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In Vivo Aroma Release of Milk Gels of Different Hardnesses: Inter-individual Differences and Their Consequences on Aroma Perception

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The effect of textural modifications of solid milk gels on in vivo aroma release and aroma perception was investigated with a panel of 14 subjects. Great inter-individual differences were observed on aroma-release data, and the consequences of these differences on aroma perception were studied. From a hierarchical cluster analysis performed with several parameters extracted from release curves, the subjects were gathered into two groups, and a specific aroma-release profile was identified for each one. Then, by using a sensory profile, we showed that the intensity of the aroma perception was dependent on the release profile presented by the panelist. Second, we observed that, during the chewing phase, the aroma was perceived as more intense for the firmer gel and for panelists for whom the aroma release begins during the chewing of the product.

KEYWORDS: Aroma release; APCI-MS; nosespace; inter-individual differences; aroma perception; texture; perceptual interactions

INTRODUCTION

Breath-by-breath measurements by mass spectrometry, applying techniques such as atmospheric pressure chemical ionization mass spectrometry (APCI-MS) or proton transfer reaction mass spectrometry (PTR-MS), have been in use for a few years as a fairly common methodology for the study of in vivo aroma release (*1–3*). Moreover, experiments are often carried out in tandem with sensory experiments, because the correlation between aroma release and perception is of special interest. In this context, many authors focused their attention on the impact of a texture modification (*2–9*). In these previous studies, the sensory results showed that the aroma intensity perceived decreased with an increase in the hardness or the viscosity of the product. The link with physicochemical data is however different depending on the study. van Ruth et al. (*9*) and Saint-Eve et al. (*10*) found a good relation between the intensity of the aroma perception and the quantity of aroma compounds released in vivo, but other authors supposed that the intensity of the aroma perception was linked with the rate of the aroma-compounds release (*2, 5, 6, 11*). Finally, it was also postulated that the aroma perception was determined by perceptual interactions rather than by the aroma release because the nosespace flavor concentration was found to be independent of the gel hardness or viscosity (*3, 4, 8*).

From another perspective, a high variance between the panelists has been reported in some papers dealing with nosespace experiments (*5–7*). Different aroma-release patterns have often been observed, but to our knowledge, this variance has not been the subject of an in-depth analysis. The differences in aroma releases seem to be related to the opening and closing of the velum, which controls the extent to which the air in the mouth can be transported to the stream of air from the lungs to the nasal cavity during the main steps of the consumption process (chewing and swallowing) (*12, 13*). Moreover, the connection between these panelist-specific aroma-release patterns and aroma perception has not been studied. Only Mestres et al. (*14*) found a correlation between individual-specific aroma-release patterns and the respective aroma perception evaluated with the time−intensity methodology.

The aim of the present study was therefore to look specifically into inter-individual differences regarding aroma release and aroma perception. To do that, by using in vivo aroma-release data obtained from a panel of 14 subjects (*15*), we first studied the variations of the release profiles and used a statistical method (hierarchical cluster analysis (HCA)) to constitute groups with subjects having similar aroma-release profiles. In a second step, a sensory profile was performed with the same panelists, and the sensory data were analyzed in order to evaluate the influence of a specific aroma-release pattern on the aroma perception. These two studies were realized with three milk gels, models of cheese prepared with the same protein concentration but having different textures.

MATERIALS AND METHODS

Preparation of Gels. Three milk gels, obtained from the combined action of chymosin and bacterial fermentation on milk, were prepared and flavored by using the procedure described in a previous publication

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Table 1. List of Attributes Used during the Sensory Profile with Their Definition or Reference

descriptor	definition or reference
Texture	
hardness	force necessary to compress the product between the tongue and the palate
moisture	perceived degree of moisture in mouth
stickiness	force necessary to remove the product adhering to mouth surfaces (palate, teeth) during and after mastication
granularity	degree to which solid particles are perceived at the surface of the product by the tongue
heterogeneity of the breakdown (hbreakdown)	behavior of the product subjected to breakdown. For the chewing phase, a product is described as homogeneous when it tends to spread or flow, and a product is described as heterogeneous when it is more brittle and breaks into several pieces. For the postswallowing phase, a homogeneous product leaves homogeneous residues in mouth, and a heterogeneous product leaves a few particles in mouth
Aroma	
overall aroma	overall intensity of the product
Taste	
salty	NaCl solution (2 g/L)
sour	lactic acid solution (2 mL/L)
bitter	caffeine solution (0.5 g/L)

