and texture properties and thereby for overall palatability. Fat acts as a carrier and reservoir of aroma compounds, stimulates the senses during eating and acts as a precursor for certain flavours. Moreover, the amount and composition of fat and its physical state influence the dynamic release of flavour compounds during consumption (Hort & Cook, 2007). Overall, increasing the fat content involves a decrease in aroma release and in flavour intensity (De Roos, 1997; Shamil, Wyeth, & Kilcast, 1991/92).

The effect of fat depends on the physicochemical characteristics of flavour compounds, particularly the volatility and hydrophobicity expressed by the log \( P_{o-w} \) value (logarithm of the oil–water partition coefficient) (De Roos, 1997; Taylor, 1998). Lipophilic aroma compounds (log \( P_{o-w} > 1 \)) are influenced more by changes in fat content than the more hydrophilic compounds (De Roos, 1997). Lipophilic compounds are released faster and with higher intensities from low fat compared to high fat formulations (Afoakwa, Paterson, Fowler, & Ryan, 2009; Brauss, Linforth, Cayeux, Harvey, & Taylor, 1999; Chung, Heymann, & Grün, 2003; Miettinen, Hyvonen, Linforth, Taylor, & Tuorila, 2004).

In addition to taste, salt influences textural properties of foods (Desmond, 2006; Saint-Eve, Lauverjat, Magnan, Déléris, & Souchon, 2009) and contributes to flavour release by increasing volatility of aroma compounds (salting-out phenomenon) (Rabe, Kring, & Berger, 2003). Salt solubilisation involves the binding of water molecules by salt ions, leading to increased mobility and release of flavour compounds caused by the decreased availability of water molecules for the solubilisation of these compounds (Rabe et al., 2003).

Flavour and texture, particularly juiciness and tenderness, have a clear relationship to meat palatability (Behrends et al., 2005; Calkins & Hodgen, 2007). Meat products are complex food matrices including a great variety of components which can interact with flavour compounds affecting their release and perception. Among these components, fat and salt are some of the most interesting since their presence in meat products are in continuously...
Flavour and texture perception are dynamic processes since continuous changes in their intensities are perceived during eating as a result of mixing with saliva and the breakdown of the food matrix through chewing. The time–intensity (TI) method allows monitoring the intensity over time and thus provides more real and valid information compared to static techniques (Dijksterhuis & Piggott, 2001). A graphical relationship between the perceived strength of a sensory attribute recorded while foodstuff is processed in the mouth and the duration of its perception is obtained using the TI technique (Dijksterhuis & Piggott, 2001). This sensory method has been extensively applied to dairy products, particularly ice creams and yoghurts, to study the temporal perception affected by matrix composition (Miettinen, Hyvönen & Tuorila; 2003; Frést, Heymann, Bredie, Dijksterhuis, & Martens, 2005; Chung et al., 2003). Regarding meat products, first studies that applied the TI technique evaluated changes in meat tenderness during chewing (Butler, Posh, Mackie, & Jones, 1996; Zimoch & Gullett, 1997). More recently, Emrick, Penfield, Bacon, Van Laack, and Breeke (2005), Reinbach, Toft, and Møller (2009) analysed temporal flavour perception in chicken and pork patties, respectively. Finally, saltiness perception was also studied in cured ham by TI analysis (Bertram, Wu, Stradtt, Aagaard, & Anslyng, 2006).

The objective of the present study was to investigate the effect of fat and NaCl content on the dynamic perception of flavour (mushroom and saltiness) and texture (juiciness) in flavoured sausages. Nine cooked bologna type sausages varying in NaCl and fat content according to a 3 × 3 factorial design were prepared and flavoured with a mixture of 1-octen-3-ol (100 mg kg⁻¹) and 2,6-dimethylpyrazine (200 mg kg⁻¹) (Aldrich, Kosher Food Grade, Germany): low fat–low salt (LF–LS), low fat–medium salt (LF–MS), low fat–high salt (LF–HS), medium fat–low salt (MF–LS), medium fat–medium salt (MF–MS), medium fat–high salt (MF–HS), high fat–low salt (HF–LS), high fat–medium salt (HF–MS) and high fat–high salt (HF–HS). Fat contents in sausages were varied by combining the amount of lean pork and pork back fat in the formulations. Formulation of sausages included: 59% (LF), 46% (MF) or 35% (HF) of lean pork (3–5% fat); 3.5% (LF), 16% (MF) or 28% (HF) pork back fat (87% fat); 6.8% pork skin emulsion (35% fat), 24% water, 6% potato flour, 0.5% sodium caseinate, 0.06% ascorbic acid; 0.03% phosphate, 0.012% sodium nitrite; 1.4% (LS), 1.8% (MS) or 2.2% (HS) NaCl, 100 mg kg⁻¹ of 1-octen-3-ol and 200 mg kg⁻¹ of 2,6-dimethylpyrazine in milliQ water (purified and deionized water).

