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Reducing salt and fat content: Impact of composition, texture and cognitive interactions on the perception of flavoured model cheeses

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ABSTRACT

To better understand which composition levers are available to reduce salt content in food without altering flavour perception, this paper aimed at quantifying the impact of texture and composition (salt, fat and dry matter) of a model cheese: (i) on salt and flavour perception, and; (ii) on profile texture and flavour release.

Variations of salt, fat and dry matter highly influenced texture perception and instrumental texture parameters. Differences in aroma release and olfactory perception ("blue cheese" odour perception) between different model cheeses were highlighted when salt and fat content varied. However, a major result of this study showed that salty perception was not influenced by texture characteristics of model cheeses. Furthermore, olfactory perception modified texture perception but only for model cheeses with low fat and low-dry matter contents. Variations in salt content and sensory interactions therefore seem to have a greater impact on products with low fat content than on those with high-fat content.

1. Introduction

Sodium intake exceeds the nutritional recommendations in many industrialised countries. It has been clearly demonstrated that a high-salt diet leads to health issues such as hypertension, coronary disease and stroke (Law, 1997). Consequently, there is an increasing interest in the production of low-sodium food, in accordance with recommendations for reducing dietary intake of sodium chloride. However, salt is a major ingredient in food; when its content is decreased, it is known to highly affect texture and flavour characteristics, which are essential for determining product quality and consumer acceptance. Among foods with a particular interest in salt reduction (soups, sausages, etc.), cheese represents an interesting study model because of its wide diversity of composition and texture. Cheese has been identified as one of the main food vectors contributing to salt intake. For example, if a person consumed an average quantity of 40 g of cheese per day, this alone would account for 10% of the recommended daily salt intake (calculated from a mean salt intake of 8 g/day and 2% NaCl in cheese). Thus, a better understanding of salt impact on the sensory and physicochemical characteristics of cheeses could make it possible to find formulation levers to satisfy consumers' expectations.

When considering the influence of salt content on cheese texture, data from the literature appears to be conflicting. Most of the authors observed that raising the salt level increased firmness and decreased springiness of several cheese products (Mistry & Kasperson, 1998; Stampanoni & Noble, 1991). An explanation for this is that a salt increase could induce a pH decrease, leading to an aggregation of casein fractions and, thus, firmer cheeses. However, some studies reported that salt had no influence on the texture of cream cheese (Wendin, Langton, Caous, & Hall, 2000). Moreover, in addition to perceived saltiness, sodium chloride brought out some characteristic cheese tastes such as sourness or bitterness (Mistry & Kasperson, 1998; Stampanoni & Noble, 1991; Wendin et al., 2000). Salt is also reported to influence the release of aroma compounds responsible for olfactory perception, as reported by Guichard (2002). This effect was shown to be dependent on physicochemical properties of volatile compounds and on salt type (NaCl, KCl, MgCl, etc.) and concentration. In numerous studies, salts are often added to samples to increase the sensitivity of headspace analyses. In this case, salt has a salting out effect or modifies the polarity of protein surfaces that could affect their binding ability and, thus, the retention of aroma compounds by matrices (Guichard, 2002; Guichard & Langourieux, 2000; Perez-Juan, Flores, & Toldra, 2007).

The impact of salt reduction on cheese quality could also be dependent on the other ingredients of cheese matrices and, in particular, on fat content. The effect of fat on cheeses has been widely investigated and unanimous agreement has been reached in the literature on its effect on texture characteristics (Rudan, Barbano, Yun, & Kindstedt, 1999). On the contrary, the impact of fat content on taste perception has been the subject of controversy. Some studies reported no influence of fat reduction on salty perception (Stampanoni & Noble, 1991), whereas other studies showed the decrease of saltiness intensity with the decrease of fat content

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(Shamil, Wyeth, & Kilcast, 1992; Wendin et al., 2000). In the case of cooked "bologna-type" sausages, saltiness perception seemed to depend more on protein content than on fat content (Ruusunen, Simolin & Puolanne, 2001). Moreover, fat content is also known to highly influence the olfactory properties of food products: a decrease in fat content is often responsible for an increase in aroma release and in the intensity of flavour perception (De Roos, 1997; Shamil et al., 1992).

