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Interactions between flavour release and rheological properties in model custard desserts: Effect of starch concentration and milk fat

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Abstract

The influence of the concentration of various reagents and of the storage time on the flavour release of custard desserts was evaluated by headspace solid-phase microextraction and supported by rheological measurements. The presence of milk fat induced a significant decrease of the headspace concentration of flavour compounds, mainly due to hydrophobic matrix–flavour interactions. An elevated starch concentration enhanced the strength of the custard gels considerably. However, the increasing starch concentration resulted in an increased flavour release at low flavour concentrations, while a tendency to flavour retention was noted at higher flavour concentrations. During storage time, a denser network was formed as shown by rheological measurements, but no significant difference in flavour release was noted upon storage (three days). These results show that the complex interactions between flavour compounds and the food matrix in a model custard are difficult to predict and have to be carefully evaluated by a combination of rheological parameters and physicochemical interactions.

Keywords: Custard dessert; Rheology; SPME; Flavour release

1. Introduction

The release of flavour compounds from food is an essential but very complex determining factor for flavour perception. On the one hand, it can describe the partitioning of the flavour compounds between the food matrix and the headspace above it in a static equilibrium. On the other hand, the release of flavour compounds during eating can be monitored in the mouth or in the nose where the system represents real time flavour release in vivo. The partitioning of flavour compounds to the headspace of a food is largely dependent on food–flavour interactions. Lipids are the food ingredients that have the biggest effect on the partitioning of flavour compounds between products and the gaseous phase (De Roos, 1997). In numerous model emulsions (Doyen, Carey, Linforth, Marin, & Taylor, 2001; Haahr, Bredie, Stahnke, Jensen, & Refsgaard, 2000) and more complete foods (Brauss, Balders, Linforth, Avison, & Taylor, 1999; Brauss, Linforth, Cayeux, Harvey, & Taylor, 1999), the differences in headspace concentration (Welty, Marshall, Grun, & Ellersieck, 2001) and the resulting sensory intensity (Gwartney, Foegeding, & Larick, 2000) due to discrete modifications of the lipid level are well noted. For example, higher amounts of fats and oils generally lower the volatility of hydrophobic odorants such as long-chain aldehydes. Polysaccharides can bind volatiles in a number of ways. Some carbohydrates can bind volatiles via hydrogen bonding between appropriate functional groups (Maier, 1975). Others, such as starch, consist of three-dimensional structures with hydrophobic regions

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capable of forming inclusion complexes with various hydrophobic volatiles (Godshall & Solms, 1992). Cyclodextrins are capable of entrapping volatiles (Maier, 1975) and have been used to bind certain undesirable off-flavours selectively (Szente & Szejtli, 1988). For proteins, the physicochemical conditions and the composition of a food or a model system, e.g., pH, temperature, ionic strength and water content, influence the protein conformational changes, and, hence, the flavour binding. Bonds between aroma compounds and proteins are generally weak and include reversible bonds, van der Waals bonds, hydrogen bonds, and/or hydrophobic interactions. It has also been suggested that chemical reactions may occur between volatile compounds and proteins, leading to strong or irreversible binding, e.g., between aldehydes and lysine or arginine residues of proteins (Hansen & Heinis, 1991; Plug & Haring, 1993). Texturing agents have an influence on flavour release by increasing the viscosity, often resulting in a significant decrease in perceived flavour (van Ruth, de Witte, & Uriarte, 2004). Interactions between flavour compounds and non-volatile food constituents have mainly been studied with simple model systems. Therefore, a more complex custard dessert has been developed as a model as part of a European cooperation project (COST Action 921 – Cooperation in the field of Scientific and Technical Research) to study the effect of different ingredients and rheological parameters on headspace flavour concentration and sensory perception.

The presented study was developed to investigate the impact of different concentrations of milk fat and tapioca starch on the rheological properties of dairy custards and on the release of strawberry flavour compounds after different storage times. The flavour release from the matrix was measured by automated headspace solid-phase microextraction (SPME) and the rheological properties of dairy custard with different composition were evaluated by measuring flow and viscoelastic properties of the custard.

2. Materials and methods

2.1. Materials

The model custard system was composed of skim milk powder purchased from dairy company "Pieno žvaigždės" (Lithuania); full fat milk powder (2.6% fat) obtained from "Marijampoles pieno konservai" (Lithuania); sucrose purchased from the local market (Belgium); κ-Carrageenan (Meypro™ Lact HMF, Gelymar); modified Tapioca Starch E1142, FARINEX VA 60 T (AVEBE, Veendam, The Netherlands).

A strawberry flavour mixture of 15 compounds in triacetin was obtained from Givaudan (Switzerland) and proposed by COST Action 921. The composition of the flavour mixture is shown in Table 1. A 10% stock solution of the strawberry flavour mixture was prepared in ethanol to improve the solubility. Concentrations of 40 ppm and 200 ppm (calculated according to the concentration of ethyl hexanoate) were prepared by adding 100 μl and 500 μl of stock solution to 5 ml of the model system tested, respectively.