(*15*). They contained the same concentration of protein (10% (w/w)), lactose (4% (w/w)), NaCl (1% (w/w)), and starter culture (0.2% (v/w)) but different amounts of chymosin; M0 was obtained without chymosin and M3 and M10 were obtained with 3 and 10 μg/kg of chymosin, respectively. The products were flavored with 0.9 mL/kg of an aroma formulation providing a global flavor of cheese with dominant notes of blue cheese and mushroom. The aroma formulation was composed from 10 aroma compounds dissolved in triacetin: 3-methylbutanal (1221 mg/kg), oct-1-en-3-ol (2442 mg/kg), octanal (37 mg/kg), heptan-2-one (2779 mg/kg), ethyl butanoate (914 mg/kg), hexanoic acid (2356 mg/kg), nonan-2-one (2779 mg/kg), ethyl hexanoate (914 mg/kg), diacetyl (22779 mg/kg), and phenylacetaldehyde (9135 mg/kg). The gels were prepared in ice cube molds in order to obtain 5 g gel cubes to be given to the panelists. They were stored at 4 °C and analyzed within 5 days. Prior to consumption, they were stored for 1 h at 15 °C. The absence of listeria, salmonella, and total coliform bacteria was verified for each preparation by the Laboratoire départemental de Côte d'Or (Dijon, France). The three gels were self-supporting, and their hardness, determined instrumentally by penetrometry tests (TA-XT2, Stable Micro System), significantly increased between M0 (0.53 N), M3 (1.15 N), and M10 (2.11 N) (*15*).

Panelists. A group of 14 volunteers (nine females and five males aged between 19 and 53) participated in the study. The volunteers were instructed not to smoke, eat, drink, or use any persistent-flavored product for at least 1 h before each session.

Breath-by-Breath Aroma-Release Measurements. The online in vivo aroma-release measurements were performed by using APCI-MS as described previously (*15*). Air from the nose was sampled from one nostril at a flow rate of 30 mL/min and introduced into the source of the Esquire-LC mass spectrometer (Bruker Daltonique, France) via a fused silica capillary tubing (i.d. = 0.53 mm). The transfer line was heated at 150 °C to avoid water condensation. Acetone (*m*/*z* 59, an indicator of the panelists' breathing patterns), 3-methylbutanal (*m*/*z* 69), oct-1-en-3-ol (*m*/*z* 111), heptan-2-one (*m*/*z* 115), ethyl butyrate (*m*/*z* 117), nonan-2-one (*m*/*z* 143), and ethyl hexanoate (*m*/*z* 145) were analyzed. For this paper, because we were interested only in the shape of the aroma-release profile, we worked on a signal resulting from the sum of the intensity of the different ions contained between *m*/*z* 111 and *m*/*z* 145. However, the same observations as those which will be presented in the Results and Discussion section have been made for each individual ion.