Proximate chemical composition and description of sausages are shown in Table 1. Moisture content was determined by drying samples at 135 °C for 3 h. Protein content was determined by the Kjeldahl method (NMKL, 1976) and fat content by Soxhlet method (Association of Analytical Chemists, 1990). NaCl concentration was determined by analysing chloride-ion content (Corning 926 Chloride Analyzer, Corning Medical and Scientific Corning Limited, England). All analyses were carried out in duplicate.

Volatiles concentrations providing moderate odour and flavour intensities were chosen in sensory pre-tests of three types of low fat (LF) sausages (LF–LS, LF–MS and LF–HS) flavoured with both volatile compounds at different concentrations (50–200 mg kg⁻¹ of 1-octen-3-ol and 150–350 mg kg⁻¹ of 2,6-dimethylpyrazine) within the same sausage sample.

Sensory profiling was performed on all sausages, whereas TI evaluations were carried out on samples with the highest and the lowest fat and salt content.

2.2. Sensory evaluation

2.2.1. Assessors

Eight panellists (three males and five females, range age 25–59 years) with previous experience in sensory evaluation participated in the study (training and evaluation sessions). All of them were staff of the University of Helsinki and had a normal sense of smell based on SOIT (Scandinavian Odour Identification Test) (Nordin, Brämerson, Liden, & Bende, 1998) (11–16 correct identifications out of 16). Each assessor signed an informed consent form before the study started.

2.2.2. Sensory profiling

Prior to time–intensity, descriptive sensory analysis of the nine sausages was carried out. The development of a conventional sensory profile of sausages can be considered as part of the TI training (Peyvieux & Dijksterhuis, 2001) to test if the selected attributes are applicable to the product under investigation and to allow panelists to get familiar with the attributes and samples later used in

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Proximate chemical composition of sausages with different fat (low fat = LF, medium fat = MF and high fat = HF) and NaCl content (low salt = LS, medium salt = MS and high salt = HS) (means ± SD).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sausage type</td>
<td>Fat content</td>
</tr>
<tr>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>LF–LS</td>
<td>5.3 ± 0.44c</td>
</tr>
<tr>
<td>MF–LS</td>
<td>4.8 ± 0.43c</td>
</tr>
<tr>
<td>HF–LS</td>
<td>4.4 ± 0.70c</td>
</tr>
<tr>
<td>MF–MS</td>
<td>13.7 ± 0.09b</td>
</tr>
<tr>
<td>MF–HS</td>
<td>14.5 ± 0.48b</td>
</tr>
<tr>
<td>HF–LS</td>
<td>14.3 ± 0.59b</td>
</tr>
<tr>
<td>MF–MS</td>
<td>22.5 ± 0.05b</td>
</tr>
<tr>
<td>HF–HS</td>
<td>22.0 ± 0.45b</td>
</tr>
</tbody>
</table>

Within the same column, sample means with different letter are significantly different (one-way ANOVA) (p < 0.05).
the TI study. To generate and set up the list of attributes characterizing the sausages, three different sausages were evaluated: LF–LS (200 mg kg\(^{-1}\) 1-octen-3-ol + 350 mg kg\(^{-1}\) 2,6-dimethylpyrazine), LF–MS (150 mg kg\(^{-1}\) 1-octen-3-ol + 250 mg kg\(^{-1}\) 2,6-dimethylpyrazine), LF–HS (50 mg kg\(^{-1}\) 1-octen-3-ol + 150 mg kg\(^{-1}\) 2,6-dimethylpyrazine). Samples (one slice, 7 g) were prepared in plastic cups (200 ml) covered with plastic lids, with a list of potential attributes. After discussion the panel reached an agreement and selected 12 attributes and their verbal anchors on the scale.

Sensory profiling sessions were carried out over three consecutive days with two sessions per day (morning and afternoon). The afternoon session was a replication, thus a total of 16 ratings were collected for each sample and attribute. For each panelist, the presentation order of the nine sausages over the sessions was randomized following the Williams Latin Square design. Three samples within a session consisted of two half slices (3.5 g each) in plastic cups (200 ml) marked with random three-digit codes and covered with plastic lids. Evaluations were conducted in individual booths at room temperature (25 °C) and samples were allowed to equilibrate at this temperature for at least 15 min. Panellists took away the lid and rated the intensity of the selected attributes using an unstructured scale (10 cm). The attributes and their verbal anchors were for external appearance: colour intensity (0 = very weak, 10 = very strong), shine (0 = pale, 10 = bright); for odour: mushroom (0 = not at all, 10 = very strong), cocoa (0 = not at all, 10 = very strong), cooked (0 = not at all, 10 = very strong); for texture: juicy (0 = very dry, 10 = very juicy), chewy (0 = very easy to chew, 10 = very hard to chew); for flavour: salty (0 = not at all, 10 = very strong), mushroom (0 = not at all, 10 = very strong), cocoa (0 = not at all, 10 = very strong), cooked (0 = not at all, 10 = very strong) and after-taste (0 = very weak, 10 = very strong). Mushroom and cocoa attributes are odour and flavour descriptors of 1-octen-3-ol and 2,6-dimethylpyrazine, respectively (http://www.flavornet.org/flavornet.html). Tap water and unsalted crackers were provided for rinsing between samples. Data were collected using the FIZZ software (Sensory Analysis and Computer Test Management) (Biosystemes, France, 2002).

