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Volatile Flavor Analysis and Sensory Evaluation of Custard Desserts Varying in Type and Concentration of Carboxymethyl Cellulose

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The influence of type and concentration of carboxymethyl cellulose (CMC) on flavor and textural properties of custard desserts was examined. A synthetic strawberry flavor mixture was used to flavor the custards; it comprised 15 volatile flavor compounds. The viscosity of the custards was determined using rheometric measurements. Static headspace gas chromatography and in-nose proton transfer reaction−mass spectrometry analyses were conducted to determine the custards' volatile flavor properties. Perceived odor, flavor, and textural properties were assessed in sensory analysis experiments using magnitude estimation against a fixed modulus. Both type and concentration of CMC altered the viscosity of the custards. Softer custards had higher static headspace flavor concentrations. On the contrary, firmer custards demonstrated higher in-nose flavor concentrations. In sensory analysis, firmer custards showed higher thickness and lower sweetness intensities than their low-viscosity counterparts. The thickness perception corresponded to the viscosity of the custards. Removal of sucrose from the custards affected sweetness intensity only and not the intensity of other attributes. Therefore, the influence of the viscosity of the custards on the release of sweet-tasting components is held responsible for the effect on perceived sweetness intensity. Odor intensities were generally higher for the low-viscosity custard, whereas fruity flavor intensities were higher for the firmer custards. Odor intensities correlated with static headspace concentrations and flavor intensities related reasonably well with in-nose concentrations. Opening and closing of the nasal cavity is regarded as an important factor determining the discrepancy between static and in-nose measurements.

KEYWORDS: Carboxymethyl cellulose; flavor; proton transfer reaction−mass spectrometry; strawberry

INTRODUCTION

Sensory perception of the flavor and texture of food products depends on the composition and structure of the food systems. Variables such as hardness, water-holding capacity, or microstructure have been shown to affect the perception of flavor. The formulation of foods with controlled sensory properties remains, therefore, a challenge. The influence of texturing agents has still not been well elucidated. Their main effect is a modification of the viscosity, often resulting in a significant decrease in perceived flavor (*1*, *2*). The given explanation is that increased viscosity hinders the mixing processes by which flavor molecules are brought from the interior of the sample to the surface (*3*). However, thickened solutions of similar viscosity do not induce the same flavor perception. Furthermore, some studies showed that although thickening of solutions affected flavor intensities, it did not result in a change in the in-nose measured flavor concentration (*4*, *5*). Moreover, one study claims that the texture of gels determines the perception of volatile flavor intensity rather than in-nose flavor concentrations (*5*).

During the consumption of food products, the brain receives a constant stream of information about flavor, texture, and appearance. Interactions among senses occur and are generally known as cross-modal interactions. Different possible levels of interaction between stimuli can be identified (*6*). Applied to flavor−texture interactions, texture can affect the flavor of food products through physical or chemical interactions resulting in a change of availability of the flavor stimuli. Flavor compounds may be bound, entrapped, etc., to textural agents, which alters the thermodynamic properties of the system (*7*). Texture can also have an effect on the kinetic aspects of flavor release, through reducing flavor transport through the food product (*8*). Interactions at the receptor level are unlikely, as aroma, taste, and texture are sensed by different systems (*9*). The cross-modal interactions are most likely to occur at the cognitive perception level during neural processing (*6*). For instance, the perception of fruity notes (*10*) or mint (*11*) can be enhanced by sweetness perception. Texture−sweetness interactions have been reported for model dairy desserts (*12*). Thus, there are a large number of factors that determine whether, to what extent, and at what level flavor−texture interactions occur.

