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Flavor Perception and Aroma Release from Model Dairy Desserts

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Six model dairy desserts, with three different textures and two sucrose levels, were equally flavored with a blend of four aroma compounds [ethyl pentanoate, amyl acetate, hexanal, and (*E*)-2-hexenal] and evaluated by a seven person panel in order to study whether the sensory perception of the flavor and the aroma release during eating varied with the textural characteristics or the sweetness intensity of the desserts. The sensory perception was recorded by the time intensity (TI) method, while the in vivo aroma release was simultaneously measured by the MS−nose. Considering the panel as a whole, averaged flavor intensity increased with sucrose level and varied with the texture of the desserts. Depending on the aroma compound, the averaged profile of in vivo aroma release varied, but for each aroma compound, averaged aroma release showed no difference with the sucrose level and little difference with the texture of the desserts. Perceptual sweetness−aroma interactions were the main factors influencing perception whatever the texture of the desserts.

KEYWORDS: Aroma release; time intensity; MS-nose; APCI, API; nosespace; texture; sweetness; carrageenan; custards

INTRODUCTION

Increasing the viscosity of liquid solutions or foods with thickeners changes the sensory properties of these systems. Both taste and aroma perception can be depressed, depending on the type of hydrocolloid, the taste modality, and the flavoring (*1*, *2*). In such viscous systems, Baines and Morris (*3*, *4*) distinguished two phases depending on the apparent viscosity of the solution. In the dilute concentration range, i.e., as long as the zero-shear viscosity remains lower than 10 mPa s, the intensity of both taste and aroma does not change with the concentration of the thickener. Above this level, both taste and aroma are suppressed with increasing hydrocolloid concentration. In general, the same trend was found for gelled systems; i.e., an increase in the concentration of the gelling agent causes a decrease in the sensory rating of flavor perception (*5*) or a decrease in the maximum perceived intensity when TI methodology was used (*6*, *7*). Contradictory results were found by Gwartney who changed the texture of the protein gels by variation of salt type and ionic strength: gel hardness and perceived intensity of flavor were not related, but gel structure seemed to have an effect with particulate gels showing a low waterholding capacity having a lower maximum perceived intensity than gels with a stranded structure (*8*). In all of these studies, release of aroma compounds was not measured.

Several methods have been developed to measure the in vivo release of aroma molecules during the consumption of a food product (*9*−*11*). Using API-MS, it was shown (*12*) for gelatin gels that the maximum perceived intensity (TI) did not correlate with the maximum in vivo aroma release but with the rate of volatile release. Using a strictly defined chewing and swallowing time in the eating protocol, the flavor perception from flavored whey protein gels was found to decrease with increasing gel hardness with no change in the in vivo release of flavor (*13*). A psychophysical texture−flavor interaction was hypothesized. Similarly, whereas the nosespace release of either benzaldehyde or strawberry aromas from hydroxypropyl methyl cellulose (HPMC) solutions was not affected by increasing the thickener concentration, sensory perception of almond and strawberry flavors significantly decreased (*14*). Cook et al. found similar results for the impact of HPMC or λ-carrageenan on the perception of mushroom or garlic flavors (*15*) and about the impact of various thickeners on the sweetness perception of sucrose and aspartame and the saltiness perception of sodium chloride (*16*). Recently, a high correlation was found between the Kokini oral shear stress, which can be calculated from rheological measurements, and both taste and aroma intensities in viscous solutions (*17*). Potential perceptual interactions of volatiles and nonvolatiles (tasting agents) should be considered as the perception of aroma compounds can be modified by nonvolatiles (*18*). Although the sensations of taste and aroma have often been studied separately, perception of mint chewing

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Table 1. Composition of the Desserts (Quantities Expressed in g for 1 kg of Dessert)

Fixed Components				
UHT skim milk	831			
cream	50			
aroma	72×10^{-3}			
starches	17			
carrageenans	2			
Variable Components				
	test samples			reference
sucrose level	low	high		medium or high
	25	100		50 or 100
type of carrageenan	κ	ι	λ	mix

gum flavor was shown to follow sucrose release rather than menthone release (*19*).

Recently, we formulated model dairy desserts to study the occurrence of texture−flavor interactions during the consumption of such complex systems. Texture was found to modulate sweetness perception (*20*) and aroma perception (*21*). At the high level of sucrose (100 g kg^{-1}), the most unctuous and the most brittle desserts were perceived as the sweetest whereas sweetness did not depend on the textural agent at 25 g kg^{-1} (*20*). At a constant high level of aroma, the most unctuous dessert appeared to be the most flavored and sweetness influenced intensity of aroma whereas there was no change in the aroma composition of the air above the desserts and no change in the description of the fruity aroma with sucrose level nor texture (*21*). To investigate further the mechanisms of these interactions, in vivo measurements of aroma release needed to be performed.

The aim of the present study was therefore to determine whether simultaneous flavor perception using TI methodology and in vivo aroma release using MS-nose measurements from model dairy desserts would be affected by the textural characteristics and the sweetness/sucrose level.