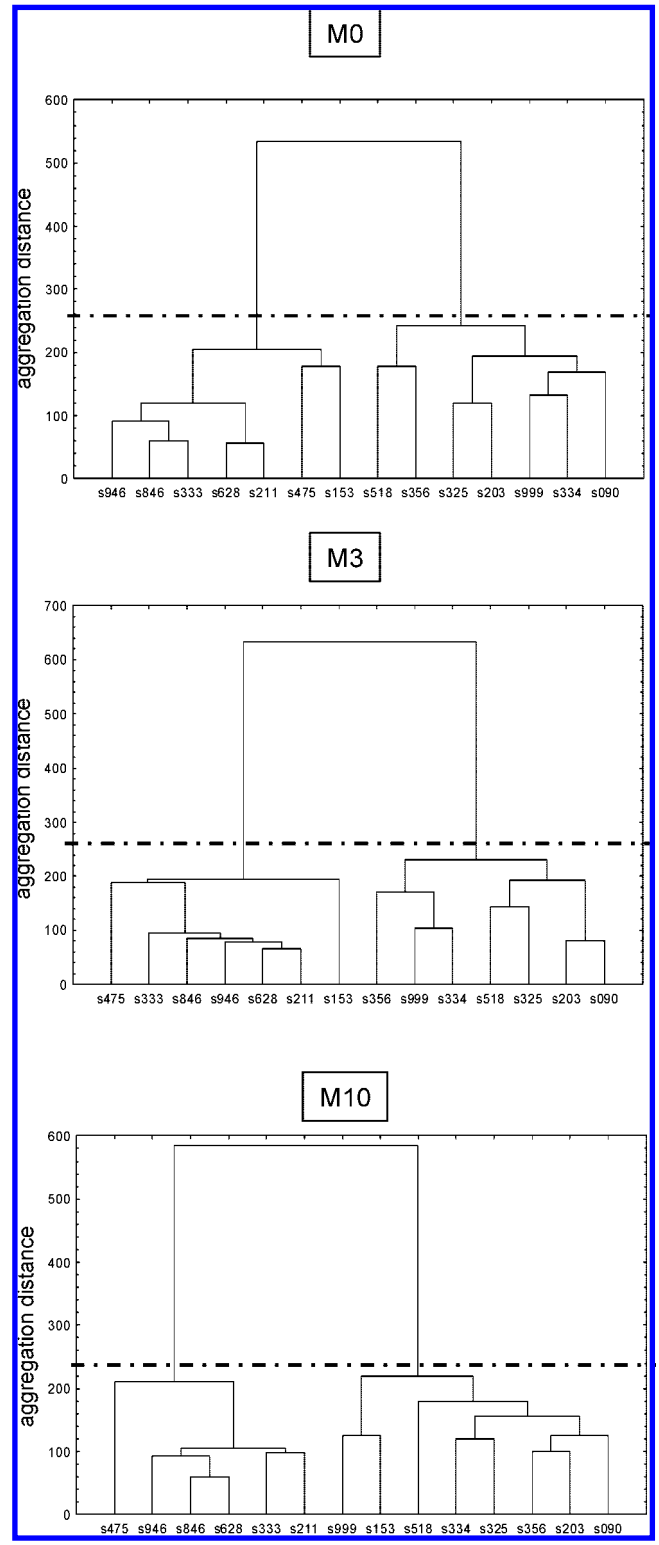

Figure 1. Dendograms obtained from a HCA performed on the aroma-release data of the 14 panelists and for each gel, M0, M3, and M10. The dotted line symbolizes the level of clusterization used to constitute the groups of panelists.

The samples, gel cubes of 5 g served on a spoon, were taken into the oral cavity and chewed for 20 s by the volunteers with their mouth closed and without swallowing (chewing phase). Then, the panelists were instructed to swallow the bolus, and the recording continued for 36 s (postswallowing phase). The panelists were asked to clean their mouths with bread, apple, and water between two samples. The products were analyzed in random order, and eight replicates of the release profile

Table 2. Composition of the Two Groups of Panelists Generated by the HCA Performed on Aroma-Release Data

gel	group A	group B
M0	s356, s999, s334, s203, s090, s518, s325	s475, s846, s333, s628, s946, s211, **s153**
M3	s356, s999, s334, s203, s090, s518, s325	s475, s846, s333, s628, s946, s211, **s153**
M10	s356, s999, s334, s203, s090, s518, s325, **s153**	s475, s846, s333, s628, s946, s211

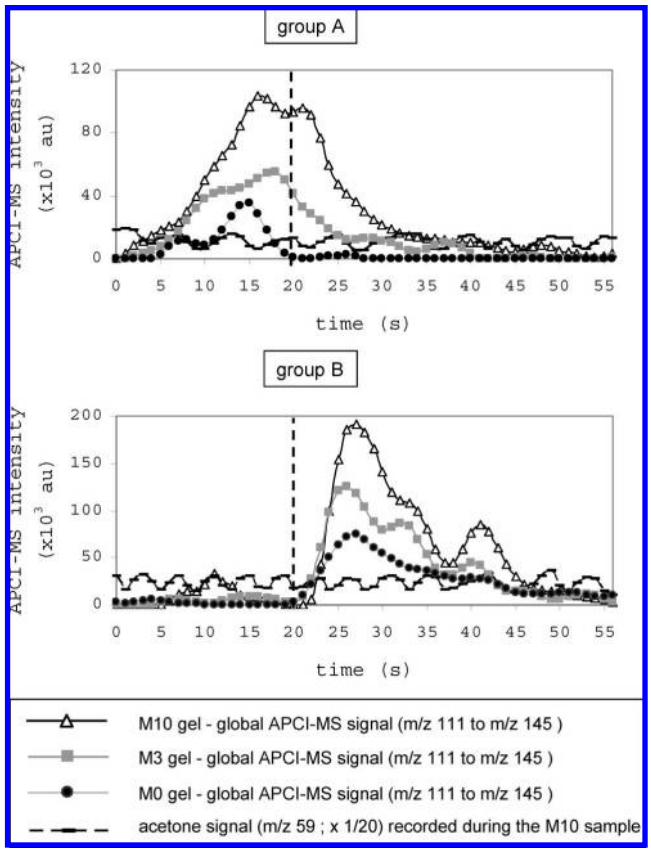

Figure 2. Typical aroma-release profile presented by each group of panelists for the three gels, M0, M3, and M10. Each curve is one replicate release curve obtained with one panelist of each group. The dotted line on the release profile symbolizes the moment when the principal swallow of the bolus occurs.

were performed for each gel. These replicates were obtained during two different sessions.