2.2.3. TI training

Dynamic sensory properties of bologna type sausages affected by salt and fat content were studied using TI methodology. The training procedure described by Peyvieux and Dijksterhuis (2001) was applied. Three training sessions (2 h per session) were performed, divided in different steps.

During the first session, the TI method (computer screen instructions) and the product (ingredients and composition) under investigation were introduced to the panelist in general terms. Panellists got familiar with the TI data collection (FIZZ software) by rating the intensity of three aqueous solutions in individual booths: sour (3.5 g l\(^{-1}\) citric acid), salty (10 g l\(^{-1}\) NaCl) and sweet (33 g l\(^{-1}\) sucrose).

Panellist participated in two further training TI sessions evaluating the overall flavour intensity of three different sausage samples (described in the sensory profiling training) using a 10 cm unstructured vertical scale anchored “not at all” and “very strong”. Sample size was standardised at half slice (3.5 g, and 3 mm thickness) and the protocol was established as follows: panelists should keep the sample in their mouths, chew for 18 s and then swallow. After swallowing panelists should continue the evaluation until they did not perceive anything. Panelists were instructed to move the cursor along the line according to the intensity of their perception. The time of the evaluation was fixed in 100 s, but panelists could stop before by moving the mouse completely down towards “not at all” extreme. During the data collection, specific messages were displayed in the computer screen showing the commands as “indicate the intensity during chewing the sample by moving the cursor along the scale”, “swallow the sample” and “move the cursor completely down if you do not perceived anything more”. The final rinsing protocol between samples was tap water and a piece of unsalted crackers. This standardised protocol was used in the TI evaluations.

2.2.4. Time–intensity evaluations

Based on the results obtained by sensory profiling, sausages with the highest and the lowest fat and salt content (LF–LS, LF–HS, HF–LS and HF–HS) and the attributes mushroom flavour, saltiness and juiciness were chosen to be evaluated by TI methodology. Evaluations were carried out on three consecutive days, with two sessions per day. Mushroom flavour and saltiness were evaluated in the morning sessions, while juiciness was evaluated during the afternoon. Panellists rated one attribute at a time and all attributes were evaluated in triplicate, thus a total of 24 TI-curves of each attribute were obtained for each sample. Evaluation of the four types of sausages was performed in the same session, with the serving order of the samples randomised according to the Williams Latin Square design.

Samples (one half of slice, 3.5 g) were served in plastic cups (200 ml) covered with plastic lids and coded with three digit numbers. For mushroom flavour evaluation, before opening the plastic cups and taking the sample, panelists used nose-clips to avoid odour influence. Once the sample was in the mouth they removed the nose-clip and started to evaluate the mushroom flavour intensity. For saltiness and juiciness evaluations, nose-clips were not used. Sessions took place in individual booths under red light to avoid visual cues.

The intensity recordings started when assessors clicked on the scale and stopped after 180 s or when the assessors returned the marker completely down in the scale. In mushroom flavour and saltiness evaluations, the message “swallow” was displayed after 18 s of chewing. Attributes were scored on a 10 cm unstructured vertical scale anchored with “not at all” and “very strong” for mushroom and saltiness attributes and with “very dry” and “very juicy” for juiciness. Between samples, panelists were required to follow the rinsing protocol. Data were collected using the FIZZ software (Sensory Analysis and Computer Test Management) (Biosystemes, France, 2002).

2.3. Instrumental analysis of sausages

Compression test as a measurement of instrumental texture of the sausages was carried out using an Instron model 4465 (Instron Co., USA). A 5 kN load cell was used. The maximum load (Max Load) and the maximum strength (Max Strength) exerted by the instrument caused by the load cell compression (10 mm of maximum distance) over sausages surface (5 cm thickness) were registered. Measurements were made at room temperature (25 °C). Values of Max Load (kN) and Max Strength (MPa) were given as means of 4 measurements per sample.

The relative amounts of 1-octen-3-ol and 2,6-dimethylpyrazine were analysed in the headspace of the nine type of sausages. Volatiles extraction was performed using solid-phase microextraction (SPME) technique coupled to gas chromatography–mass spectrometry (GC–MS) (gas chromatograph Hewlett-Packard 5890 series II coupled to a mass selective detector Hewlett-Packard HP-5791 A). One gram of sample was placed in a vial (10 ml) and equilibrated for 10 min at 37 °C in a bath with controlled temperature. Extraction was carried out with a divinylbenzene-carboxen-poly(dimethylsiloxane) (DVB/CAR/PDMS) stationary phase by exposing to sample headspace for 15 min at 37 °C. All samples were analysed in triplicate. After extraction, the SPME fibre was immediately transferred to the chromatograph injector, in splitless mode at 220 °C. Separation was performed with a 5%-diphenyl-
95%-dimethyl polysiloxan capillary column (60 m × 250 μm × 0.10 μm) and helium was the carrier gas (28.3 ml min⁻¹). Oven program was: 50 °C (5 min), 4 °C min⁻¹ to 96 °C, 6 °C min⁻¹ to 150 °C and 30 °C min⁻¹ to 240 °C. Volatiles were tentatively identified by comparing their mass spectra with those reported in the Wiley library. Results are expressed as peak arbitrary units (AU × 10⁻⁶).