MATERIALS AND METHODS

Materials. UHT skim milk, corn starches (standard, ref 680 888-lot E7048 and waxylis 200, ref 690 889-lot S8160), and enriched fractions of carrageenans (κ, lot 0089/692; ι, lot 00102/819; and λ, lot 0100/005) were given by Lactalis (Vitré, France), Roquette (Lestrem, France), and SKW Biosystems SAS (Baupte, France), respectively. Commercial sucrose, UHT full fat cream, and low-mineralized water were purchased from a local supermarket.

Aromas (ethyl pentanoate, amyl acetate, hexanal, and (*E*)-2-hexenal; purity was checked by gas chromatography and mass spectrometry to be greater than 98%) and propanediol were supplied by Sigma Chemical Co. (St. Quentin-Fallavier, France).

Preparation of the Flavored Desserts. The composition of the desserts is given in **Table 1**. Sweetness was varied through sucrose level (25 or 100 g kg^{-1}) with adjustment of the total weight to 1 kg with low-mineralized food water, and the texture was varied through the type of carrageenan (fractions enriched in κ-carrageenan, 93.3%; ι-carrageenan, 92.3%; λ-carrageenan, 30−40%; or an equal weight mixture of these three fractions). UHT skim milk, liquid full-fat cream, corn starches [25% (w/w) waxylis 200 and 75% (w/w) standard corn starches], and aroma blend remained unchanged. Final fat content of the desserts was 15 g kg^{-1}, and the overall aroma concentration was 72 mg kg^{-1}. In such desserts, the aromas mix led to a fruity perception, mainly described with "apple" and "green apple" terms (*21*).

A blend of aroma compounds (0.24 g of hexanal, 0.26 g of ethyl pentanoate, 0.44 g of amyle acetate, and 0.55 g of (*E*)-2-hexenal in 10 g of propanediol) was prepared by accurate weighing and gently stirred for 1 h at ambient temperature. The required amount of this solution (0.48 g) was then added to one-half of the full-fat cream. Powders (sucrose, carrageenan, and starches) were mixed together and dispersed by gentle stirring for 30 min at ambient temperature in a mix composed of milk, (nonflavored) half of the full-fat cream, and water. This preparation was then heated in an agitated water bath up to 95 °C for 10 min. The temperature was decreased to 80 °C to introduce the flavored full-fat cream, and after it was mixed for 5 min, the dessert was poured into glass vials (44 mL, Ø 30 mm, H 43 mm) closed with hermetic caps for TI and flavor release measurements and in polypropylene vials with screw caps (60 mL, Ø 53 mm, H 52 mm) for rheological measurements. Vials were set in a temperature-controlled room (4 °C) before the temperature of the product reached 55 °C and were stored for 3 days.

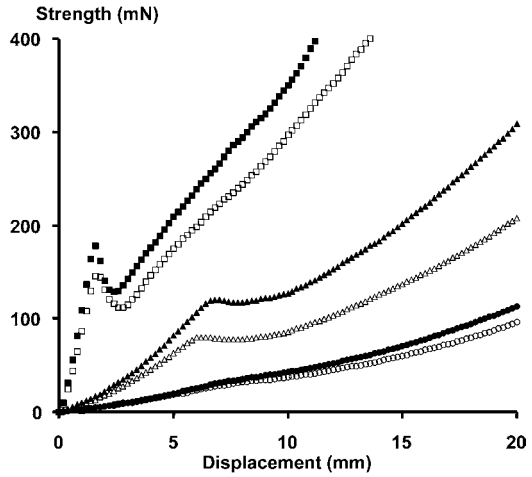

Figure 1. Rheological profiles obtained by truncated cone penetrometer method for dairy desserts varying in sucrose level (□, △, ○: 25 g kg^{-1}; ■, ▲, ●: 100 g kg^{-1}) and in carrageenan type (□, ■: κ; △, ▲: ι; ○, ●: λ).

Mechanical Properties of the Desserts. Mechanical properties of dairy desserts were evaluated using a traction−compression device (INSTRON 4501, Instron S. A., MA) with a truncated cone penetrometer (10 mm truncated; angle, 20°). Maximum cell capacity was 10 N, and total movement of the cone was fixed at 30 mm with a rate of 1 mm s^{-1}. Measurements were done in the polypropylene vials at 10 °C. Data were recorded using INSTRON Series IX v 4.09 software and smoothed using PEAKFIT v. 4.00 software (SPSS Science, Chicago, IL) according to Savitzky−Golay's algorithm (3% smoothing for ι- or κ-carrageenans dairy desserts and 6% for dairy desserts composed of λ-carrageenan). As the height of dairy dessert in the vials was not standardized, the contact between cone and dairy dessert surface was first determined and displacement was consequently corrected.