Each individual release curve was smoothed with a spline function, and different parameters were extracted from each individual smoothed release curve: Imax, which corresponds to the maximum intensity of the APCI-MS signal; Iswallow, which corresponds to the intensity of the APCI-MS signal when the principal swallow occurs (20 s); and AUC, which corresponds to the area under the curve of the release profile. The AUC was determined for the chewing phase (AUCc = area under the curve between 0 and 20 s), for the postswallowing phase (AUCps = area under the curve between 20 and 56 s), for the whole release run (AUCt = area under the curve between 0 and 56 s), and for each period of 5 s (AUCx = area under the curve between $x - 5$ and x s) (*15*). As the recording lasted 56 s, 11 values of the parameter AUCx were obtained. Then, the parameter Iswallowc was calculated as the ratio between Iswallow and Imax, and the parameter pAUCx was calculated as the ratio between AUCx and AUCt. These ratios were preferred to the quantitative parameters because they were found to be more representative of the shape of the release curves.

Sensory Analysis. By using a sensory profile, the sensory properties of the texture, taste, and aroma of the three gels were evaluated by 13 of the 14 panelists. The three gels, M0, M3, and M10, were evaluated without nose clips during a first profile and with nose clips during a second profile. A common vocabulary was developed by the panelists (**Table 1**), who were trained (without and with nose clips) during 24 sessions to evaluate the different attributes by using identification and ranking tests performed both in water and in commercial fresh cheese. They were also trained to assess intensities for each attribute on a linear scale. To be consistent with the eating protocol used during the aroma-release measurements and to be able to compare the sensory data with the aroma-release data, the two sensory profiles (without and with nose clips) were performed at two phases of the consumption process. First, the sensory properties of the gels were evaluated during a 20 s chewing period (chewing phase). Second, the product was swallowed, and the residual perceptions were evaluated (postswallowing phase). These two evaluation periods were randomly evaluated by each panelist, and during the assessment of one evaluation period, the three products were successively evaluated but randomly presented to each panelist. The samples, gel cubes of 5 g served on a spoon coded with a three-digits code, were presented in a monadic way. The subjects were asked to clean their mouth with water, bread, and sometimes an apple between two samples. The acquisitions were achieved by using the FIZZ software (FIZZ Biosystèmes, Couternon, France). The measurements were conducted in an air-conditioned room ($T = 23$ °C), under red light to avoid product recognition, and in individual boxes. Three replicates of the sensory profiles were performed for each gel. These replicates were obtained during three different sessions.

Statistical Analysis. By using the aroma-release data, a hierarchical cluster analysis (HCA) was performed with the R software version 2.0.1 (http://www.R-project.org), and the Ward's method was applied in order to gather in a same group subjects having similar aroma-release pattern.

The analysis of variance (ANOVA) was performed with the general linear model procedure of SAS 9.1 (SAS Institute Inc., Cary, NC). When significant differences were observed ($p < 0.05$), the mean intensities were compared by using the Student–Newman–Keuls (SNK) multiple comparison test. Two models of ANOVA were used. By using the data of the whole panel, the aroma-release data and the sensory perception data were analyzed with a three-way model (model 1 = group, product, random subject) with group*product and subject*product interactions. Then, by using the data of each group of subjects separately, the aroma-release data and the sensory perception data were analyzed with a two-way model (model 2 = product, random subject) with subject−product interactions.

RESULTS AND DISCUSSION

Interindividual Differences among In Vivo Aroma-Release Data. In order to characterize the different aroma-release profiles observed for the 14 subjects of our panel, we tried to gather panelists having similar aroma-release profiles. To do that, a HCA was performed with 12 parameters obtained from the aroma-release curves (Iswallowc and pAUCx). As the behavior of the panelists may change with the texture of the product, we realized three HCA, one for each of the three gels, M0, M3, and M10. Each HCA resulted in a dendogram that grouped panelists with similar values of the parameters (**Figure 1**). For each dendogram, the first level of clusterization, the most significant one, led us to define two groups of panelists called group A and group B. The composition of these groups is summarized in **Table 2**. We can notice that the distribution of the subjects is balanced, because the two groups have almost the same number of subjects for each gel. Moreover, the behavior of the panelists is quite stable with the evolution of the texture of the gel. Indeed, only one subject (s153) does not

Table 3. Statistical Results (*F* and *p* of ANOVA) Obtained from the Analysis of Aroma-Release Data (AUCc, AUCps, AUCt) with Data Pooled on the Whole Panel

	AUCc	AUCps	AUCt
product effect	$F(2;22) = 5.55$; $p = 0.0108$	$F(2;22) = 11.82$; $p = 0.0003$	$F(2;22) = 9.68$; $p = 0.0009$
group effect	$F(1;13) = 78.36$; $p < 0.0001$	$F(1;13) = 24.59$; $p < 0.0001$	$F(1;13) = 0.23$; $p = 0.6308$
product*group interaction	$F(2;35) = 0.62$; $p = 0.5479$	$F(2;35) = 0.55$; $p = 0.5853$	$F(2;35) = 0.53$; $p = 0.5935$

belong to the same group for the three gels. This subject belongs to group A for M10, the harder gel, and to group B for M3 and M0.