Table 1
Complete composition of strawberry flavour mixture, as proposed by COST Action 921

No.	Component	Amount (mg/g)	Log P[a]	P_{vap} (mm Hg)[a]
1	Furaneol	5	0.82	0.000936
2	Vanillin	5	1.21	0.000118
3	Methyl cinnamate	24	2.62	0.0465
4	Ethyl hexanoate	20	2.83	1.56
5	Ethyl butanoate	90	1.85	12.8
6	Benzyl acetate	2	1.96	0.177
7	1-Phenylethyl acetate	1	2.50	0.112
8	γ-Decalactone	20	2.72	0.00512
9	Methyl anthranilate	1	1.88	0.0271
10	Ethyl 3-methylbutanoate	10	2.26	8.3
11	Hexanal	1	1.78	11.3
12	Z-3-Hexenyl acetate	5	2.61	1.14
13	Z-3-Hexenol	15	1.61	0.937
14	Methyl Dihydrojasmonate	5	3.00	0.000412
15	β-Ionone	1	3.84	0.054
16	Triacetin	Solvent (795)		

[a] Howard and Meylan (1997).

2.2. Sample preparation

Four different dairy custard samples were made (Table 2). Either skim or full-fat milk powder was mixed with water (1:9) at a temperature of 45 °C with magnetic stirrer and left for 24 h in the refrigerator. κ-Carrageenan and sucrose were mixed in the dry state in a flask, starch was added to the mixture, and finally milk at a temperature of 25 °C was added to the mixture. The flask was placed in a water bath at 97 ± 0.5 °C and stirred constantly with a propeller stirrer at 150 rpm. The water bath temperature was controlled using a thermostat and the product temperature was measured. After 15 min the product temperature reached 94 ± 1 °C and heating was continued at this temperature for 15 min. After the heating process the evaporated water was replaced gravimetrically. The hot dairy dessert was divided into two parts; the first was used to measure viscoelastic properties, namely G', G'' and the second part was preserved for the determination of flow behaviour. Both parts of samples were cooled in an ice water bath within 5 min and stored for one or three days. For flavour release

Table 2
Composition of dairy custard samples (g/100 g product)

Rehydrated skim milk powder	Rehydrated fat milk powder (2.6%)	Modified tapioca starch	Sucrose	κ-Carrageenan
91	–	4	5	0.01
87	–	8	5	0.01
–	91	4	5	0.01
–	87	8	5	0.01

studies 5 ml of freshly prepared hot dessert were transferred into 20 ml headspace vials, well-defined amounts of the flavour mixture stock solution were added and the vials were closed with 13 mm polypropylene hole caps and PTFE/silicone septa (Supelco, Bornem, Belgium). The samples were cooled and stored for one or three days. Three batches were prepared for all of the measurements.

2.3. Measurements of rheological properties

The rheological properties of dairy dessert samples were characterized by flow behaviour and viscoelastic properties. Flow behaviour of the samples was measured after one and three days of storage at 4 °C using a Carri-Med CSL2 500 Rheometer (TA Instrument, UK) in controlled shear rate mode. The cone-plate geometry (diameter 4 cm) was used. The temperature of the sample was adjusted to 5 ± 0.2 or 25 ± 0.2 °C and kept steady during the measurement. The shear rate was increased linearly from 0.1 to 150 s^{-1} in one minute (upward curve) kept constant for one minute and reduced back to 0.1 s^{-1} (downward curve) in the next minute and the resulting shear stress was measured every second. Data were fitted to the simplified Carreau model according to Tarrega, Duran, and Costell (2005):

$$\eta_{ap} = \eta_0/(1 + (\gamma/\gamma_c)^2)^m$$

where: η_0 (Pa s) is the limit viscosity at low shear rates, γ_c (s^{-1}) is the critical viscosity at the start of the pseudoplastic region and m is a parameter related to the slope of the latter region.

Thixotropic behaviour was evaluated by calculating the area of the hysteresis loop between the upward and downward apparent viscosity/shear rate curves.

Small-deformation measurements of storage modulus (G') and loss modulus (G'') were performed in a controlled-stress rheometer (Carri-Med CSL2 500 Rheometer), using cone-plate geometry (4 cm). Gap between cone and 144 plate was 55 μm. Samples were transferred to the lower plate, with the adjusted temperature to 5 ± 0.2 or 25 ± 0.2 °C. Without disturbing the gel, frequency sweeps were conducted, with oscillation frequencies ranging from 0.1 to 100 rad/s at constant strain of 0.5%. The storage modulus G' and loss modulus G'' were measured as a function of frequency. Three replicates of measurement were made for each batch of samples.