Varying the type of carrageenan resulted in different mechanical properties of the desserts, and varying the sucrose content increased recorded strengths at any time, but the profiles remained similar (**Figure 1**). Desserts formulated with κ-carrageenan showed a rapid increase in strength and a sudden and early rupture whereas desserts formulated with ι-carrageenan exhibited a slower increase in strength and a rupture at higher displacement. Desserts formulated with λ-carrageenan were the least resistant and strength increased steadily. These differences in mechanical behavior resulted in different texture evaluation by a sensory panel with profile methodology (*20*) with desserts formulated with κ-carrageenan assessed as firm and brittle, desserts formulated with ι-carrageenan assessed as firm and springy, and desserts formulated with λ-carrageenan as the most unctuous.

General Setup of Simultaneous Aroma Release Measurements and TI Recordings. Seven panelists, familiarized with the desserts and a chewing protocol, were trained in performing TI measurements while their nosespace volatile concentration was simultaneously measured by the MS-nose during three sessions. They were instructed to put the dessert (5 mL, presented in a syringe of which the end had been cut) in the mouth, to close the mouth, and to chew regularly for 20 s, thereby destructuring the product with the tongue onto the palate without swallowing, then to swallow the entire bolus and to continue

chewing for 40 s. No information about the purpose of the experiment nor the composition of the samples was given to the panelists. One panelist after another performed these measurements, and he/she was given the samples in the specified order.

Nosespace Flavor Concentration Measurements. Aroma concentrations in the breath of panelists were monitored by on-line sampling of part of the exhaled air by the MS-nose, an APCI gas phase analyzer attached to a VG Quattro II mass spectrometer (MS) (Micromass UK Ltd., Manchester, U.K.). The sampled part of the breath was introduced at 70 mL min^{-1} into the source, through a capillary tube (0.53 mm internal diameter, heated to 100 °C). The compounds were ionized by a 3.0 kV discharge. Source and probe temperatures were 80 °C.

Amyl acetate, (*E*)-2-hexenal, hexanal, ethyl pentanoate, and acetone were analyzed in selected ion mode (0.08 s dwell on each ion), at *m*/*z* values of 61.0, 99.0, 101.0, 103.0, and 58.8, respectively. The cone voltages used were 23, 21, 19, 28, and 19 V, respectively. Acetone was measured as an indicator of the panelists' breathing pattern. Acetone, (*E*)-2-hexenal, and hexanal were measured as their molecular ions. Ethyl pentanoate and amyl acetate, both with a molecular ion of *m*/*z* 131.0, were monitored independently as fragment ions. Spectra of the daughter ions of the molecular ions of ethyl pentanoate and amyl acetate were recorded by a second in-line MS, to prove that the fragments of *m*/*z* 61.0 and 103.0 originated from amyl acetate and ethyl pentanoate, respectively. Argon was used as a collision gas, and the collision energy was set to 4.0 eV. Each chosen *m*/*z* value was unique for each compound, allowing these compounds to be measured in a mixture.

Calibration of the MS signal was performed by static headspace measurements. Air−water partition coefficients for the compounds used followed from previous work (*22*). They were 3.3×10^{-3} for amyl acetate; 4.4×10^{-4} for (*E*)-2-hexenal, 2.5×10^{-3} for hexanal, and qj2.8×10^{-3} for ethyl pentanoate. Amounts of 100 mL of four concentrations of each aroma compound in 500 mL glass bottles were equilibrated for 30 min at 30 °C under gentle shaking. Subsequently, the MS signal was measured and the calibration curve was calculated. A linear response was found for all compounds. The four concentrations (5, 10, 25, and 70 mg L^{-1}) were chosen in such a way that the resulting MS signal covered the range of responses exhibited by the panelists.

TI Recordings. *Flavor Sessions.* TI curves were recorded using FIZZ software (Biosystemes, Couternon, France) every second over a 60 s period. During six sessions, panelists evaluated flavor intensity of the aromatized desserts on a scale from 0 to 10. Every session began by testing a blank sample (nonaromatized dessert with medium sucrose concentration and mix carrageenan composition), followed by assessment of a reference sample (aromatized dessert, medium sucrose concentration, and mix carrageenan composition). The panelists agreed that the I_{max} of the aromatized reference dessert was set at 5 on the scale for flavor sessions. The six aromatized desserts were then judged once by each panelist at each session, and six sessions were performed. The presentation order of the six samples varied for each panelist and was such that the sucrose level and the texture were alternated for each panelist. Per session, each panelist had a different presentation order than the previous session. After six replicates, each panelist had assessed all of the six possible orders of presentation. Between samples, panelists rinsed their mouths with water.

Sweetness Sessions. Panelists evaluated three nonaromatized desserts (high sucrose level, three types of carrageenan) identified by three digit random codes for sweetness intensity on a scale from 0 to 10 during six sessions. The three nonaromatized desserts were judged once by each panelist at each session. Six sessions were performed according to a random order of presentation: each panelist tested one of the six possible orders, and attributions of the orders changed at each session. Every session began by testing a nonaromatized dessert (high sucrose level and mix carrageenan composition) presented as a reference. The panelists agreed that the I_{max} of this nonaromatized reference dessert was set at 5 on the 0−10 scale. Then, the order of the samples varied as follows: each panelist tested one of the six possible orders, and attributions of the orders changed at each session. Between samples, panelists rinsed their mouths with water.