For each of the two groups, A and B, the signal of *m*/*z* 59 representing the breathing pattern of the subject was regular during the whole sequence of the consumption, but a specific aroma-release profile was identified whatever the product studied (**Figure 2**). For group A, the aroma compounds are continuously detected in the nasal cavity during the chewing phase and until the end of the consumption process. For group B, the aroma compounds are detected in the nasal cavity mainly after the swallowing of the product, and only a low release signal is observed during the chewing phase for a few subjects. Moreover, the shape of these two profiles is similar for the three products studied. Our results are consistent with previous studies (*5, 6*), which also mentioned the two aroma-release patterns we identified among the 14 subjects of our panel. However, we must highlight the fact that, in our study, we tried to investigate inter-individual differences not only by observing aroma-release curves, but also by performing an objective classification of the subjects by using relevant parameters extracted from each release curve and by characterizing the shape of these curves. It is during the chewing that the most important difference is found between the two release patterns. Indeed, during this phase, an intense release signal is observed for only part of the subjects. These differences may be explained by physiological considerations (*12–14, 16, 17*). Indeed, we may suppose that, for subjects of group A, the barrier formed by the connection between the velum and the back of the tongue regularly opens during the whole chewing phase, thereby allowing the transfer of aroma compounds from the mouth to the nasal cavity until the swallowing of the product. This phenomenon probably occurs for the subjects of group B, but in a much less-marked way than for the subjects of group A. During swallowing, the velum opens to allow the transfer of the bolus into the pharynx and into the esophagus (*17*). The air charged with aroma compounds is delivered to the pharynx and transported to the nose at a subsequent exhalation. This explains why aroma compounds are detected in the nasal cavity during the postswallowing phase for all the subjects. The physiological difference between the subjects in opening and closing of the velum−tongue barrier observed during the chewing phase may be due to the different masticatory efforts performed by the subjects. For instance, Hodgson et al. (*16*) showed that each chewing action on a chewing-gum resulted in a peak of aroma release. In our case, we may suppose that the subjects of group A performed more chewing actions than the subjects of group B, thereby allowing the opening of the velum−tongue barrier and the transfer of the aroma compounds to the nasal cavity during the chewing phase.

In addition, we observed that the behavior of one subject, s153, was different depending on the texture of the gel. For the harder gel, this subject belongs to group A, and the aroma release occurs during both the chewing and the postswallowing phases. On the contrary, for the less hard gels M3 and M0, subject s153 belongs to group B, and the aroma release occurs only after the bolus has been swallowed. This phenomenon has already been observed by Mestres et al. (*6*) on protein gels. Indeed, these authors showed that, for few panelists, the aroma release occurred as soon as the firmer gel was chewed, although the aroma release occurred only after swallowing for the softer gel. Peyron et al. (*18*) showed that the intensity of the masticatory effort decreases with a decrease in the hardness of a product. Therefore, the fact that in our study one subject did not present the same release pattern for the three products may be attributed to an evolution of his chewing pattern with the texture of the product. In particular, we may suppose that subject s153 produced fewer chewing actions for gels M3 and M0 than for gel M10, thereby limiting the opening of the velum−tongue barrier and the transfer of the aroma compounds via the retronasal route.

Finally, we investigated to what extent the quantity of aroma compounds released differed between groups A and B. To do that, the model 1 of ANOVA was applied to the three parameters, AUCc, AUCps, and AUCt. For the quantity of aroma released during the chewing phase (AUCc) and the postswallowing phase (AUCps), a significant group effect was found (**Table 3**). However, for the whole consumption sequence (AUCt), no group effect was observed (**Table 3**). The results of means comparison test representing the differences between the groups are shown in **Figure 3**. For the chewing phase, we observe that the quantity of aroma released is significantly higher for group A than for group B. For the postswallowing phase, the quantity of aroma released is, on the contrary, significantly higher for group B than for group A. Finally, it is very interesting to see that, at the end of the consumption process, the same quantity of aroma compounds is released for the two groups of subjects. This tends to prove that, even if the kinetic of the aroma release is very different between the two groups, the products are broken to the same level by the subjects of groups A and B, so that the aroma compounds can be released to the same extent. However, as it has been seen by Mestres et al. (*19*), we may suppose that the breakdown of the products happens in different ways for each group of subjects, probably because of the different chewing patterns performed by each group of subjects. We may indeed suppose that the subjects of group A chew the products, whereas the subjects of group B perform shearing actions with mainly back and forth or sideways