2.4. Data analysis

Three-way ANOVA (repeated measures) (GLM procedure) was applied for each attribute (sensory profiling) to study the main effects of salt and fat and their interaction. In this model, salt content (low, medium and high), fat content (low, medium and high) and replications (session 1 and 2) were included as within-subject factors. Bonferroni correction was applied for multiple comparisons of main factors (salt and fat).

Data from individual TI curves of mushroom flavour, saltiness and juiciness were analysed and average TI-curves were computed for each attribute over eight assessors and three replications using HIZZ software. Five TI parameters were extracted from TI curves: (1) maximum intensity (Imax), (2) computed end time (Tend) – total duration of the evaluation in seconds, (3) plateau start time (TSPlat) – time in seconds to reach the plateau, (4) total area under the curve (AUC) and (5) duration of the decreasing phase (DurDec).

Three-way ANOVA (repeated measures) (GLM procedure) was carried out for each TI parameter. In this model, salt content (low and high), fat content (low and high) and replications (session 1, 2 and 3) were included as within-subject factors.

Headspace data were analysed by two-way ANOVA, salt and fat levels as main effects and testing means differences by Tukey post hoc test.

Finally, to study the relationship among sensory attributes, instrumental texture and headspace data, and to examine differences in the sample set, a principal component analysis (PCA) was performed. A second PCA were performed with TI parameters extracted for mushroom flavour, saltiness and juiciness, headspace values of 1-octen-3-ol and instrumental texture measurements. Analyses were carried out on the mean values across assessors and repetitions for all sensory attributes and all TI parameters and across repetitions for instrumental texture and headspace data in each evaluated sample.

SPSS software (v 15.0) for windows was used for all statistical analyses.

3. Results

3.1. Sensory profiling

Regarding the appearance of sausages, increasing the fat content decreased the colour intensity and the shine of sausages [main effect of salt, F(2;14) = 203.5, p < 0.001 for colour and F(2;14) = 59.4, p < 0.001 for shine]. Nevertheless, sausages with the highest salt content had a more intense colour and were shinier compared to sausages with lower salt content [main effect of salt, F(2;14) = 4.4, p < 0.05 for colour and F(2;14) = 15.8, p < 0.001 for shine]. Mushroom odour was perceived as more intense in HS sausages compared to MS and LS [main effect of salt, F(2;14) = 4.1, p < 0.05] but for cocoa odour, the highest intensity was found in MS sausages [main effect of salt, F(2;14) = 23.3, p < 0.001]. Increasing the fat content significantly decreased mushroom odour intensity [main effect of fat, F(2;14) = 75.4, p < 0.001] but increased cocoa odour [main effect of fat, F(2;14) = 19.7, p < 0.001]. Sausages with the highest salt content (HS) were perceived as less juicy and harder to chew than those with lower salt content (MS and LS) [main effect of salt, F(2;14) = 4.8, p < 0.05 for juiciness and F(2;14) = 113.7, p < 0.001 for chewiness]. Moreover, sausages with the highest fat content were perceived juicier and easier to chew compared to those with lower fat content [main effect of fat, F(2;14) = 19.8, p < 0.001 for juiciness and F(2;14) = 11.08, p < 0.01 for chewiness]. Moreover, sausages with the highest fat content had a more intensive colour and were shinier compared to those with lower fat content [main effect of fat, F(2;14) = 19.8, p < 0.001 for juiciness and F(2;14) = 11.08, p < 0.01 for chewiness]. No significant differences in saltiness between MS and HS sausages were observed, but LS sausages were perceived less salty than the others [main effect of salt, F(2;14) = 21.02, p < 0.01]. Similarly to odour, mushroom flavour intensity increased with salt content and decreased with fat content [main effect of salt, F(2;14) = 61.1, p < 0.001 and main effect of fat, F(2;14) = 105.3, p < 0.001]. The same pattern was found for cocoa flavour [main effect of salt, F(2;14) = 32.7, p < 0.001 and main effect of fat, F(2;14) = 26.4, p < 0.001]. After-taste flavour increased with salt content but decreased with fat content [main effect of salt, F(2;14) = 16.5, p < 0.001 and main effect of fat, F(2;14) = 83.4, p < 0.001]. Finally, cooked flavour intensity decreased with salt content but increased with fat content [main effect of salt, F(2;14) = 8.0, p < 0.01 and main effect of fat, F(2;14) = 26.11, p < 0.001].

No significant main effect of session was observed for any of the evaluated attributes. Fat–salt interaction effect on mushroom odour and flavour was more pronounced in sausages with the lowest fat content [fat–salt interaction F(4;28) = 58.75, p < 0.001 for mushroom odour and F(4;28) = 159.93, p < 0.001 for mushroom flavour]. Increasing the fat content from medium to high levels noticeably increased juiciness in LS and MS sausages but decreased in HS sausages [effect of fat–salt interaction F(4;28) = 38.31, p < 0.001].