Extracting Data from in Vivo Aroma Release Profiles, TI Profiles, and Statistical Analysis. TI and nosespace data were first averaged. For each set of data, individual results by product and by session (replicate) were averaged to obtain the panel's response. Characteristic parameters were then extracted from the averaged curves. Classically, I_{max} and T_{max} were determined to characterize when intensity was maximal. Three other parameters were calculated as follows: AUC, to characterize the global perception or release during the whole test; ABS, to characterize the perception or release during the chewing phase when the dessert was in the mouth; and AAS, to characterize the perception or release when the dessert was no more in the mouth. Characteristic parameters were extracted from the averaged curves using Microsoft Excel for I_{max} and T_{max} or Peakfit (v 4.00 software, SPSS Science) for AUC, ABS, and AAS. ANOVA and subsequent multiple range tests (LSD) were performed using Statgraphics Plus 3.0 software (Manugistic, Rockville, MD) at the significance level of 5%.

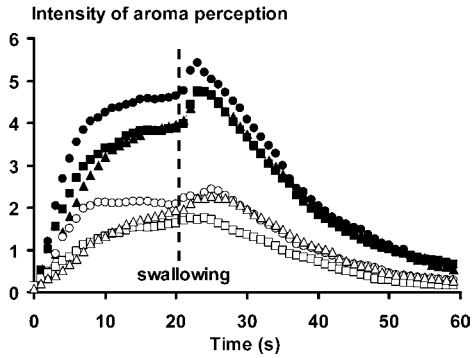

Figure 2. Averaged TI recordings of perceived flavor for dairy desserts varying in sucrose level (□, △, ○: 25 g kg^{-1}; ■, ▲, ●: 100 g kg^{-1}) and in carrageenan type (□, ■: κ; △, ▲: ι; ○, ●: λ).

RESULTS

Both Sucrose Level and Carrageenan Type Influence Flavor Perception. Figure 2 shows the averaged TI profiles of the six flavored desserts, eaten by seven panelists in six replicates. Each curve represents the average of 42 single curves. **Figure 2** shows that the perceived intensity of the flavor greatly increases with an increase in sucrose level and that desserts prepared with λ-carrageenan show a higher perceived intensity than desserts prepared with ι- and κ-carrageenans. In addition to graphical analysis, statistical analysis was applied. Each averaged curve across the whole panel by product and by replicate was summarized by different parameters: T_{max}, I_{max}, AUC, ABS, and AAS value. **Table 2** summarizes the results of the three way ANOVA (replicate, carrageenan type, and sucrose concentration as factors) and subsequent LSD tests performed on these values. Whatever the parameter, two way interactions and the replicate factor were insignificant. Significant sucrose and carrageenan effects were evidenced for AUC, ABS, AAS, and I_{max} but not for T_{max}. The fact that T_{max} remained unchanged is probably related to the experimental procedure, which required the desserts to be swallowed at 20 s. T_{max} occurred 2−3 s later than swallowing whatever the composition of the dessert. A highly significant effect of sucrose level was found, in agreement with previous results on the same desserts obtained by another panel (19 panelists) and using profiling methodology (*21*). The higher the sucrose level, the more aromatized the desserts were assessed, whatever the texture. An LSD test confirmed that the carrageenan effect corresponded to higher I_{max}, AUC, and ABS values extracted from TI curves for desserts prepared with λ-carrageenan and lower AAS values for desserts prepared with κ-carrageenan. Besides analysis across the whole panel, data were also analyzed by panelist. On one hand, all of the panelists, except one (panelist 3), exhibited the same significant sucrose effect on I_{max}, AUC, and ABS as

Table 2. *p* Values of Three Way ANOVA (Sucrose, Carrageenan, Replicate, and Their Two Way Interactions) of TI Parameters for Perceived Aroma and Results of the Subsequent LSD (Desserts with Different Letters Are Significantly Different at Level 5%)

ANOVA					
	T_{max}	I_{max}	AUC	ABS	AAS
source of variation					
sucrose (A)	0.564	**0.000**	**0.000**	**0.000**	**0.000**
carrageenan (B)	0.498	**0.043**	**0.005**	**0.001**	**0.0160**
replicate (C)	0.525	0.974	0.263	0.289	0.300
interaction A*B	0.356	0.761	0.288	0.267	0.259
interaction A*C	0.358	0.282	0.195	0.414	0.135
interaction B*C	0.793	0.393	0.272	0.221	0.259