To evaluate the influence of texture on some of the various levels, the present study examined the influence of different

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Table 1. Composition of Custard Desserts Varying in Type and Concentration of CMC

	HV-0.1	HV-0.5	HV-1.0	MV	LV
type of CMC (viscosity)	high	high	high	medium	low
CMC (g)	1	5	10	10	20
milk (g)	936	932	927	927	917
sucrose (g)	63	63	63	63	63

Table 2. Three Compounds of the Strawberry Flavor Mixture, Their Molecular Weights (MW), and Intensities of Their Major Ions Determined by Proton Transfer Reaction–Mass Spectrometry

		intensities of major ions[a]		
compound	MW	*m*/*z*	*m*/*z*	*m*/*z*
ethyl butyrate	117	117 (100)	89 (37)	43 (13)
ethyl isopentanoate	131	131 (100)	39 (95)	121 (43)
ethyl hexanoate	145	145 (100)	146 (9)	43 (8)

[a] Data of the first three major ions are presented by normalizing the background and transmission corrected counts per second of the most abundant mass fragment to a value of 100. All other intensities are calculated relative to the most abundant mass fragment.

types and concentrations of carboxymethyl cellulose (CMC) in custard desserts on flavor release and perception. The effect of custard composition on its firmness was assessed by rheometric measurements. The influence of the firmness of the custards on the thermodynamic properties of the system was analyzed by static headspace analysis, the effects on flavor release by in-nose analysis, and the impact on perception by sensory analysis.

MATERIALS AND METHODS

Chemicals. A commercial strawberry flavor mixture was obtained from Givaudan (Duebendorf, Switzerland). It was composed of 4-hydroxy-2,5-dimethyl-3(2*H*)-furanone (Furaneol; 5 mg/g), vanillin (5 mg/g), methyl cinnamate (24 mg/g), ethyl hexanoate (20 mg/g), ethyl butyrate (90 mg/g), benzyl acetate (2 mg/g), styrallyl acetate (1 mg/g), γ-decalactone (20 mg/g), methyl anthranilate (1 mg/g), ethyl isopentanoate (10 mg/g), hexanal (1 mg/g), *cis*-3-hexenyl acetate (5 mg/g), *cis*-3-hexenol (15 mg/g), methyl dihydrojasmonate (5 mg/g), and β-ionone (1 mg/g) in triacetin. Three CMCs were used, which differed in degree of polymerization. They were specified to have low-, medium-, and high-viscosity properties (C-5678, C-4888, and C-5013, respectively; Sigma-Aldrich Chemie, Steinheim, Germany).

Custard Preparation. Five different custards were prepared: one custard with the low-viscosity CMC (LV), one custard with a medium-viscosity CMC (MV), and three with different concentrations of a high-viscosity CMC (0.1, 0.5, and 1.0 g/100 g: HV-0.1, HV-0.5, and HV-1.0, respectively). The compositions of all custards are presented in **Table 1**. For custard preparation, full-fat milk was heated to 60 °C. Sucrose (Siucra; Irish Sugar Ltd., Carlow, Ireland) was added and the mixture stirred for 3 min. The CMC was added in small increments to ensure that the CMC was fully dispersed. To obtain the custard texture, the mixture was stirred again for 5 min. The custard was transferred to a water bath at 95 °C, with continued stirring. When the custard reached a temperature of 90 °C, heating continued for another 10 min. It was subsequently cooled at room temperature for 15 min and further to 30 °C by placing the bottle in cold water. Forty grams of the custard was placed in a 100 mL glass bottle, 14 μL of the flavor mixture was injected in the custard, and the bottle was sealed. Final total flavor concentration was 56 mg/kg of custard (not including the solvent triacetin). The mixture was stirred for 5 min and stored at 6 °C for 24 h prior to analysis. For each type of custard and type of analysis at least two batches were prepared.

For sensory analysis the same custards were also prepared without sucrose; milk was used to replace the sucrose content, and the concentrations of other components remained the same.

Viscosity Measurements. After sample preparation, 100 mL of custard was transferred to the rheometer flask. The measurements were carried out at 20 °C. The apparent viscosity was determined at a shear rate of 10−100 1/s using a rotational rheometer (Rheolab MC1; Physica Mestechnik, Stuttgart, Germany) for the LV, MV, HV-0.5, and HV-1.0 custards. A shear rate of 145−600 1/s was used for the HV-0.1 custard samples as this sample had a considerably lower viscosity than the others. Flow curves were obtained for all of the samples (*13*). Three replicate custards were analyzed.