The first two principal components of PCA accounted for 74.6% of the total variance (Fig. 1). The first PC (50.3% of the total variance) was negatively loaded with juiciness and cooked flavour and positively with mushroom odour and flavour, 1-octen-3-ol chromatographic area, after-taste flavour and appearance attributes (colour and shine). The second PC (24.1% of the total variance) was defined by saltiness and cocoa odour with positive loadings and by the instrumental texture parameters (Max Load and Max Strength) with negative loadings. Loadings plot (Fig. 1a) shows that mushroom odour and flavour strongly correlated with the chromatography area of 1-octen-3-ol and with after-taste flavour. Appearance attributes, colour intensity and shine also showed a high correlation. LF–HS samples were associated with a high mushroom odour, mushroom flavour and after taste, with a more intensive colour shine compared to the rest of samples. LS samples were less salty and exhibited higher values for instrumental texture parameters. HF and MF samples were juicier and had a higher intensity of cooked odour and flavour than samples with the lowest fat content. First PC separated samples based on fat content and the second PC based on salt content. There was a trend of decreasing the fat content along PC1 and increasing salt content along PC2. According to Fig. 1b, sausages with the highest and lowest fat and salt content (LF–HS, LF–HS, HF–LS and HF–HS) displayed the greatest differences.

3.2. Time–intensity study

Results from TI evaluations are shown as means (±SEM) of the extracted TI parameters (Table 2) and as average TI-curves (Fig. 2) for each attribute.

3.2.1. Mushroom flavour

Salt and fat content significantly affected all TI parameters extracted from mushroom flavour curves. Intensity of mushroom...
Fig. 1. Principal component analysis of sensory profiling (O = odour attributes, F = flavour attributes and T = texture attributes), instrumental texture measurements and chromatographic areas of volatile compounds (headspace analysis). Parameter loadings (a) and factor scores (b) plots for the two first principal components.

Table 2
Main effect of salt (S) and fat (F) on TI parameters for mushroom flavour, saltiness and juiciness (means ± SEM): maximum intensity observed for the curve (Imax), computed end time (Tend), plateau star time (TSPlat), total area under the curve (AUC) and duration of the decreasing phase (DurDec). Significance level for salt (S), fat (F), session (Se) and S–F interaction:*p < 0.05; **p < 0.01 and ***p < 0.001.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>Salt</th>
<th>Fat</th>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Low (LS)</td>
<td>High (HS)</td>
<td>Low (LF)</td>
<td>High (HF)</td>
<td>S</td>
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<tr>
<td>Mushroom flavour</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Imax</td>
<td>5.33 ± 0.29</td>
<td>7.53 ± 0.19</td>
<td>7.55 ± 0.27</td>
<td>5.32 ± 0.26</td>
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<tr>
<td>Tend</td>
<td>29.2 ± 1.06</td>
<td>44.21 ± 0.98</td>
<td>46.99 ± 1.37</td>
<td>26.42 ± 0.80</td>
<td>***</td>
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<tr>
<td>TSPlat</td>
<td>8.31 ± 0.46</td>
<td>6.92 ± 0.29</td>
<td>8.04 ± 0.33</td>
<td>7.19 ± 0.33</td>
<td>++</td>
</tr>
<tr>
<td>AUC</td>
<td>129.22 ± 6.18</td>
<td>222.52 ± 7.66</td>
<td>244.03 ± 7.64</td>
<td>107.71 ± 7.12</td>
<td>***</td>
</tr>
<tr>
<td>DurDec</td>
<td>14.19 ± 0.73</td>
<td>25.34 ± 0.81</td>
<td>26.44 ± 0.84</td>
<td>13.30 ± 0.71</td>
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<tr>
<td>Saltiness</td>
<td></td>
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<tr>
<td>Imax</td>
<td>5.73 ± 0.17</td>
<td>7.10 ± 0.10</td>
<td>6.52 ± 0.15</td>
<td>6.31 ± 0.10</td>
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<tr>
<td>Tend</td>
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<tr>
<td>TSPlat</td>
<td>9.66 ± 0.40</td>
<td>8.92 ± 0.32</td>
<td>8.94 ± 0.43</td>
<td>9.63 ± 0.27</td>
<td>n.s.</td>
</tr>
<tr>
<td>AUC</td>
<td>128.44 ± 5.77</td>
<td>157.06 ± 9.78</td>
<td>142.13 ± 7.34</td>
<td>143.36 ± 7.35</td>
<td>++</td>
</tr>
<tr>
<td>DurDec</td>
<td>16.71 ± 0.63</td>
<td>18.4 ± 0.86</td>
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<td>n.s.</td>
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<td>Juiciness</td>
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<tr>
<td>Imax</td>
<td>5.14 ± 0.19</td>
<td>6.76 ± 0.20</td>
<td>5.43 ± 0.11</td>
<td>6.47 ± 0.22</td>
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<td>Tend</td>
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<tr>
<td>TSPlat</td>
<td>6.14 ± 0.13</td>
<td>7.25 ± 0.28</td>
<td>6.49 ± 0.32</td>
<td>6.90 ± 0.31</td>
<td>++</td>
</tr>
<tr>
<td>AUC</td>
<td>76.38 ± 2.10</td>
<td>113.76 ± 4.98</td>
<td>89.94 ± 2.10</td>
<td>100.2 ± 4.98</td>
<td>***</td>
</tr>
<tr>
<td>DurDec</td>
<td>6.24 ± 0.30</td>
<td>6.43 ± 0.61</td>
<td>6.45 ± 0.46</td>
<td>6.22 ± 0.51</td>
<td>n.s.</td>
</tr>
</tbody>
</table>
perception increased with salt content, particularly in LF samples (Fig. 2a), confirmed by the higher Imax [main effect of salt, $F(1,7) = 133.9, p < 0.001$] and AUC [main effect of salt, $F(1,7) = 117.9, p < 0.001$] obtained in HS compare to LS samples (Table 2). The total duration of the mushroom flavour (Tend) was longer in sausages with the highest salt content [main effect of salt, $F(1,7) = 238.0, p < 0.001$], particularly in LF ones. Moreover, less time was needed to reach the maximum mushroom flavour intensity (plateau phase) (TSPlat) in HS sausages [main effect of salt, $F(1,7) = 8.2, p < 0.05$]. Fat exhibited an opposite effect on mushroom flavour, leading to a decrease in the intensity perception in HF sausages [main effect of fat, $F(1,7) = 229.8, p < 0.001$] and DurDec [main effect of fat, $F(1,7) = 284.0, p < 0.001$] parameters.