LSD Tests (Mean ± Standard Error)					
	T_{max}	I_{max}	AUC	ABS	AAS
for carrageenan					
κ	22.3 ± 1.1 a	3.3 ± 0.2 a	102.7 ± 3.8 a	40.8 ± 1.7 a	59.1 ± 2.3 a
ι	24.1 ± 1.1 a	3.6 ± 0.2 ab	108.4 ± 3.8 a	38.7 ± 1.7 a	66.7 ± 2.3 b
λ	22.6 ± 1.2 a	4.1 ± 0.2 b	128.2 ± 4.3 b	52.8 ± 1.9 b	71.9 ± 2.7 b
for sucrose					
25 g kg^{-1}	22.6 ± 1.0 a	2.1 ± 0.2 a	69.9 ± 3.4 a	26.8 ± 1.5 a	41.9 ± 2.1 a
100 g kg^{-1}	23.4 ± 0.9 a	5.0 ± 0.1 b	156.3 ± 3.1 b	61.4 ± 1.4 b	90.7 ± 1.9 b

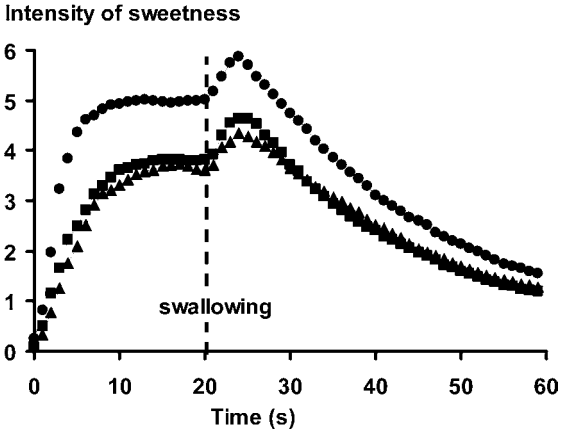

Figure 3. Averaged TI recordings of sweetness for nonflavored dairy desserts (sucrose: 100 g kg^{-1}) varying in carrageenan type (■: κ; ▲: ι; ●: λ).

exhibited by the whole panel: the sweeter the dessert, the more intense the aroma perception. On the other hand, desserts prepared with λ-carrageenan were judged to have a more intense aroma than the other desserts but only one panelist (panelist 6) exhibited a significant carrageenan effect.

Carrageenan Type Influences Sweetness Intensity of the Desserts. Figure 3 shows the average TI profile of sweetness performed by the panel on the desserts varying in texture at the high level of sucrose (100 g kg^{-1}). Results of the two way ANOVA (carrageenan type, replicate) on extracted parameters are given in **Table 3**. Desserts prepared with λ-carrageenan were assessed sweeter than desserts prepared with κ- or ι-carrageenans. This result confirms previous results on these desserts obtained by another panel (19 panelists) with profile methodology (*20*).

Sucrose Level and Carrageenan Type Have Little Impact on Aroma Release. Figure 4 shows the averaged in vivo aroma release profiles (seven panelists in six replicates) according to the six flavored desserts for each aroma compound. Each curve represents the average of 42 single curves. The flavor release profiles of each aroma compound remain quite similar whatever the sucrose level and the texture of the desserts. Statistical analysis was applied on characteristic parameters extracted from each averaged curve across the whole panel by product and by replicate. The same parameters as for TI measurements were selected. **Table 4** summarizes the results of the three way ANOVA (sucrose level, carrageenan type, replicate) by aroma compound. Statistical analysis first reveals no significant replicate effect (except for AAS parameter of the esters) nor two way interactions with replicate. For three of the aroma compounds (amyl acetate, ethyl pentanoate, and hexanal), statistical analysis second confirms that before swallowing, no effect of sucrose level could be detected on the release of those

Table 3. *p* Values of Two Way ANOVA (Carrageenan, Replicate) of TI Parameters for Perceived Sweetness and Results of the Subsequent LSD Tests (Desserts with Different Letters Are Significantly Different at Level 5%)

ANOVA					
	T_{max}	I_{max}	AUC	ABS	AAS
source of variation					
carrageenan (A)	0.611	**0.000**	**0.000**	**0.000**	**0.001**
teplicate (B)	0.241	0.015	0.088	0.101	0.103

LSD Tests (Mean ± Standard Error)					
	T_{max}	I_{max}	AUC	ABS	AAS
for carrageenan					
κ	23.8 ± 0.4 a	4.7 ± 0.1 a	165.0 ± 6.4 a	60.3 ± 2.8 a	100.9 ± 4.1 a
ι	23.3 ± 0.4 a	4.4 ± 0.1 a	161.8 ± 6.4 a	55.8 ± 2.8 a	101.4 ± 4.1 a
λ	23.3 ± 0.4 a	6.0 ± 0.1 b	221.6 ± 6.4 b	85.7 ± 2.8 b	129.9 ± 4.1 b