Static Headspace Analysis. Two grams of custard was transferred into a 10 mL headspace vial. Two replicate vials were prepared for each batch (= four samples for each type of custard). Samples were incubated at 37 °C and agitated at 750 rpm for 10 min in the automated headspace unit (Combipal-CTC Analytics System, JVA Analytical Ltd., Dublin, Ireland) of the gas chromatograph (GC; Varian CP-3800; JVA Analytical Ltd.). The GC was equipped with an injector at 225 °C, a BPX5 capillary column (60 m length, 0.32 mm i.d., 1.0 μm film thickness, helium carrier gas at 1.9 mL/min; SGE, Kiln Farm, Milton Keynes, U.K.), and a flame ionization detector (FID) at 275 °C. One milliliter of headspace was injected into the GC. An initial oven temperature of −30 °C was used for 1 min, followed by a rate of 100 °C/min to 40 °C. The oven temperature was maintained at 40 °C for 4 min and was subsequently programmed to 90 °C at 2 °C/min, further to 130 °C at 4 °C/min, and finally to 250 °C at 8 °C/min. Reference compounds were used to identify the compounds detected.

In-Nose Analysis. For in-nose analysis, a fork-shaped glass nosepiece was placed with its two inlets in the nostrils of each subject. The nosepiece had one outlet for breathing and an orthogonal outlet for sampling. The latter was used to remove the air, without disturbing the assessor's breathing or eating pattern. The air was drawn in at a rate of 100 mL min^{-1}, 15 mL of which was led into the proton transfer reaction−mass spectrometer. The background was measured for 30 s. During that time an assistant placed 7 g of custard (20 °C) on a spoon. The assessor transferred the custard to his/her mouth and chewed and swallowed freely, without further instructions. Preliminary scans (mass range = *m*/*z* 30−220) of the flavored custards as well as the individual flavor compounds revealed that the masses *m*/*z* 117, 131, and 145 could be exclusively assigned to ethyl butyrate, ethyl isopentanoate, and ethyl hexanoate, respectively. The other compounds were either below detection limits or had parent/major product ions in common. The intensities of the parent and major product ions of the three flavor compounds are shown in **Table 2**. Five subjects participated in the in-nose analyses. Two batches of the individual custards were analyzed in triplicate (six replicates per type of custard per person). The samples were analyzed according to the method described by Lindinger and co-workers (*14*), employing a constant drift voltage of 600 V. Transmission of the ions through the quadrupole was considered according to the specification of the instrument. The spectra were background and transmission corrected. From the individual curves, maximum intensities ($I_{\max}$), time to maximum intensities [$t(I_{\max})$], and total release were determined.

Sensory Analysis. Sensory analysis, in the form of magnitude estimation against a fixed modulus, was carried out on four of the custards (HV-0.1, HV-0.5, HV-1.0, MV). For practical reasons, LV was not analyzed. To determine the influence of the sucrose, a second set of custards was examined without this component. The MV custard was used as a reference. An experienced panel (eight assessors) was trained in 4 days to develop the vocabulary and the scale. The first 2 days were focused on developing the vocabulary, which resulted in three categories: odor (orthonasal aroma perception), flavor (retronasal aroma and taste perception), and texture. The odor attributes developed were strawberry, milky, grassy, and overripe fruit, whereas the flavor attributes were strawberry, milky, grassy, sweet, and overripe fruit. The only texture attribute was thickness. The panel was further trained to use the 100 mm analogue scale, the ends of which were anchored "weaker" and "stronger". The reference was permanently set on 50, the center of the scale. All four custards (20 °C) with and without sucrose were evaluated twice.

Table 3. Apparent Viscosity of Custard Desserts with and without Sucrose Varying in Type and Concentration of CMC (Pa s)[a]

	HV-0.1	HV-0.5	HV-1.0	MV	LV
with sucrose	0.027	0.43	1.86	0.83	0.69
without sucrose	0.023	0.43	2.19	0.84	0.67

[a] Shear rate = 100 1/s, except for HV-0.1, for which the shear rate is 145 1/s. Mean coefficient of variance is 3.3% ($n = 3$).