2.4. Measurements of flavour release from dairy custard

The different custards were flavoured with the strawberry flavour mixture at two different concentrations, a low concentration corresponding to an ethyl hexanoate concentration of 40 ppm and a higher concentration corresponding to a concentration of 200 ppm ethyl hexanoate. The headspace flavour concentrations of the custards were measured by automated headspace solid-phase microextraction (HS–SPME), followed by GC–MS analysis. A very short sampling time of one minute was applied, since this was shown to represent equilibrium headspace concentrations (Roberts, Pollien, & Milo, 2000). At least two replicates of each measurement were made after different times of storage (one or three days) in the fridge at 5 °C. Using HS–SPME of aqueous solutions, only 9 of the 15 strawberry flavour compounds gave chromatographic peaks that could be integrated, whereas from custards only five compounds could be consistently integrated. These five compounds were used in the aroma release studies, namely ethyl hexanoate, ethyl butanoate, ethyl 3-methylbutanoate, Z-3-hexenyl acetate, and hexanal, in decreasing order of chromatographic response. The headspace flavour concentrations from the custards were always compared with equally concentrated aqueous solutions and the results are expressed in terms of percentage of the headspace concentrations of these aqueous solutions. The release of a compound from an aqueous solution was referred to as 100%, and as such an increased release (>100%) or a flavour retention (<100%) can be noted.

The flavour release in the headspace of prepared model samples was measured by headspace SPME with a 50/30 μm DVB/Car/PDMS fiber (Supelco, Bornem, Belgium). Aroma compounds were analysed on an Agilent HP 6890 series gas chromatograph equipped with PTV injector, an MPS-2 Multipurpose Sampler (Gerstel, Germany), a HP 5973 MSD detector (Mass Selective Detector-Quadrupole type) and an EC–5MS capillary column (30 m × 0.25 mm i.d.; coating thickness 0.25 μm). Equilibration of the samples (20 ml vials containing 5 ml of the flavoured model system) was reached, headspace SPME extracts were taken and desorbed automatically using following MPS-2 parameters: incubation temperature 30 °C; incubation time 30 min; extraction time 1 min; desorption time 5 min. GC–MS operating conditions were injector 250 °C; transfer line to MSD 260 °C; oven temperature start 35 °C, hold 5 min, programmed from 35 °C to 150 °C at 5 °C/min, from 150 °C to 250 °C at 20 °C/min, hold 2 min; carrier gas He 1.2 ml/min; splitless injection, ionization EI 70 eV.

2.5. Statistical analysis

All the flavour release data for triplicate custards were subjected to multivariate analysis of variance (MANOVA) and least significant difference Tukey test to determine significant differences between the different custards (SAS 9.1.3 software). A significance level of $p < 0.05$ was applied.

3. Results and discussion

3.1. Rheological studies

Model custard desserts were prepared with different contents of modified tapioca starch (4% or 8%), different types of milk powder (skim or full-fat), 0.01% of carrageenan, 5% of sucrose and water. Flow behaviour and viscoelastic properties of prepared samples were measured at

the temperatures of 5 and 25 °C, because these are refrigerating and daily consumption temperatures, respectively. Flow curves were measured only for the model custard desserts with 4% of tapioca starch but containing different types of milk powder. Such limitation of the measurement was caused by difficulties in obtaining reproducible flow behaviour data for all the model custard samples at the same conditions of rheological measurements.

3.1.1. Flow behaviour of dairy custard

Flow curves for dairy desserts produced with rehydrated skim and fat milk are shown in Figs. 1 and 2, respectively.

All samples exhibited pseudo-plastic behaviour with clear shear rate dependent flow. These data are in agreement with the results obtained by other researchers (Tarrega et al., 2005; Velez-Ruiz, Gonzalez-Tomas, & Costell, 2005). The apparent viscosity values of dairy custards made from skim milk stored for three days were slightly higher than those stored for one day. No changes in apparent viscosity were noticed in the case of custard made from fat milk. However, the influence of the temperature on the flow behaviour was similar in the case of both custard recipes. An increase in temperature caused a decrease in apparent viscosity.

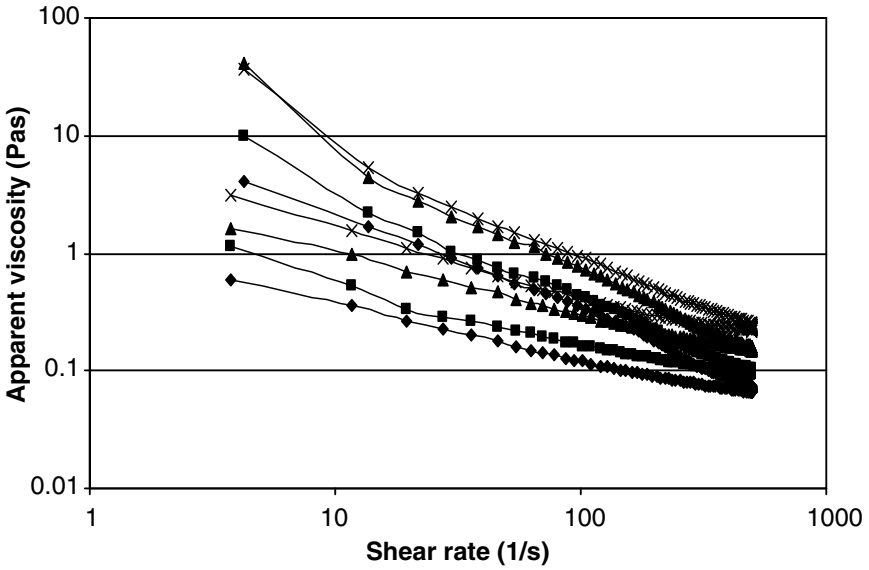

Fig. 1. Flow curves (forward and backward) of skim milk custard containing 4% of modified tapioca starch: ♦ – measured at 25 °C after one day of storage, ■ – at 25 °C after three days, ▲ – at 5 °C after one day and × – at 5 °C after three days.