### 3.2.2. Saltiness
Fat content had a significant effect on DurDec whereas Imax, Tend and AUC were significantly affected by salt content. The intensity (Imax and AUC) and duration (Tend) of saltiness perception was higher and longer respectively in sausages with the highest salt content besides the fat level [main effect of salt, $F(1,7) = 73.6, p < 0.001$ for Imax, $F(1,7) = 12.7, p < 0.01$ for AUC and $F(1,7) = 12.4, p < 0.05$ for Tend]. Regarding fat effect, the duration of the decreasing phase (DurDec) was the only TI parameter significantly affected, it was longer in HF than in LF sausages [main effect of fat, $F(1,7) = 59.8, p < 0.001$].

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**Fig. 2.** Average TI-curves for the attributes mushroom flavour (a), saltiness (b) and juiciness (c) ($n = 24$; 8 panellists × 3 replications). Curves are sorted by fat content of sausages.
3.2.3. Juiciness

The dynamic perception of juiciness in the evaluated sausages was influenced by both salt and fat content in the same direction (Table 2). Sausages with the highest salt content displayed a higher Imax and AUC and exhibited a longer time to reach the phase in which the intensity of juiciness remains constant (TSPlat) [main effect of salt, \(F(1,7) = 26.1, p < 0.01\) for Imax, \(F(1,7) = 47.8, p < 0.001\) for AUC and \(F(1,7) = 16.8, p < 0.01\) for TSPlat]. These results are particularly evident in LF sausages (Fig. 2c). Differences in TI parameters due to fat content were not so evident except for Imax which was higher in HF sausages [main effect of fat, \(F(1,7) = 16.3, p < 0.01\)].

3.2.4. Principal component analysis

PCA were carried out on the TI parameters of flavour (mushroom and saltiness) and texture (juiciness) attributes, the instrumental headspace analysis of 1-octen-3-ol and instrumental texture measurements (Max Load and Max Strength) (Fig. 3). The first two components accounted 89.4% of the total variance. The first PC (56.3% of the total variance) shows that most mushroom TI parameters (Imax, Tend, AUC and DurDec) and 1-octen-3-ol area were strongly correlated and this component was positively loaded by these parameters. First PC was negatively defined by TSPlat of saltiness. The second PC (33.1% of the total variance) was positively loaded by DurDec of saltiness and Imax of juiciness and negatively by TSPlat of mushroom flavour. Imax, Tend and AUC of saltiness were located in the upper right quadrant and were correlated.

For juiciness, TI parameters related to the duration of the perception (Tend and DurDec) were inversely correlated with those related to the perceived intensity (Imax and AUC) and the time to reach the plateau phase (TSPlat). Instrumental texture measurements positively correlated with Tend and DurDec and negatively with Imax, AUC and TSPlat of juiciness. TI parameters related to juiciness perception were positively correlated with saltiness and negatively with mushroom TI parameters, suggesting that the influence of texture on flavour perception was dependent on the stimuli.

Factor scores plot (Fig. 3b) shows that LF–HS sausages displayed higher (Imax and AUC) and longer mushroom flavour (Tend and DurDec) perception, were perceived juicy for a longer time (Tend) and exhibited higher 1-octen-3-ol chromatographic areas compared to the rest of samples. LS sausages are associated with a longer time to maximum intensity of saltiness (TSPlat). Samples with the highest fat and salt content (HF–HS) were the juiciest (Imax) and displayed a longer duration of the decreasing phase for saltiness perception (DurDec-salt). Moreover, a shorter time to maximum intensity (TSPlat) of mushroom flavour is shown by HF–HS sausages.