Table 4. Static Headspace Analysis of Custards Varying in Type of CMC and/or Concentration: Peak Areas (mV)[a]

	HV				
	0.1 g/100 g c	0.5 g/100 g c	1.0 g/100 g a	MV b	LV d
ethyl butyrate	386 c	385 c	340 a	367 b	411 d
ethyl isopentanoate	33 b	33 b	24 a	32 b	36 c
ethyl hexanoate	13 b	14 b	9 a	13 b	16 c
CV (%)	2	8	8	3	3

[a] Different letters in a row indicate significant differences (MANOVA, $P < 0.05$); sample codes in **Table 1**.

Statistical Analysis. The equilibrium headspace data, the in-nose data, and the sensory data were subjected to multivariate analysis of variance (MANOVA) to determine significant differences between samples, flavor compounds, and, when applicable, between assessors. Principal component analysis (PCA) was conducted on the sensory data set, as well as on the combined instrumental/sensory data sets, to find correlations. A significance level of $P < 0.05$ was used throughout the study.

RESULTS AND DISCUSSION

Viscosity of the Custards. The apparent viscosity of the custards was assessed by rheometric measurements. The results are displayed in **Table 3** for one shear rate. The flow curves of the samples showed non-newtonian and pseudoplastic behavior: the viscosity decreased when the shear rate was increased. Other studies reported similar behavior for a solution of CMC in distilled water (*13*). Change in the type of CMC (LV < MV < HV) as well as increase in CMC concentration (HV-0.1 < HV-0.5 < HV-1.0) resulted in enhanced viscosity (firmness) of the custard.

Static Headspace Flavor Concentrations. Concentrations of volatile strawberry flavor compounds were measured in the headspace of the five custards under static conditions (**Table 4**). Three of the 15 compounds could be detected under the experimental conditions: ethyl butyrate, ethyl isopentanoate, and ethyl hexanoate. These compounds were highest in concentration among the compounds present in the mix. However, retention by the matrix played a role as well. Ethyl hexanoate was found in lower concentrations in the headspace of the custards than ethyl isopentanoate, whereas the concentration of ethyl hexanoate was twice as high as the concentration of ethyl isopentanoate in the custard. These results show higher affinity of the larger, more hydrophobic compound for the matrix, which is probably due to the presence of milk fat.

A firmer texture of the custards due to CMC type or concentration resulted in lower headspace concentrations of the volatile flavor compounds. The relative effect of the firmness increased with the chain length of the compounds; that is, the more hydrophobic compounds were retained to a larger extent by a higher viscosity CMC or higher concentrations of CMC. Although it has been reported that CMC does not bind flavor compounds from a physicochemical perspective (*15*), it may have altered the overall matrix properties, resulting in a slightly less polar matrix. Both concentration and polymerization degree of the CMC (type of CMC) demonstrated this effect.

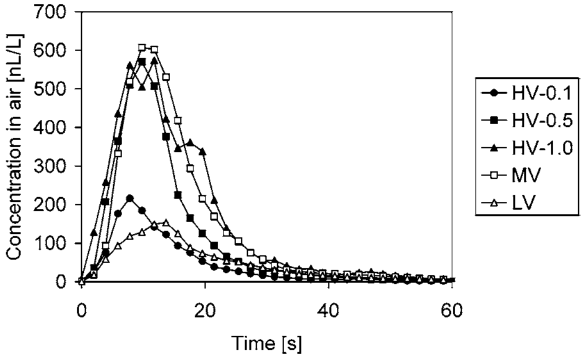

Figure 1. In-nose measurements of ethyl butyrate during consumption of custards varying in type or concentration of CMC analyzed by proton-transfer reaction–mass spectrometry ($n = 5$ subjects, 6 replicates; sample codes in **Table 1**).