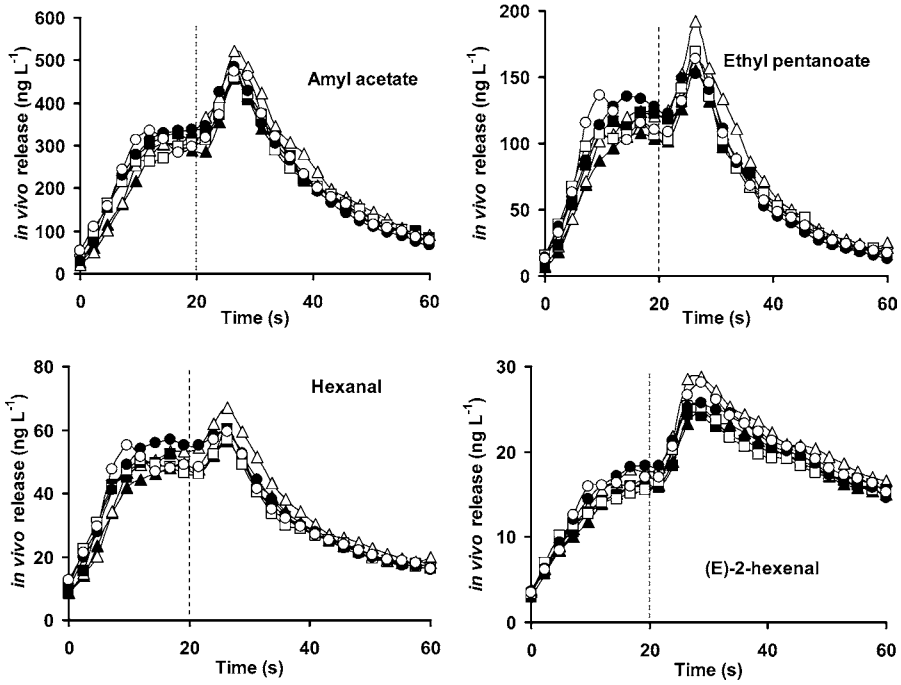

Figure 4. Averaged in vivo release profiles of the four aroma compounds from dairy desserts varying in sucrose level (□, △, ○: 25 g kg^{-1}; ■, ▲, ●: 100 g kg^{-1}) and in carrageenan type (□, ■: κ; △, ▲: ι; ○, ●: λ) flavored with a blend of amyl acetate, ethyl pentanoate, hexanal, and (*E*)-2-hexenal.

Table 4. *p* Values of Three Way ANOVA (Sucrose, Carrageenan, Replicate, and Their Two Way Interactions) of in Vivo Aroma Release Parameters for the Four Aroma Compounds of the Blend

aroma compound	source of variation	T_{max}	I_{max}	AUC	ABS	AAS
amyl acetate	sucrose (A)	0.148	0.570	0.156	0.969	**0.045**
	carrageenan (B)	0.593	0.294	0.739	**0.014**	0.165
	replicate (C)	0.533	0.858	0.351	0.940	**0.037**
	interaction A*B	0.110	0.601	0.153	0.530	**0.044**
	interaction A*C	0.393	0.697	0.839	0.389	0.6777
	interaction B*C	0.188	0.774	0.804	0.572	0.782
ethyl pentanoate	sucrose (A)	0.721	0.103	0.151	0.597	0.035
	carrageenan (B)	0.575	0.762	0.733	**0.035**	**0.060**
	replicate (C)	0.822	0.279	0.125	0.718	**0.019**
	interaction A*B	0.421	0.190	0.142	0.510	**0.055**
	interaction A*C	0.465	0.794	0.335	0.212	0.630
	interaction B*C	0.070	0.481	0.872	0.836	0.8207
hexanal	sucrose (A)	1.000	0.145	0.396	0.721	0.206
	carrageenan (B)	0.865	0.274	0.332	**0.057**	**0.019**
	replicate (C)	0.709	0.738	0.711	0.874	0.292
	interaction A*B	0.6280	0.135	0.154	0.651	**0.037**
	interaction A*C	0.9554	0.969	0.816	0.621	0.927
	interaction B*C	0.9339	0.939	0.868	0.740	0.914
(*E*)-2-hexenal	sucrose (A)	0.782	**0.010**	**0.053**	0.391	**0.032**
	carrageenan (B)	0.840	0.252	**0.041**	**0.048**	**0.031**
	replicate (C)	0.607	0.111	0.309	0.332	0.232
	interaction A*B	0.870	0.198	**0.065**	0.274	**0.073**
	interaction A*C	0.828	0.703	0.878	0.543	0.782
	interaction B*C	0.707	0.587	0.976	0.987	0.964