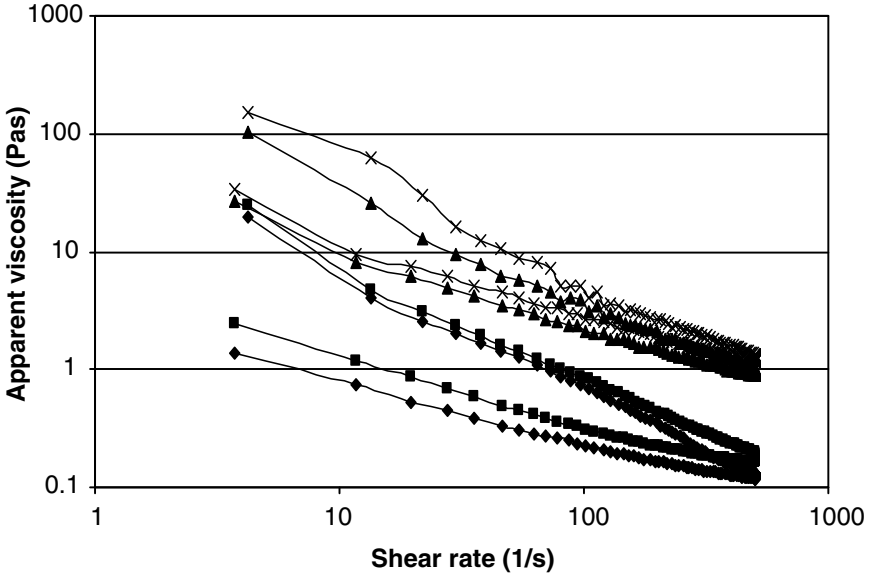

Fig. 2. Flow curves (forward and backward) of fat milk custard containing 4% of modified tapioca starch: ♦ – measured at 25 °C after one day of storage, ■ – at 25 °C after three days, ▲ – at 5 °C after one day and × – at 5 °C after three days.

The simplified Carreau model was used to model the apparent viscosity data of the dairy custards at increasing shear rate (Table 3). The analysed dairy custard samples showed differences in the Carreau model parameters. Skimmed milk desserts in comparison with those containing full fat milk had lower Newtonian viscosity (η_0), higher critical shear rate values (γ_c) and slightly lower m values indicating lower pseudoplasticity of the systems. The effect of temperature on the Carreau model parameters was observed as well, however this effect was different for all parameters. The most effected parameter was η_0 which was lower at 25 °C than at 5 °C for all samples. According to the data presented in Table 3, it can be stated that η_0 was influenced by storage. All samples stored for three days showed a higher Newtonian viscosity and a higher critical shear rate value indicating a higher resistance to flow and a higher stability under the effect of shear.

Thixotropy of structured systems is caused by the structural breakdown of the structure under shear. The return curves showed thixotropic behaviour for all the dairy custard samples. The influence of storage and temperature of measurement as well as composition of custards on the thixotropic properties was studied (Table 3). After storage, the custards displayed a higher degree of hysteresis. Such behaviour can be explained by an extended formation of the network with a higher content of interparticle bonds which were formed during storage time and were broken under shear. Thixotropic behaviour was different for the custards made from skim milk and fat milk. Samples with skimmed milk exhibited a lower degree of hysteresis than full-fat custards, with respective values of 809 and 822 Pa s^{-1} at 25 °C and 1428 and 1396 Pa s^{-1} at 5 °C, suggesting a lower connectivity of the formed structure of the system. The flow behaviour measured at 25 °C was characterized by a bigger area of the hysteresis loop between upward and downward apparent viscosity/shear rate curves than at 5 °C. For the fat milk custards the calculated hysteresis areas were 1094 and 1155 Pa s^{-1} at 25 °C and 1736 and 1828 Pa s^{-1} at 5 °C.

3.1.2. Viscoelastic properties of dairy custard

Mechanical spectra of dairy dessert samples are presented in Figs. 3–6. Frequency sweeps of samples containing 4% of tapioca starch (Figs. 3 and 4) showed that the storage modulus G' values were about one decade higher

Table 3
Carreau model fitting data for skim and fat milk desserts containing 4% of tapioca starch at 5 and 25 °C

Type of milk powder used	Temperature (°C)	Days of storage	η_0 (Pa s)	γ_c (s^{-1})	m	Thixotropy (Pa s^{-1})
Skim	25	1	4.25	1.2×10^{-4}	0.44	809
		3	4.87	1.7×10^{-4}	0.44	822
	5	1	13.13	1.6×10^{-4}	0.42	1428
		3	17.95	1.8×10^{-4}	0.45	1396
Full-fat	25	1	19.40	2.0×10^{-4}	0.44	1094
		3	24.17	2.1×10^{-4}	0.45	1155
	5	1	27.90	2.3×10^{-4}	0.48	1736
		3	57.27	2.7×10^{-4}	0.48	1828

$0.967 \leqslant R^2 \leqslant 0.995$.