Table 5. Parameters of In-Nose Flavor Analysis of Custards Varying in Type of CMC and/or Concentration Determined by Proton Transfer Reaction–Mass Spectrometry: Maximum Intensity (I_{max}), Time to Maximum Intensity [$t(I_{max})$], Total Release of a Particular Flavor Compound (Total Release), and Rate of Flavor Release to I_{max} (Initial Release Rate)[a]

	HV				
	0.1 g/100 g	0.5 g/100 g	1.0 g/100 g	MV	LV
I_{max} (nL/L)	a	b	b	b	a
ethyl butyrate	255 a	813 b	938 b	985 b	262 a
ethyl isopentanoate	19 a	67 b	86 b	85 b	15 a
ethyl hexanoate	6 a	30 b	41 b	38 b	5 a
CV (%)	62	64	104	73	67
$t(I_{max})$ (s)	a	a	b	b	b
ethyl butyrate	8.1 a	8.2 a	9.2 a	10.2	9.3 a
ethyl isopentanoate	8.4 a	9.1 ac	10.8 bcd	11.3 be	10.0 ade
ethyl hexanoate	11.3 a	11.7 ab	14.1 bc	13.7 ac	15.3 c
CV (%)	35	35	36	50	40
total release (nL)	a	b	b	b	a
ethyl butyrate	600 a	1790 b	2463 c	2248 bc	741 a
ethyl isopentanoate	54 a	181 bd	265 d	231 cd	51 a
ethyl hexanoate	27 a	150 b	201 c	185 bc	19 a
CV (%)	52	55	93	56	52

[a] Different letters in a row indicate significant differences (MANOVA, $P < 0.05$); sample codes in **Table 1**.

In-Nose Flavor Concentrations. In-nose analysis was carried out on the five custards varying in type and/or concentration of CMC. The release curves of ethyl butyrate from the different custards are presented in **Figure 1**. At first glance, the HV-0.1 and LV custards exhibited lowest release. Extraction of the parameters I_{max} and total release from the curves (**Table 5**) confirms these observations: the low CMC concentration custard (HV-0.1) and the low-viscosity CMC (LV) custards resulted in significantly lower I_{max} and total release values (MANOVA, $P < 0.05$) than the other custards with a firmer texture. The increased release from firmer gels as determined by in-nose analysis is opposite to the static headspace data, which showed higher headspace concentrations for the softer gels (**Table 4**). It is unlikely that this is caused by kinetic factors of flavor release. From that perspective, a higher release from the least viscous sample would be expected, not from the most viscous sample. As a consequence the differences observed during consumption cannot be attributed to concentration, thermodynamic aspects, or direct kinetic effects, but must be the indirect result of oral processing. Buettner et al. (*16*)

Table 6. Mean Scores ± Standard Deviations of Sensory Attributes of the Custards with Sucrose Varying in Type of CMC and/or Concentration ($n = 9$)[a]

	HV			
	0.1 g/100 g	0.5 g/100 g	1.0 g/100 g	MV
odor				
strawberry	48 ± 17 a	49 ± 20 a	39 ± 21 a	51 ± 21 a
milky	53 ± 20 a	48 ± 24 a	40 ± 22 a	41 ± 24 a
grassy	53 ± 12 a	53 ± 20 a	51 ± 18a	50 ± 17 a
overripe fruit	50 ± 24 a	55 ± 22 a	37 ± 28 a	54 ± 24 a
flavor				
strawberry	43 ± 19 a	50 ± 18 a	38 ± 13 a	55 ± 19 a
milky	50 ± 20 a	62 ± 16 a	57 ± 18 a	54 ± 19 a
grassy	51 ± 3 a	49 ± 16 a	47 ± 13 a	45 ± 15 a
sweet	75 ± 13 b	62 ± 19 ab	51 ± 22 a	61 ± 18 ab
overripe fruit	43 ± 21 a	52 ± 22 a	48 ± 21 a	53 ± 21 a
texture				
thickness	9 ± 7 a	52 ± 8 b	89 ± 7 c	56 ± 8 b

[a] Different letters in a row indicate significant differences (MANOVA, $P < 0.05$); sample codes in **Table 1**.