3.3. Headspace analysis of volatile compounds

Chromatographic areas (means ± SD) of 1-octen-3-ol and 2,6-dimethylpyrazine detected in the headspace of the nine different

![Fig. 3](image-url)
of salt sausages (LS: low salt, MS: medium salt and HS: high salt). This effect is attributed to the salting-out phenomenon, where NaCl reduces this ability by modifying the polarity of surface proteins (Ruusunen et al., 2005) and by causing protein denaturation (Hatchwell, 1994) and thus suppressing their release. Therefore, the higher retention of 1-octen-3-ol by fat decreased the intensity of mushroom perception in HF compared to LF sausages. Accordingly, most TI studies reported a less intense flavour in high-fat compared to low fat formulations (Guinard, Wee, McSunas, & Fritter, 2002; Shamil et al., 1991/92; Chung et al., 2003; Fröst et al., 2005). Hydrophilic volatile compounds are less affected by changes in fat content than lipophilic compounds (Hort & Cook, 2007), thus the effect of fat content on 2,6-dimethylpyrazine (log $P_	ext{o-w} = 0.54$) release and perception (cocoa odour and flavour) was less evident compared to the effect on 1-octen-3-ol.

The resistance to mass transport affects the rate of partition of flavour compounds over the different phases being higher in fat and oil compared to water (De Roos, 1997). The higher resistance of 1-octen-3-ol to transfer in HF compared to LF sausages partly explains the suppression effect of fat on mushroom flavour perception. Moreover, high amounts of fat in the mouth can acts as a coating hindering flavour perception (Emrick et al., 2005), as the fat/water proportion was higher in sausages with the highest fat content.

Conflicting effects of fat on total duration of flavour perception have been reported. De Roos (1997) and Fröst et al., 2005 found a longer duration of flavour with fat content, whereas Guinard et al. (2002) and Chung et al. (2003) described a shorter persistence of flavour in high-fat compared to low fat systems. In the present study, all TI parameters, including time to maximum perception (TSPlat) and total duration (Tend) of mushroom flavour, decreased in HF compared to LF sausages. Maximum intensity of mushroom flavour (Imax) was lower in HF sausages and subsequently less time was needed to reach this maximum flavour (TSPlat) in HF compared to LF sausages. However, a longer duration of the perception (Tend) would have been expected in sausages with the highest fat content since release of 1-octen-3-ol was apparently slower in HF compared to LF sausages. One possible explanation is that 18 s of chewing before swallowing were not enough to allow the complete release of 1-octen-3-ol from HF sausages. Part of the sample containing 1-octen-3-ol retained by the higher fat content was swallowed and thus less compound remaining in the mouth to produce a longer mushroom flavour perception. Guinard et al. (2002) explained similarly the shorter garlic flavour perception found in high-fat compared to low fat dressing salads.

4. Discussion

4.1. Effect of salt and fat content on release and perception of 1-octen-3-ol

Sensory profiling and TI revealed that NaCl potentiated the perceived mushroom odour and flavour. This effect was supported by the higher release of 1-octen-3-ol to the headspace of HS compared to LS sausages. This potentiator effect is well established (Salles, 2006) and reported (Mirhosseini, Salmah, Nazimah, & Tan, 2007; Pérez-Juan, Flores, & Toldrà, 2008) and it depends on the physicochemical properties of the aroma compound and on the salt type and concentration (Saint-Eve et al., 2009). According to previous studies (Rabe et al., 2003; Salles, 2006), NaCl is likely to increase the volatility of the most hydrophobic compound (1-octen-3-ol) by decreasing the water molecules available for its solubilisation. Moreover, meat proteins are able to bind volatile compounds (Pérez-Juan et al., 2008) and NaCl reduces this ability by modifying the polarity of surface proteins (Ruusunen et al., 2005) and by causing protein denaturation (Pérez-Juan et al., 2008). Temporal analysis of mushroom flavour confirmed that changes in NaCl content of sausages affected both the intensity (Imax and AUC) and duration (Tend and DurDec) of flavour perception.

Intensity of mushroom odour and flavour decreased with fat content in cooked bologna sausages, agreeing with the chromatographic areas for 1-octen-3-ol. Physicochemical interactions of fat and 1-octen-3-ol (log $P_	ext{o-w} = 2.60$) partly explain this effect as fat acts as solvent for lipophilic compounds decreasing their vapour pressure (Hatchwell, 1994) and thus suppressing their release. Furthermore, the higher retention of 1-octen-3-ol by fat decreased the intensity of mushroom perception in HF compared to LF sausages. Accordingly, most TI studies reported a less intense flavour in high-fat compared to low fat formulations (Guinard, Wee, McSunas, & Fritter, 2002; Shamil et al., 1991/92; Chung et al., 2003; Fröst et al., 2005). Hydrophilic volatile compounds are less affected by changes in fat content than lipophilic compounds. This effect was supported by the rest of samples (Fig. 4). Headspace results for 1-octen-3-ol were found, likely due to the higher concentration of this volatile compound.
with fat content if lean pork was replaced with fat pork in high fat formulations. However, this effect was not observed in the present study.