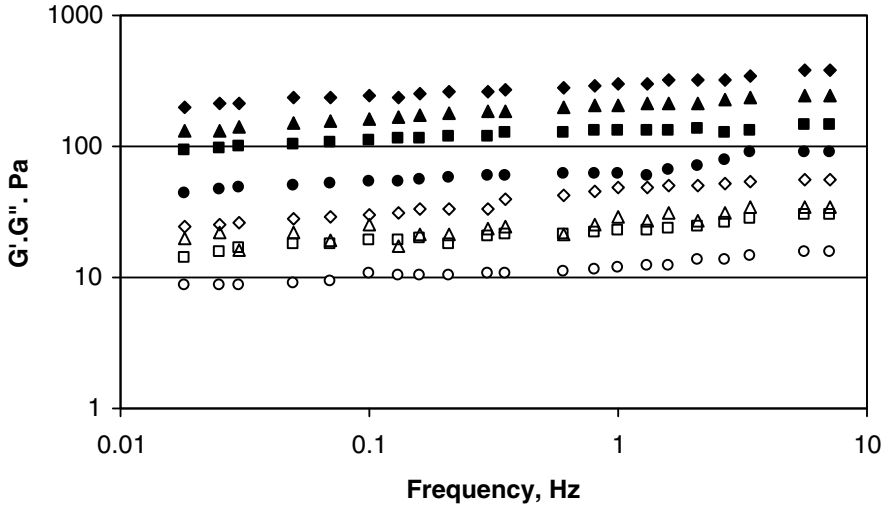

Fig. 3. Elastic modulus G' (filled symbols) and loss modulus G'' (open symbols) as a function of frequency for skim milk custard containing 4% of modified tapioca starch: ○ ● – measured at 25 °C after one day of storage; □ ■ – at 25 °C after three days; Δ ▲ – at 5 °C after one day; ◇ ◆ – at 5 °C after three days.

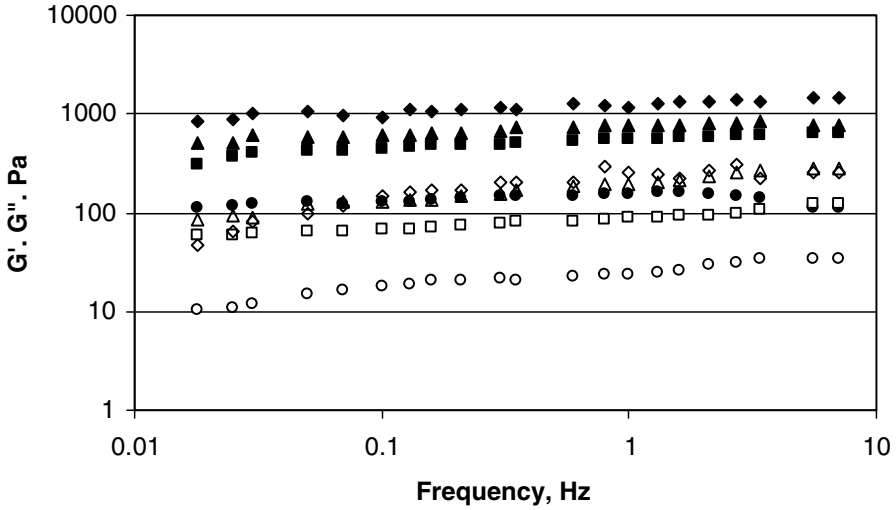

Fig. 4. Elastic modulus G' (filled symbols) and loss modulus G'' (open symbols) as a function of frequency for fat milk custard containing 4% of modified tapioca starch: ○ ● – measured at 25 °C after one day of storage; □ ■ – at 25 °C after three days; Δ ▲ – at 5 °C after one day; ◇ ◆ – at 5 °C after three days.