demonstrated, using videofluoroscopy and real-time magnetic resonance imaging, that the barrier between the mouth and the pharynx (velum) opens intermittently during consumption. Studies of Hodgson et al. (*17*) confirmed Buettner's data showing that chewing affected nasal airflow, with the flow fluctuations following the mastication pattern. The regular opening of the velum during eating may be sample dependent. Samples that are relatively liquid need less chewing, which may lead to less frequent openings as well as a shorter mastication time. On the other hand, firmer samples are likely to be chewed more extensively. More and perhaps more extensive chewing movements increase the possible frequency of the velum openings, which in turn can explain higher in-nose flavor concentrations. This hypothesis is confirmed by studies of Buettner and Montserrat (*18*), who reported that firmer gels were always treated mechanically by the molars in the back part of the oral cavities and that bolus breakdown products of these gels were kept in the cheeks until further processing or swallowing. In contrast, softer gels were kept in the front part of the oral cavity. Although no significant differences in flavor release were observed between softer and firmer gels in this particular study due to the large variance, authors reported generally higher $I_{\max}$ and overall release values for the firmer gel. Their results agree with the present data. The more extensive chewing of firmer samples in the present study is confirmed by the fact that $t(I_{\max})$ tends to increase with firmness of the custard (**Table 5**). The longer time to swallowing in itself, the longer time for opening of the pharynx, and the more extensive chewing, which may have led to more frequent openings, as well as the likely position of the sample in the mouth all contributed to increased nasal flavor concentrations.

Flavor Perception. Four custards (HV-0.1, HV-0.5, HV-1.0, and MV) were subjected to sensory analysis. Intensities of four odor, five flavor, and one texture attribute were recorded, and their scores are presented in **Table 6**. The custards exhibited significant differences for the attributes sweet and thickness. The firmer custards (e.g., HV-1.0) resulted in a lower score for sweetness [MANOVA, $F(3,48) = 3.806$, $P < 0.05$] and a higher score for thickness [MANOVA, $F(3,48) = 259.135$, $P < 0.05$]. No significant effect of the firmness of the custards on those flavor attributes that were more likely to be related to volatile flavor was observed, for example, strawberry, milky, grassy, and overripe fruit. A principal components plot (**Figure 2**) illustrates which samples are more similar and with which attributes they were associated. The samples were separated along the first PC, with thickness having a high negative loading. The attribute thickness correlated with the firm custard (HV-1.0). The middle-range samples MV and HV-0.5 had a low score on PC1, whereas the most liquid custard (HV-0.1) had a high positive score. Samples MV and HV-0.5 demonstrated both low scores on PC1 and high positive scores at PC2. They were associated with overripe fruit odor, overripe fruit flavor, and strawberry flavor. The least viscous sample (HV-0.1) was more associated with sweet flavor and milk odor.

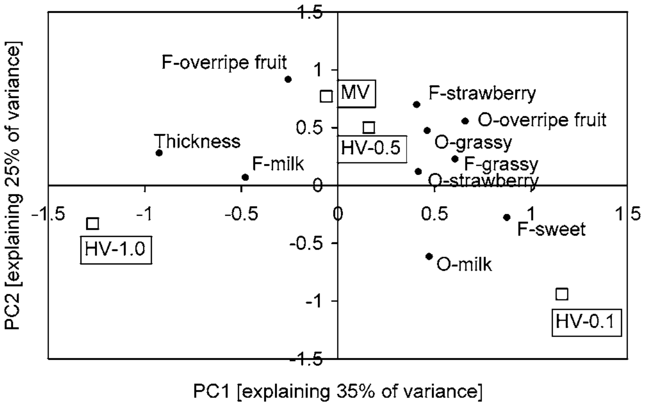

Figure 2. First and second dimensions of PCA on the intensities of sensory attributes for four custards (O = odor, F = flavor; sample codes in **Table 1**).

Table 7. Mean Scores ± Standard Deviations of Sensory Attributes of the Custards without Sucrose Varying in Type of CMC and/or Concentration ($n = 9$)[a]