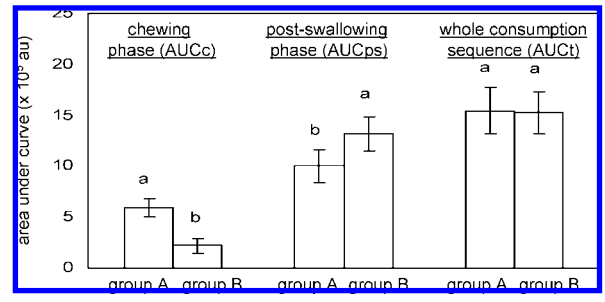

Figure 3. Quantity of aroma compounds released in vivo for the two groups, A and B, and averaged on the three gels for each phase of the consumption process. Mean values and 95% confidence intervals. The letters a and b indicate that the means are different at $p < 0.05$ (SNK test).

Table 4. Statistical Results (*F* and *p* of ANOVA) Obtained from the Analysis of Aroma-Perception Data (Intensity of Aroma Perception)[a]

	whole panel (ANOVA model 1)	group A (ANOVA model 2)	group B (ANOVA model 2)
	Chewing Phase		
product effect	$F(2;21) = 2.32$; $p = 0.1227$	$F(2;10) = 3.99$; $p = 0.0532$	$F(2;11) = 0.73$; $p = 0.5053$
group effect	$F(1;12) = 33.53$; $p < 0.0001$	ni	ni
product*group interaction	$F(2;33) = 0.83$; $p = 0.4493$	ni	ni
	Postswallowing Phase		
product effect	$F(2;21) = 1.12$; $p = 0.3450$	$F(2;10) = 1.00$; $p = 0.4030$	$F(2;11) = 0.42$; $p = 0.6655$
group effect	$F(1;12) = 12.71$; $p < 0.0001$	ni	ni
product*group interaction	$F(2;33) = 0.14$; $p = 0.8735$	ni	ni

[a] ni means that the effect was not included in the ANOVA model.

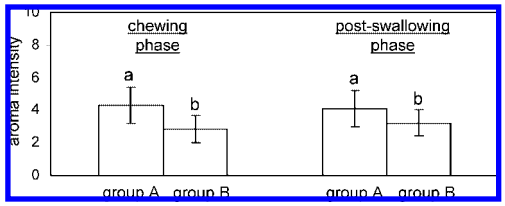

Figure 4. Overall aroma intensity perceived by the panelists of of the two groups, A and B, and averaged on the three gels for both the chewing phase and the postswallowing phase. Mean values and 95% confidence intervals. The letters a and b indicate that the means are different at $p < 0.05$ (SNK test).

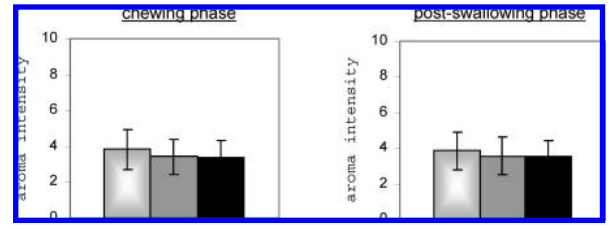

Figure 5. Overall aroma intensity perceived for M0 (light gray), M3 (dark gray), and M10 (black) during the chewing phase and the postswallowing phase. Mean values for the whole panel and 95% confidence intervals.

movements of the jaw rather than real chewing with an opening of the jaw and teeth. For these panelists, the products would be therefore mainly pressed with the tongue in the frontal part of the oral cavity against the hard palate, so that no opening of the tongue−velum barrier occurs.

Sensory Analysis. *Link between Panelist-Specific Aroma-Release Profile and Intensity of Aroma Perception.* In a first step, the data obtained from the sensory profile were analyzed to evaluate the aroma-perception differences between the two groups of panelists (group A and group B) established from the shape of the aroma-release curves. To do that, by considering the data of the whole panel for each evaluation period separately, a three-way model of ANOVA (model 1) was performed. A significant group effect was found for the aroma descriptor for the chewing and the postswallowing phases (**Table 4**, column 1). The aroma was perceived as significantly more intense by the panelists of group A than by the panelists of group B (**Figure 4**).

This result clearly shows a link between the panelist-specific aroma-release patterns and the aroma perception, and it proves the fact that the intensity of the aroma perception is different depending on the release pattern presented by the subject. During the chewing phase in particular, the subjects who present a higher quantity of aroma compounds released perceive the aroma to a more intense level. For the postswallowing phase, although the quantity of aroma released is higher for the subjects of group B, the aroma intensity is still perceived more intensely by the subjects of group A. One could hypothesize that the aroma intensity evaluated during the postswallowing phase was influenced by the aroma perception during the chewing phase rather than by the stimulus released after the swallowing of the product.