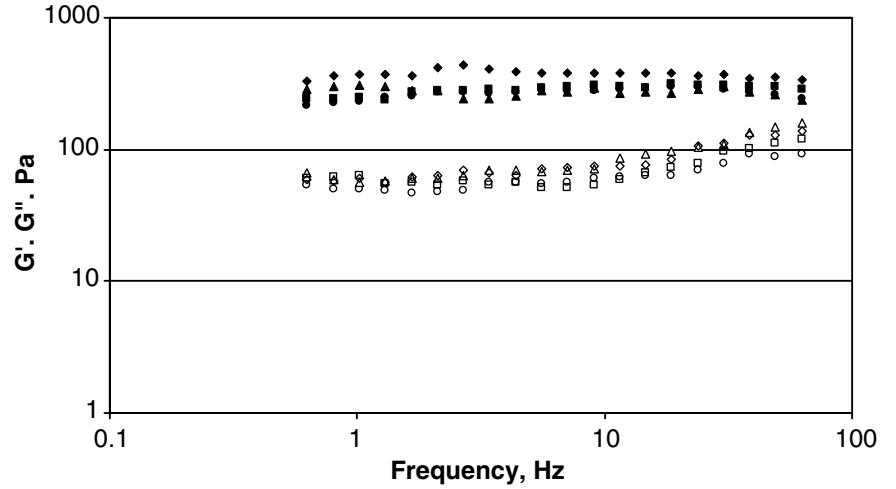

Fig. 5. Elastic modulus G' (filled symbols) and loss modulus G'' (open symbols) as a function of frequency for skimmed milk custard containing 8% of modified tapioca starch: ○ ● – measured at 25 °C after one day of storage; □ ■ – at 25 °C after three days; Δ ▲ – at 5 °C after one day; ◇ ◆ – at 5 °C after three days.

than the loss modulus G'' values and were both slightly frequency dependent through the whole range of frequencies. Such behaviour can be considered as typical for weak gel systems (Nunes, Raymundo, & Sousa, 2006). Similar mechanical spectra were recorded for all dairy custard samples containing 4% of tapioca starch.

Viscoelastic properties of dairy custard containing 8% of tapioca starch (Figs. 5 and 6) showed a slightly different character of the formed system. The G' values of the samples were always higher than those of G'' through the whole range of frequencies, indicating a solid state of the system. They were also independent of frequency, showing the formation of an elastic network. A slight increase in G'' with increasing frequency was observed in the model dessert systems with 8% of tapioca starch. However, the predominant elastic character where G' was more than 10 times higher than G'' was observed in all systems. Similar mechanical spectra were obtained by other researchers for hydrocolloids gels (Bayarri, Duran, & Costell, 2004; Ikeda & Nishinari, 2001).

For all the dairy custard samples the tested storage modulus increased with the time, indicating that a denser network is formed during storage. However, increase of the measurement temperature caused a decrease of the modulus. In the case of dairy custards with 4% of tapioca starch G' values of samples containing milk fat were higher than those with rehydrated skim milk powder, suggesting a more structured gel system in the first samples. An opposite effect was observed at the higher 8% tapioca starch concentration, since the values of the complex modulus were higher for the samples with no milk fat. These results are in agreement with the data obtained by Velez-Ruiz et al.

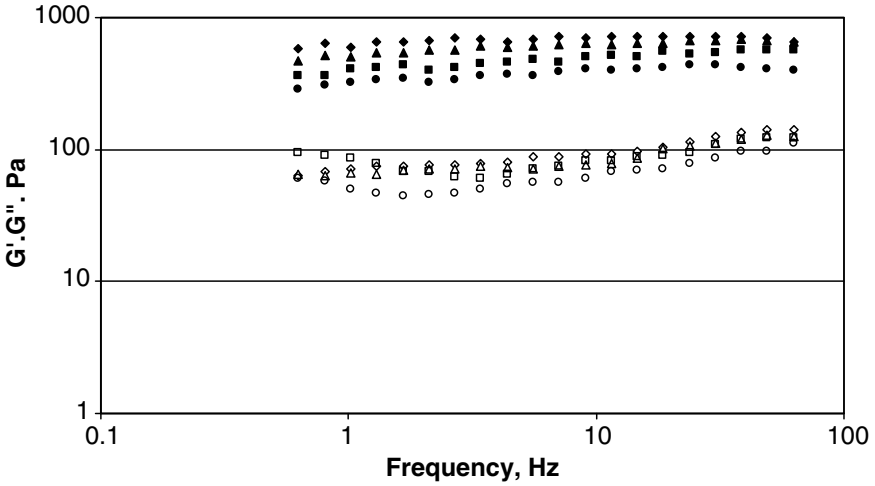

Fig. 6. Elastic modulus G' (filled symbols) and loss modulus G'' (open symbols) as a function of frequency for fat milk custard containing 8% of modified tapioca starch: ○ ● – measured at 25 °C after one day of storage; □ ■ – at 25 °C after three days; Δ ▲ – at 5 °C after one day; ◇ ◆ – at 5 °C after three days.

(2005), who showed that the samples of dairy custard with fat milk presented higher G' values than samples with skim milk, although most differences between them occurred at a starch concentration of 4%, while at 5% and 6% these differences were negligible. It seems that milk fat strengthens weak gels and weakens strong gels. As swollen starch granules occupy a considerable volume in the dessert, milk fat becomes more concentrated in the continuous water phase and probably interferes with the carrageenan network, thus weakening it.

3.2. Flavour release studies

The flavour release data from model custards with different values of starch, milk fat and storage time were compared and are put together in Table 4. For this purpose, the headspace strawberry flavour concentrations from the custards were always compared with equally concentrated aqueous solutions and the results are expressed in terms of percentage of the headspace concentrations of these aqueous solutions. This allows a more straightforward comparison among the different custards.