three compounds and that texture of the product only had a significant effect on the ABS parameter and no effect on T_{max} and I_{max}. This effect of carrageenan type on ABS is also found for the fourth aroma compound [(*E*)-2-hexenal]. In each case, desserts prepared with λ-carrageenan exhibited a higher ABS value [for amyl acetate: 4684 (κ), 4262 (ι), and 4999 (λ) ng L^{-1} s; for ethyl pentanoate: 1793 (κ), 1618 (ι), and 1962 (λ) ng L^{-1} s; for hexanal: 815 (κ), 759 (ι), and 865 (λ) ng L^{-1} s; for (*E*)-2-hexenal: 243 (κ), 250 (ι), and 269 (λ) ng L^{-1} s]. In the case of (*E*)-2-hexenal, a significant sucrose effect is found on I_{max}: the higher the sucrose level, the lower the I_{max} value (28.5 ng L^{-1} for 25 g kg^{-1}; 26.1 ng L^{-1} for 100 g kg^{-1}). Close examination of the results shows that the sucrose effect is mainly found from data of the ι-carrageenan desserts; however, whereas the effect of sucrose is significant, it does not correlate with the TI results where aroma intensity was higher with an increase of sucrose concentration. These effects of sucrose on I_{max} and carrageenan on ABS result in significant sucrose and carrageenan effects on AUC for this aroma compound. After swallowing, an interaction between sucrose level and type of carrageenan is systematically evidenced. Release of three of the aroma compounds (amyl acetate, ethyl pentanoate, and hexanal) was significantly greater at low sucrose level (25 g kg^{-1}) for desserts formulated with ι-carrageenan than for the five other desserts. This result on AAS is also found for the fourth aroma compound [(*E*)-2-hexenal] for which release from desserts formulated with κ-carrageenan was also systematically lower than the release from desserts formulated with λ-carrageenan.

To resume the major consideration, data show that sucrose level had no impact on averaged in vivo aroma release of three of the four aroma compounds before swallowing and that the carrageenan type only had a small impact on the ABS value for all of the aromas. One could hypothesize that the ABS parameter was more related to the texture of the product and the way it was processed in the mouth during the chewing phase. The fourth aroma compound [(*E*)-2-hexenal], whose aroma release profile differed markedly from that of the three other aroma compounds, showed a slight sucrose effect, which is not in accordance with the very large opposite effect of sucrose on aroma perception. After swallowing, the elastic dessert at low sucrose level exhibited a greater release of the aroma compounds.

Differences in Aroma Release between the Four Compounds. Figure 4 also shows that the four aroma compounds did not have the same aroma release profile. This is more evident in **Figure 5**, where averaged curves per aroma compound (all panelists and all desserts mixed together) have been normalized. To allow a direct comparison, the average TI aroma curve was

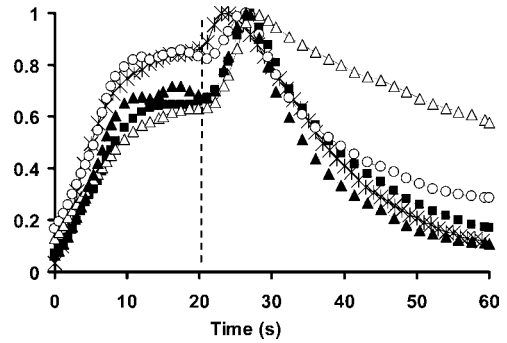

Figure 5. Standardized in vivo release profiles from dairy desserts flavored with a blend of amyl acetate (■), ethyl pentanoate (▲), hexanal (○), and (*E*)-2-hexenal (△) and related standardized TI profile (★). Data from the six desserts were averaged and standardized.

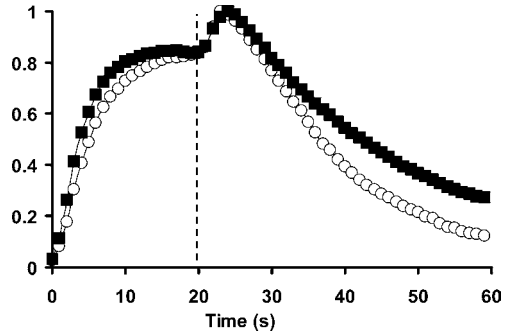

Figure 6. Standardized TI profiles for sweetness (■) and flavor perception (○) for dairy desserts. Data from the three desserts (sucrose: 100 g kg^{-1}) were averaged and standardized.

also plotted on this figure. The aroma release profiles exhibited T_{max} values similar for three aroma compounds (26.7 s for amyl acetate, 26.6 s for ethyl pentanoate, and 26.1 s for hexanal) and a significant higher value (28.1 s) for (*E*)-2-hexenal. All of these values are higher than the T_{max} value from flavor TI (23.0 s). Release lags behind perception. Linforth et al. explained this by adaptation (*23*), but in their results, this occurred only at a T_{max} of around 1 min. Hexanal showed a higher rate of release during the chewing phase than the three other compounds. After the maximum of in vivo release, aldehydes showed a slower decrease than esters, especially in the case of (*E*)-2-hexenal, which showed a longer persistence but did not seem to have a major effect on aroma TI. The TI curve follows the decrease of the other aroma compounds.