Sensory Differences between the Three Gels. Analysis on the Whole Panel. In a second step, we investigated the sensory differences between the three gels and in particular the impact of the textural modifications on aroma perception. This analysis was first performed for the whole panel, by using the model 1 of ANOVA. Regarding the aroma perception, no significant differences were observed between the three gels (**Table 4**, column 1). However, the intensity of the aroma perception tended to be more important for M0 than for M3 and M10 (**Figure 5**). For our products, the consequences of a textural modification on the aroma perception are therefore quite weak and less significant than those observed by other authors (*2, 3*), but the same tendency was obtained. The harder the gel, the less intense the aroma perception. In a previous study (*15*), we showed that the amount of aroma compounds released in vivo together with the rate of the release were higher for the M10 gel than for the M0 gel. The release data can therefore not explain the tendency observed on the aroma perception between the three gels, and we supposed that the modification of the aroma perception resulted from perceptual interactions between the aroma and the texture and/or salt perceptions. Our hypothesis was encouraged by the fact that the sensory profile highlighted texture and taste differences between the three gels. Concerning the texture perception, significant differences ($p < 0.0001$) were observed between the three gels for the chewing and the postswallowing phases and for all attributes (**Figure 6**). The M10 gel was perceived as harder, more granular, and stickier and generated a less intense moisture perception than the M3 and M0 gels. In addition, the breakdown of the M10 gel was described as heterogeneous, forming several pieces, although

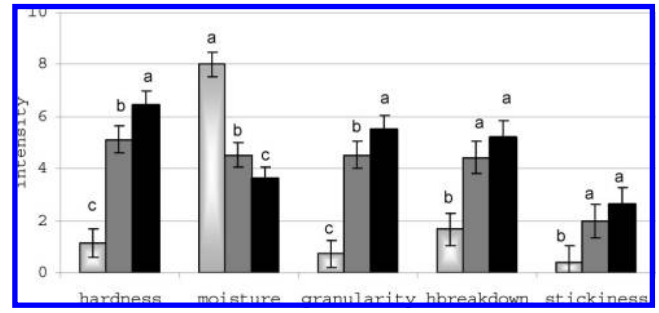

Figure 6. Textural differences perceived between M0 (light gray), M3 (dark gray), and M10 (black). Mean values and 95% confidence intervals. The mean values were calculated for the whole panel and averaged for the chewing and the postswallowing phases. The letters a and b indicate that the means are different at $p < 0.05$ (SNK test).

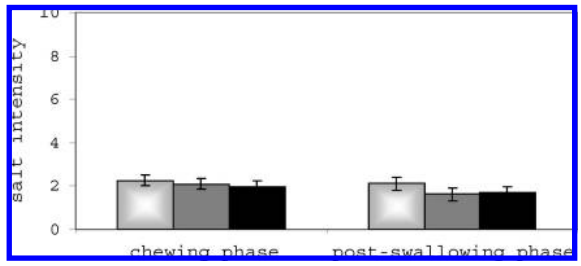

Figure 7. Differences between M0 (light gray), M3 (dark gray), and M10 (black) perceived as salty during the chewing phase and the postswallowing phase. Mean values for the whole panel and 95% confidence intervals.

the breakdown of the M0 gel was described as homogeneous, as if the product spread into the mouth during its compression between the tongue and the palate.

Regarding the taste dimension, the bitter and sour attributes never appeared as discriminating attributes. Concerning the salty attribute, the products were not perceived as significantly different for the chewing and the postswallowing phases (chewing phase: $F_{product}(2;21) = 1.31$, $p_{product} = 0.2885$; postswallowing phase: $F_{product}(2;21) = 3.58$, $p_{product} = 0.0435$), but the intensity of the salt perception tended to be more important for M0 than for M3 and M10 (**Figure 7**). When the products were evaluated with nose clips, this tendency was confirmed, and the differences between the products were significant (chewing phase: $F_{product}(2;21) = 7.13$, $p_{product} = 0.0046$; postswallowing phase: $F_{product}(2;21) = 7.48$, $p_{product} = 0.0038$). Then, as the aroma mixture provided a global flavor of cheese with dominant notes of blue cheese and mushroom, mainly encountered in salty products, we first supposed that a taste−aroma interaction may occur, as was proposed by other authors (*20*). In this situation, the reduction in the salt perception observed between M0 and M10 gel could potentially account for the decline in the aroma perception between the three products. But we also supposed that the modification of the aroma perception may result from a texture−aroma interaction (*3, 21*). In particular, we formulated the hypothesis that the firmer M10 gel, which was perceived as granular and the breakdown of which was heterogeneous, required more attention of the subject to the texture than the softer gel M0 did, which was perceived as smooth, spread, and was thus more easily destroyed. As a consequence, for the M10 gel, less attention would be paid to other perceptions, such as taste and aroma, which would be perceived as less intense.