3.2.1. The influence of tapioca starch concentration on flavour release

To investigate the effect of starch concentration, samples prepared with skim milk powder were used (Table 4). The release from custard of the strawberry flavour compounds at a low flavour concentration (40 ppm) was considerably lower than from comparable aqueous solutions (values $< 100\%$). In addition, a higher starch content led to a significantly higher flavour release from the custards. This could be due to an exclusion effect caused by the swollen starch granules. The results obtained from the measurements with a more concentrated strawberry flavour solution (200 ppm), showed no significant flavour retention from custards as compared to aqueous solutions, except for hexanal and ethyl hexanoate. In contrast with the

Table 4
Comparison of the release of selected strawberry flavour compounds as detected by SPME in the headspace of custard desserts with varying content of milk fat and modified tapioca starch, in terms of percentage of similar aqueous solutions after varying days of storage (5 °C)

Fat (%)	Starch (%)	Time (days)	Concentration (ppm)	Flavour release from custard (% of equivalent release from water)				
				Hexanal	Ethyl butanoate	Ethyl 3-methyl-butanoate	Ethyl hexanoate	*Z*-3-Hexenyl acetate
0	4	1	40	10.9^{ef}	52.9^{de}	36.7^{cde}	29.8^{def}	32.1^{cd}
0	8	1	40	38.4^{cd}	82.2^{bcd}	64.5^{bc}	52.8^{cd}	72.0^{bc}
2.6	4	1	40	9.4^{f}	41.2^{e}	14.5^{e}	1.1^{f}	0.0
0	4	3	40	19.8^{def}	87.7^{cde}	71.5^{bcd}	44.2^{de}	71.5^{cd}
2.6	4	3	40	36.5^{f}	63.9^{de}	30.3^{de}	3.6^{f}	0.0
0	4	1	200	79.9^{a}	90.7^{a}	84.3^{a}	78.2^{a}	96.6^{a}
0	8	1	200	44.1^{bc}	88.8^{a}	66.9^{ab}	52.9^{bc}	62.4^{b}
2.6	4	1	200	30.8^{cde}	70.5^{abc}	37.4^{edc}	11.2^{ef}	10.1^{d}
0	4	3	200	68.5^{ab}	105.7^{ab}	108.0^{ab}	85.7^{ab}	135.3^{b}
2.6	4	3	200	53.1^{cd}	95.4^{abc}	63.3^{bc}	23.9^{def}	20.2^{d}

[a–f] Values with different superscripts within a column are significantly different (Tukey grouping, $p < 0.05$).

results obtained from low concentrated flavour solutions, increasing the starch content to 8% imparted no significant difference or a decrease of the flavour release, as was the case for hexanal, ethyl hexanoate and Z-3-hexenyl acetate (Table 4). These results contradict with the data obtained using 40 ppm flavour solutions but are more in line with literature data obtained by Rega, Guichard, and Voilley (2002), Lubbers and Guichard (2003) and van Ruth et al. (2004), who showed that in model gels the diffusion of aroma compounds through the three-dimensional network of gelling agent chains was decreased and thus the release of flavour was lower. This can be explained by the increasing gel strength caused by the higher starch concentration, as shown by the rheological measurements. Also Decourcelle, Lubbers, Vallet, Rondeau, and Guichard (2004) reported that headspace concentrations of strawberry flavour compounds in yoghurt decreased in the presence of starch.

3.2.2. The influence of milk fat on flavour release

To study the influence of milk fat on the strawberry flavour release, custards prepared with rehydrated full-fat (2.6% fat) milk powder were used. The obtained results were compared with the release from water and skim milk custards. Both (skim and whole milk) custards contained the same amount of starch (4%).

Both the custards with low and with high flavour concentrations showed a retention of the flavour compounds by the milk fat, which was, however, only significant ($p < 0.05$) for the high flavour concentrations (except for ethyl butanoate) and for low concentrated Z-3-hexenyl acetate. Thus, it can be stated that flavour volatiles interact considerably with milk fat. These results are in agreement with the results found in literature (Roberts & Taylor, 2000). The retention of the four different esters is proportional with their hydrophobicity ($\log P$ value – Table 1): the most hydrophobic compound, ethyl hexanoate, was retained most while the least hydrophobic compound, ethyl butanoate, was retained much less by the milk fat. This clearly illustrates the hydrophobic character of the lipid–flavour interactions.

3.2.3. The influence of storage time on flavour release

In Table 4 the change in strawberry flavour release after three days of storage at 5 °C is shown for low-fat and high-fat custards. These results showed a tendency to an increase in the release of most flavour compounds after three days of storage as compared to one day of storage, which was mostly insignificant. The rheological measurements (viscosity, hysteresis and storage modulus) showed that a denser network was formed upon storage which may explain the increased expulsion of flavour compounds after three days of storage. This contradicts, however, with results obtained by Lubbers, Decourcelle, Vallet, and Guichard (2004), who observed a decrease in the released flavour concentration from fat-free yoghurt after different times of storage and related it with the increased viscosity.