DISCUSSION

Our results first show a large sucrose effect on aroma TI recordings with limited sucrose effect on aroma release, so that the impact of sweetness on aroma perception can be considered as mainly perceptual. Such perceptual interactions between taste and aroma have usually been described in the literature in the case of sweet systems combining sucrose with a sweet-associated aroma (*3*, *4*, *14*, *18*, *19*). In the present desserts, there was an association between the sweetness and the fruity perception, mainly described with "apple" and "green apple" terms (*21*). As shown in **Figure 6**, aroma perception does not superimpose with sweetness perception. Both profiles exhibited the same T_{max}, probably because the panelists evaluated both perceptions independently but with the same eating protocol with the standardization of the duration of the chewing phase. Sweetness perception seemed to proceed faster and to persist longer than aroma perception.

This study showed that changes in sweetness and texture induced changes in aroma perception, while aroma release remained largely unaffected. This has been observed before for various systems, such as viscous solutions (*14*) and gels (*12*, *13*). No definitive explanation for the effect of texture on aroma perception can be offered. Both aroma TI and sweetness TI but only ABS (aroma release) were found different for desserts composed by λ-carrageenan, as compared to desserts containing the other carrageenan types. As sweetness has an impact on aroma TI and λ-carrageenan is the sweetest dairy dessert, one can wonder whether the effect of mouthfeel perception on aroma perception is a direct effect or only an effect of sweetness perception in this dairy dessert that leads to a higher aroma evaluation. The study of Weel et al. showed an effect of texture on aroma perception of protein gels, without any sweetener present (*13*), indicating that direct interactions between aroma and texture do occur. The predictive value of aroma release for flavor perception seems to be limited when texture and taste are being modified. Texture and taste, however, could be useful tools to modify flavor perception, provided the relations between texture, taste, and aroma perception are elucidated.

Despite this, a connection between aroma release and flavor perception was observed, when looking at individual results. The panelists used a fixed common protocol, but individual results in aroma release profiles show consistent differences between the panelists, irrespective of aroma compound. The panelists can be divided into three groups. Three panelists have high release throughout the chewing and swallowing part of the protocol. There is no particular increase in release at swallowing. Three others display some release during the first 20 s of chewing, but they peak at swallowing. There was one panelist who had no release in the first 20 s but only showed release after swallowing. The same classification into three groups can be made from the individual perceived aroma intensities, and then, the same groups are observed. This suggests some individual coupling between aroma release and aroma perception. This classification into groups also applies for sweetness perception. These differences in release are related to the extent to which the air in the mouth can be transported to the stream of air from the lungs to the nose during chewing before swallowing. The amount of air that can be transported before swallowing depends on people's anatomy, the way they chew (*24*), and the extent to which the velum−tongue border is opened before swallowing (*25*). This opening would depend on the texture (liquid−solid foods) and the amount of food material in the oral cavity (*25*). The perception of maximum flavor intensity was found to occur just after the swallowing. It was reported to be close to the moment of swallowing from simultaneous sensory evaluation and electromyographic recording of mastication patterns (*7*), and it was shown that after swallowing, the subsequent exhalation (the swallow breath) goes along with an aroma pulse (*25*, *26*).

Simultaneously, the aroma perception is influenced by the product composition, but the individual aroma release is not or little. The composition influences the aroma perception via differences in texture and sweetness. Although it is clear from the results that sucrose levels and textural properties do not or little affect aroma release, individual differences in "releasing behavior" do influence their personal evaluation of the aroma of the desserts.

In vivo release showed some differences depending on aroma compound. Hexanal showed a higher rate of release during the chewing phase than the three other compounds whereas after the maximum of in vivo release, aldehydes showed a slower

decrease than esters, especially in the case of (*E*)-2-hexenal, which showed a longer persistence. Differences probably result from differences in physicochemical properties and interaction behaviors of aroma compounds at different stages of the process. Although physicochemical properties of the aroma compounds do not differ that much, esters had greater hydrophobicity (Log P = 2.3) than aldehydes (1.78 and 1.58, for hexanal and (*E*)-2-hexenal) and hexanal had the highest vapor pressure (11.3 mmHg; as compared to 3.5, 4.8, and 6.6 mmHg for amyl acetate, ethyl pentanoate, and (*E*)-2-hexenal). Aldehydes and especially unsaturated aldehydes are known to interact with proteins. In skim milk, they were shown to exhibit covalent binding with milk proteins (*27*). From headspace measurements, interactions of hexanal and the two esters with starch components of the desserts were also shown (*21*). Beside interactions with the food components, aroma compounds could also interact with proteins of the saliva (*28*−*32*) and absorb to the oral mucosa (*25*) and the nasal epithelia (*33*). Mucin was identified as the key component in saliva that affects flavor release (*30*) even if the time course of mucin aroma could be too slow to be a major factor in in vivo flavor release (*34*) and α-amylase-influenced aroma release from high starch foods (*31*).

ABBREVIATIONS USED

AAS, area after swallowing; ABS, area under the curve before swallowing; API-MS, atmospheric pressure ionization−mass spectrometry; APCI, atmospheric pressure chemical ionization; AUC, area under the curve; ANOVA, analysis of variance; I_{max}, maximum intensity; LSD, least significant difference; TI, time intensity; T_{max}, time to maximum intensity.

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