Sensory Differences between the Three Gels. Analysis for Each Group of Subjects. The sensory differences between the three gels, in particular the aroma perception differences, were then analyzed for each of the two groups, A and B, by using a two-way model of ANOVA (model 2). The statistical results relative to the product effect are presented in **Table 4**, columns 2 and 3, in comparison with those obtained for the whole panel. The result for the subjects of group A and on the chewing phase, with a p value of 0.0532, is distinguishable from the other situations where the p value is higher than 0.4. For these subjects, the aroma perception was also more important for M0 than for M3 and M10. The tendency of a slight decrease in the intensity of the aroma perception from M0 to the other gels, M3 and M10, observed for the whole panel is therefore more important for the subjects of group A and during the chewing phase. The fact that all the panelists, and more precisely that the two groups of panelists, did not present the same sensibility to the differences between the products may explain why the differences between the products analyzed with the data pooled on the whole panel are globally weak.

Then, the consideration of the groups of panelists generated from the release data allowed us to highlight once again the impact of the panelist-specific aroma-release patterns on the aroma perception and to go further in the comprehension of the perceptual interactions. In **Table 5**, we summarized the differences between the three gels, M0, M3, and M10, regarding the aroma release (area under the curve) and the aroma perception (intensity of the aroma perception) evaluated for each group separately and for each phase of the consumption process. For each situation, the probability of the product effect obtained with the model 2 of ANOVA is reported, and an arrow indicates how the value of the considered parameter evolves between M0 and M10 (stable, decrease, or increase). Three scenarios can be distinguished. For group B and during the chewing phase, no significant difference is observed whatever the set of data (release or perception) (scenario 1). For groups A and B and during the postswallowing phase, a significant increase in the quantity of aroma compounds released is observed from M0 to M10, but the subjects did not perceive aroma differences (scenario 2). We may suppose that the aroma-release differences were not large enough to be perceived by the subjects. For group A and during the chewing phase, differences between the products are found for the release and sensory data, but the effects are opposite (scenario 3). The quantity of aroma compounds released significantly increases from M0 to M10, although the intensity of the aroma perception significantly decreases from M0 to M10. The release data can therefore not explain the sensory differences between the products, and we may suppose that perceptual interactions occur between texture and aroma. For group A and during the chewing phase, the aroma release is significant, and large texture modifications occur, so we may suppose that scenario 3 corresponds to the situation where the texture−aroma interactions should have the most important impact on the aroma perception. On the contrary, during the postswallowing phase (scenario 2), the texture slightly changes, and aroma is largely released. The aroma perception would thus be dominant with regard to the texture perception for the two groups. In the same way, for group B during the chewing phase (scenario 1), the texture perception may be dominant with regard to the aroma perception for these subjects because few aroma compounds are released (**Figure 2**). In scenarios 1 and 2, because the major perception seems to be

Table 5. Aroma Release (AUCc or AUCps) and Aroma Perception (Intensity of Aroma Perception) Differences between the Three Gels, M0, M3, and M10, Evaluated for Each Group, A and B, for the Chewing and the Postswallowing Phases[a]

	group A		group B	
	aroma release	aroma perception	aroma release	aroma perception
chewing phase	↑ $p_{product} = 0.0359$	↓ $p_{product} = 0.0532$	→ $p_{product} = 0.2133$	→ $p_{product} = 0.5053$
postswallowing phase	↑ $p_{product} = 0.0263$	→ $p_{product} = 0.4030$	↑ $p_{product} = 0.0028$	→ $p_{product} = 0.6655$

[a] Arrows illustrate how the value of each parameter evolves between M0, M3, and M10 (→ means that the value does not significantly change from M0 to M10, ↓ means that the value decreases from M0 to M10, ↑ means that the value increases from M0 to M10), and $p_{product}$ represents the probability associated to the product effect.

either texture or aroma, the conditions would thus not be combined so that texture−aroma interactions occur, which would also explain why, in the three situations concerned, the subjects did not perceive aroma differences between the products.

Further investigations are needed to confirm our results, and in particular complementary experiments with a higher number of subjects would be useful. However, this study clearly highlights the impact of a panelist-specific physiological behavior on aroma release and aroma perception. We evidenced that the inter-individual differences observed among in vivo aroma-release data have to be taken into account to go further in the understanding of aroma perception and maybe perceptual interactions.

ABBREVIATIONS USED

APCI-MS, atmospheric pressure chemical ionization mass spectrometry; PTR-MS, proton transfer reaction mass spectrometry; HCA, hierarchical cluster analysis; Imax, maximum intensity; Iswallow, intensity when the principal swallow of the product occurs; AUC, area under the curve; ANOVA, analysis of variance; SNK, Student–Newman–Keuls.

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