	HV			
	0.1 g/100 g	0.5 g/100 g	1.0 g/100 g	MV
odor				
strawberry	47 ± 12 a	32 ± 21 a	40 ± 25 a	37 ± 25 a
milky	47 ± 16 a	50 ± 16 a	40 ± 21 a	52 ± 20 a
grassy	51 ± 3 a	52 ± 15 a	46 ± 16 a	48 ± 17 a
overripe fruit	56 ± 19 b	37 ± 22 a	39 ± 27 a	28 ± 21 a
flavor				
strawberry	47 ± 17 a	43 ± 17 a	36 ± 17 a	42 ± 21 a
milky	63 ± 17 a	61 ± 16 a	57 ± 14 a	64 ± 12 a
grassy	47 ± 13 a	49 ± 3 a	51 ± 2 a	48 ± 10 a
sweet	54 ± 7 b	50 ± 12 ab	41 ± 13 a	49 ± 17 ab
overripe fruit	42 ± 20 a	50 ± 15 a	46 ± 20 a	49 ± 24 a
texture				
thickness	12 ± 10 a	49 ± 8 b	84 ± 11 d	61 ± 10 c

[a] Different letters in a row indicate significant differences (MANOVA, $P < 0.05$); sample codes in **Table 1**.

Sweetness can be related to both volatile (aroma) and nonvolatile flavor (taste). Therefore, the same analysis was conducted on custards prepared without sucrose, the results of which are shown in **Table 7**. The viscosities of custards with and without sugar were similar (**Table 3**). A similar effect of the composition of the custards on their thickness was observed for the custards without sucrose [MANOVA, $F(3,56) = 139.578$, $P < 0.05$], with HV-1.0 having the highest intensity and HV-0.1 the lowest. A far less pronounced significant effect of custard composition on the sweetness intensities was obtained [MANOVA, $F(3,56) = 2.868$, $P < 0.05$] for the custards without sucrose. Obviously, in the custards with sucrose the effect of the firmness of the custards is more related to sucrose release than to volatile flavor release. This is in agreement with various studies that showed a considerable effect of food texture on sucrose release (*11*) and sweetness perception (*11*, *12*). The

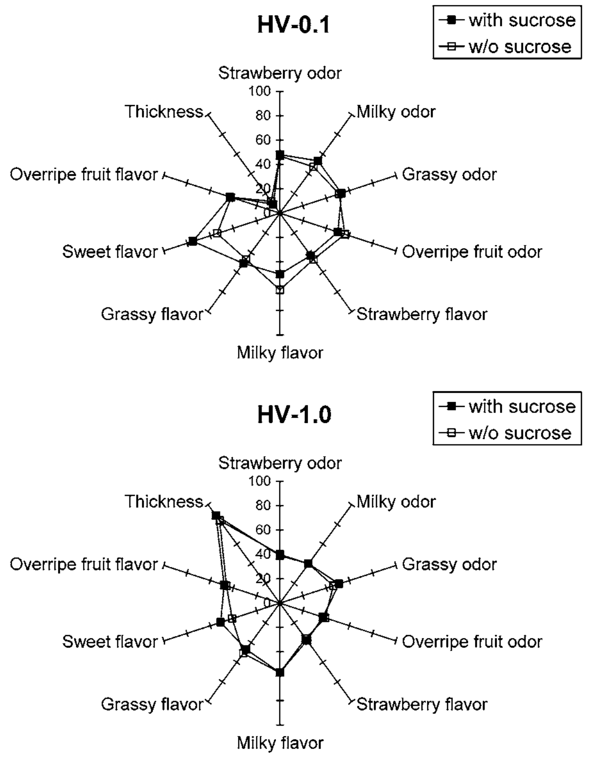

Figure 3. Spiderweb diagrams of the intensities of odor and flavor attributes of two custard desserts varying in concentration of CMC (HV 0.1 and 1.0%) with and without sucrose.

remaining effect of the custards' textures on sweetness perception may be related to volatile flavor perception, although it is more likely that also release of other carbohydrates, for example, lactose originating from the milk, played a role. **Figure 3** shows spiderweb diagrams of the intensities of sensory attributes for a soft (HV-0.1) and a firm custard (HV-1.0) with and without sucrose. Although the sucrose affected the sweetness intensities considerably, its effect on the other attributes was very limited compared to the effect of the CMC concentration.