4. Conclusion

The performed flavour release studies of the custard model system showed that the presence of milk fat had the highest influence on the release of flavour compounds. Milk fat retained the flavour compounds by means of hydrophobic interactions. For custards prepared with skimmed milk, an increase of tapioca starch concentration from 4% to 8% increased the strength of the gels and involved a slight flavour retention when high flavour concentrations were applied. However, with lower flavour concentrations, an increased flavour release was noted with increasing starch concentrations. After three days of storage, when a denser network was formed, the flavour release was in general not significantly different from the release after one day of storage. These results show that the complex interactions between flavour compounds and the food matrix in these model custards are the result of a combination of rheological parameters and physicochemical interactions.

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References

Bayarri, S., Duran, L., & Costell, E. (2004). Influence of sweeteners on the viscoelasticity of hydrocolloids gelled systems. *Food Hydrocolloids, 18*, 611–619.

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

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

De Roos, K. B. (1997). How lipids influence food flavour. *Food Technology, 51*, 60–62.

Decourcelle, N., Lubbers, S., Vallet, N., Rondeau, P., & Guichard, E. (2004). Effect of thickeners and sweeteners on the release of blended aroma compounds in fat free stirred yoghurt during shear conditions. *International Dairy Journal, 14*, 783–789.

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

Godshall, M. A., & Solms, J. (1992). How carbohydrates influence flavour. *Food Technology, 46*, 140–145.

Gwartney, E. A., Foegeding, E. A., & Larick, D. L. (2000). The role of texture and fat. In *Flavour release*. In D. D. Roberts & A. J. Taylor (Eds.). *ACS Symposium Series* (763, pp. 351–357). Washington, DC: American Chemical Society.

Haahr, A. M., Bredie, W. L., Stahnke, L. H., Jensen, B., & Refsgaard, H. H. F. (2000). Flavour release of aldehydes and diacetyl in oil/water systems. *Food Chemistry, 71*, 355–362.

Hansen, A. P., & Heinis, J. J. (1991). Decrease of vanillin flavor perception in the presence of casein and whey proteins. *Journal of Dairy Science, 74*, 2936–2940.

Howard, P. H., & Meylan, W. M. (1997). *Handbook of physical properties of organic chemicals*. Boca Raton, FL: CRC Press.

Ikeda, S., & Nishinari, K. (2001). Weak gel-type rheological properties of aqueous dispersions of nonaggregated κ-carrageenan helices. *Journal of Agricultural and Food Chemistry, 49*, 4436–4441.

Lubbers, S., Decourcelle, N., Vallet, N., & Guichard, E. (2004). Flavor release and rheology behavior of strawberry fat-free stirred yogurt during storage. *Journal of Agricultural and Food Chemistry, 52*, 3077–3082.

Lubbers, S., & Guichard, E. (2003). The effects of sugars and pectin on flavour release from a fruit pastille model system. *Food Chemistry, 81*, 269–273.

Maier, H. G. (1975). Binding of volatile aroma substances to nutrients and foodstuffs. In H. Maarse & P. J. Groenen (Eds.), *Aroma Research: Proceedings of the international symposium on aroma research* (pp. 143–157). The Netherlands: The Centre for Agricultural Publishing and Documentation.

Nunes, M. C., Raymundo, A., & Sousa, I. (2006). Rheological behaviour and microstructure of pea protein/κ-carrageenan/starch gels with different setting conditions. *Food Hydrocolloids, 20*, 106–113.

Plug, H., & Haring, P. (1993). The role of ingredient–flavour interactions in the development of fat-free foods. *Trends in Food Science & Technology, 4*, 150–152.

Rega, B., Guichard, E., & Voilley, A. (2002). Flavor release from pectin gels: Effects of texture, molecular interactions and aroma compounds diffusion. *Sciences des Aliments, 22*, 235–248.

Roberts, D. D. & Taylor, A. J. (2000). Flavour release, ACS symposium series, 763, American Chemical Society, Washington DC.

Roberts, D. D., Pollien, P., & Milo, C. (2000). Solid-phase microextraction method development for headspace analysis of volatile flavor compounds. *Journal of Agricultural and Food Chemistry, 48*, 2430–2437.

Szente, L., & Szejtli, J. (1988). Stabilization of flavours by cyclodextrins. In S. J. Risch & G. A. Reineccius (Eds.), *Flavor encapsulation* (pp. 149–157). Washington DC: American Chemical Society.

Tarrega, A., Duran, L., & Costell, E. (2005). Rheological characterization of semisolid dairy desserts. Effect of temperature. *Food Hydrocolloids, 19*, 133–139.

van Ruth, S. M., de Witte, L., & Uriarte, A. R. (2004). Volatile flavour analysis and sensory evaluation of custard desserts varying in type and concentration of carboxymethyl cellulose. *Journal of Agricultural and Food Chemistry, 52*, 8105–8110.

Velez-Ruiz, J. F., Gonzalez-Tomas, L., & Costell, E. (2005). Rheology of dairy custard model systems: Influence of milk-fat and hydrocolloid type. *European Food Research and Technology, 221*, 342–347.

Welty, W. M., Marshall, R. T., Grun, I. U., & Ellersieck, M. R. (2001). Effects of milk fat, cocoa butter, or selected fat replacers on flavour volatiles of chocolate ice cream. *Journal of Dairy Science, 84*, 21–30.