4.3. Juiciness as affected by salt and fat content

Juiciness in cooked sausages is defined as the amount of moisture or juice perceived during mastication (Matulis et al., 1995; Hayes, 2009) which is related to the ability of meat proteins to entrap water. Increase salt content in frankfurters allows the formation of a water–protein matrix by favouring the partial solubilisation of myofibrillar proteins (Matulis et al., 1995). However, in the present study, moisture content of bologna sausages was not affected by salt content and thus the increase in juiciness due to salt must be attributed to a different factor than increase in water binding capacity. NaCl acts as flavour enhancer increasing the palatability of foods and its perception involved the activation of physiologic processes such as stimulation of salivation and secretion of gastric acid (Mattes, 1997). This physiological effect of NaCl during consumption of sausages could have contributed to increased juiciness perception. Moreover, increase in juiciness perception caused by NaCl has been widely reported in cooked sausages (Matulis et al., 1995; Ruusunen et al., 2001) but no studies dealing with temporal aspects have confirmed this effect.

Results of juiciness using descriptive profiling and TI methods were apparently contradictory, confirming that static and dynamic sensory techniques can provide different type of information. Unexpected results were obtained with descriptive profiling since juiciness of sausages decreased with salt content, mainly due to LF–HS sausages which were the least juicy compared to the rest of sausages as PCA shows. Descriptive analysis entails static judgements (Dijkstraheuvel & Piggott, 2001) meaning that panellists integrate the perception over time from the moment the sample is put in the mouth to the time of swallowing. This single measurement provided from the changing juiciness could have been more influenced by the low fat content than by the high salt content in LF–HS sausages. However, TI technique allowed the evaluation of juiciness resulting from the dynamic process taking place during consumption of sausages and therefore increase in juiciness with salt and fat were faithfully reflected.

Fat had a noticeable effect on increasing juiciness intensity whereas TI parameters related to duration of the perception was not significantly affected by fat content. Similarly, Ruusunen et al. (2001) found a slight increase in juiciness with fat in bologna type sausages. However, Matulis et al. (1995) and Crehan, Hughes, Troy, and Buckley (2000) reported lower juiciness scores as fat increased in frankfurters due to substitution of water by fat in high fat formulations leading to lower moisture content in these sausages. In these studies, panellists perceived juiciness related to moisture than to fat content. In the present study, differences in fat content of sausages were obtained by different combinations of lean pork and back fat. The effect of fat on juiciness was noticeably perceived by panellists though sausages with the highest fat content and the lowest moisture content. Therefore, juiciness related to fat content was more pronounced than juiciness related to water content in sausages with the highest fat content. Stimulation of the salivary glands by fat (Miller, 1994) would have contributed to enhance the palatability and thus the juiciness of HF sausages.

Increasing the salt content enhanced the juiciness of sausages with this effect on TI parameters being different depending on the fat content. Juiciness was more intense (Imax-juic and AUC-juic) in HS if the fat content was also high (HFHS). However, without increasing fat content (LFHS), salt lead to a longer juiciness perception (Tend-juic). Therefore, fat was apparently more effective increasing juiciness intensity whereas salt might extend the duration of the perception in cooked bologna sausages.

4.4. Relationship between flavour and texture TI parameters

Remarkable results were obtained for the relationship between texture and flavour TI parameters showing in the corresponding PCA. Flavour is a multi-sensory perception produced through the integration of the senses of taste, smell and the trigeminal (Auvray & Spence, 2008). Texture properties can affect the perceived flavour (Bayarri, Taylor, & Hort, 2006). Previous studies in different systems (gel systems, desserts, whey protein gels) have lead to different conclusions (Weel et al., 2002; Lethuault, Weel, Boelrijk, & Brossard, 2004). In the present study, two flavour stimuli (NaCl and 1-octen-3-ol) were included in the cooked bologna sausages with the purpose of studying the dynamic flavour perception of the corresponding attributes (saltiness and mushroom flavour). Moreover, modifications in sausage formulations (fat and salt content) lead to differences in texture (juiciness). The positive correlation between juiciness and saltiness TI parameters confirms that saltiness was perceived more intense and for longer time in the juiciest sausages whereas the intensity and duration of mushroom flavour was negatively correlated with juiciness, suggesting lower release of 1-octen-3-ol in the juiciest sausages (HF–HS).

This study demonstrates the feasibility of dynamic sensory methods, particularly TI, for evaluating the sensory properties of meat products with modified matrix composition. Time–intensity is a powerful sensory technique for gaining information about the changes in flavour and texture during consumption of cooked sausages. Salting-out phenomenon enhanced the release of 1-octen-3-1, whereas suppression effect of fat on this compound leads to the opposite effect. Both phenomena modified the mushroom flavour intensity and duration of the perception. Salt extended juiciness perception whereas fat increased its intensity. Saltiness was evidently affected by salt content while fat did not contribute to saltiness perception. Changes in juiciness of sausages caused by modifications in salt and fat content also influenced the saltiness and mushroom flavour perception.

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