Correlation of Instrumental−Sensory Data. The static headspace data were correlated with the intensities of the odor attributes in sensory analysis for the four custards with sucrose using PCA (**Figure 4a**). The samples were separated well on the first and second PCs. The lower viscosity custards HV-0.1 and HV-0.5 had higher odor intensities than the other samples. The compounds ethyl butyrate, ethyl isopentanoate, and ethyl hexanoate correlated well with the fruity odors (overripe fruit and strawberry). No compounds were analyzed that would have given grassy or milky odors; therefore, no compounds could be directly related to these attributes. However, the highest intensities for these attributes were observed for the least viscous custard. The high-viscosity custard HV 1.0 was fairly different, showing low intensities for all odor attributes as well as low headspace concentrations of the three flavor compounds. Overall, the static headspace data correlated quite well with the sensory odor data. Changing to a CMC with higher polymerization degree or an increase in CMC concentration resulted in lower headspace concentrations of the esters and lower fruity odor intensities.

Similarly, the spectral data of the in-nose measurements were correlated with the intensities of flavor attributes in sensory analysis of the same samples (**Figure 4b**). For the flavor data and perception, this time the low-viscosity sample (HV-0.1) was separated from the other samples. The sample correlated with a high intensity of grassy flavor. This sample also showed an intense grassy odor before. The medium-viscosity custards (HV-0.5 and MV) and the high-viscosity custard (HV-1.0) demonstrated relatively high intensities of overripe fruit and milky flavor. MV and HV-0.5 had also a high strawberry intensity. These flavors correlated with high $I_{\max}$ values in the in-nose analysis of ethyl butyrate, ethyl isopentanoate, and ethyl hexanoate. Again, the instrumental and sensory data correlated quite well. The lower viscosity custard resulted in lower flavor concentrations in the exhaled breath in in-nose analysis as well as in lower fruity flavor intensities in sensory analysis.

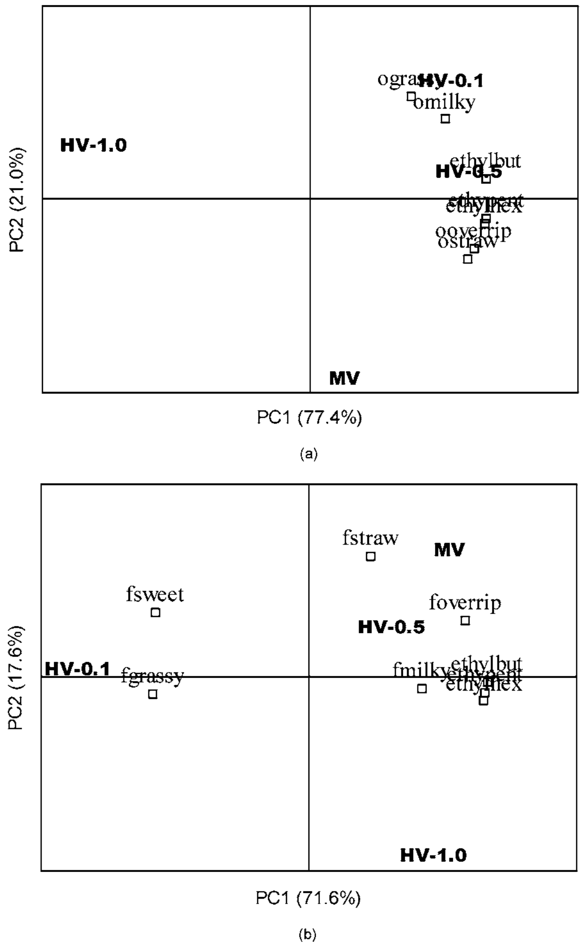

Figure 4. First and second dimensions of PCA on the intensities of (**a**) odor attributes in sensory analysis and the static headspace measurements and (**b**) flavor attributes in sensory analysis and the spectral data of in-nose measurements of four custard desserts varying in type or concentration of CMC (sample codes in **Table 1**; an "o" preceding a sensory attribute relates to an odor attribute and an "f" to a flavor attribute).

In conclusion, an opposite effect of custard viscosity on volatile flavor profiles was observed under static conditions and in exhaled air. This is likely to be due to aspects related to oral processing factors, such as transport of volatile molecules from the mouth to the nasal cavity. Instrumental and sensory evaluations correlated reasonably well. More detailed studies are needed to examine the impact of opening/closure of the velum and chewing/swallowing behavior of individuals on flavor release and perception.

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