Modification of physicochemical properties of food induced by salt reduction can explain some variation in sensory characteristics. However, perception is a much more complex process, and interaction between senses can occur. Aroma/taste/texture cross-influence was investigated on dairy products using different approaches: use of a nose-clip, variation of flavouring agent quality, eating of a non-flavoured product while delivering an aroma agent into the nasal cavity, etc. (Bult, de Wijk, & Hummel, 2007; Labbe, Damelin, Vaccher, Morgenegg, & Martin, 2006; Saint-Eve, Paci Kora, & Martin, 2004). These studies show that a decrease of flavour intensity was observed with an increase of viscosity of the dairy product concerned, and that thickness perception was a function of the quality and the complexity of the flavouring agent. However, the influence of texture perception on aroma and taste perception was widely investigated in the past, often by modification of the product composition or of the process (Baines & Morris, 1987; Boland, Delahunty, & van Ruth, 2006; Pangborn & Szczesniak, 1974), which induced other consequences of aroma/taste perceptions in products. Furthermore, the interactions between aroma and taste were shown to be both taste and odour dependent, particularly with NaCl (Frank & Byram 1988).

When aiming to reduce the salt level in food, it is of great interest to better understand the roles of structure and composition and of sensory interactions on perceptions. In this way, the first objective of the research reported here was to understand and quantify the effect of composition and process factors on physicochemical and sensory properties of flavoured model dairy products, varying not only in salt composition, but in fat and dry matter composition as well. We also aimed at assessing the respective roles of cognitive and physicochemical interactions involved in perception processes.

2. Materials and methods

2.1. Sample preparation

Five flavoured model cheeses, varying in dry matter content (370 or 440% w/w), fat content (40 or 20% w fat/w dry matter) and salt (NaCl) content (0.5 or 1.5% w/w) were manufactured using a defined protocol (Table 1). They were chosen for their good repeatability between preparations and the absence of syneresis in the matrices. The first step was to reconstitute the milk base by mixing ultrafiltrated skim milk retentate powder, anhydrous milk fat, salt and water in a blender (5000 rpm for 2 min and 15000 rpm for 10 min) (Waring blender; Waring Corp., Winsted, CT, USA). Depending on the initial pH-value of the mixture, glucono-delta-lactone or NaOH was added. When the pH-value of the mixture reached 6.2 after 2 h, flavour and rennet were added. Products were flavoured to 0.1% (w/w) with a blue cheese flavour containing three aroma compounds mixed with propylene glycol (Aldrich, France). Diacetyl, ethyl hexanoate and heptan-2-one were provided by Aldrich (Germany). These molecules differed in terms of their physicochemical properties and their final concentrations in the product (from 6 to 130 mg/kg of product, Table 2). Cylindrical plastic containers of 5 cm in diameter (Krehalon, Evry France) were filled with the product and were placed in a thermostated bath at 32 °C for 3 h for the coagulation step. Products were then transferred to a cold room (4 °C) for storage of up to 24 h. The pH and the instrumental texture profile analyses are considered as manufacturing checkpoints.

Each of the model cheeses was analysed after one day of storage. Before each sensory and physicochemical analysis, the model cheese cylinders were cut into 20 g slices of 1 cm in height and 5 cm in diameter.

Table 1
Premix composition of the seven cheese models. w-dry matter content, x-fat content, y-salt content.

Matrices (w-x-y)	Dry matter (in g/kg)	Anhydrous milk fat fat/dry matter (% in w/w)	NaCl (% in w/w)
440-40-0.5	440	40	0.5
370-40-0.5	370	40	0.5
370-20-1.5	370	20	1.5
370-40-1.5	370	40	1.5
370-20-0.5	370	20	0.5

Suppliers: Anhydrous milk fat: Corman, Belgium, NaCl: Prolabo, France, Glucono-lactone: Sigma Aldrich, Steinheim, Germany, Skim milk powder: Triballat, France.

2.2. Sensory procedure

A quantitative descriptive analysis was performed on the products to study texture, taste and olfactory perceptions. A panel of ten subjects participated in the study (from 22 to 41 years old, nine women, one man). The subjects were recruited according to their motivation and their availability. Cheese slice samples were placed on disposable Petri dishes, coded with three-digit random numbers and tempered for 1 h at 13 °C before tasting. This temperature corresponds to the average consumption temperature of cheeses. Subjects were provided with mineral water and plain crackers as palate cleansers between samples. Sensory evaluation was conducted in a neutral environment: an air-conditioned room (20 °C), under white light, in separate booths. Scores were directly recorded on a computer system using FIZZ software (Biosystèmes®, 1999).

Subjects underwent twelve training sessions before descriptive analysis was performed. These sessions included the identification and the recognition of basic tastes and aromas (in aqueous solutions or in model cheeses) and the evaluation of texture properties on commercial cheese products. The panel was trained in the proper use of the unstructured linear scale anchored with the terms "very weak" and "very intense". These training sessions led to the establishment of a precise tasting protocol and a common vocabulary for the description of cheese sensory properties. Attribute generation was performed during one training session. After the elimination of non-relevant descriptors and the selection of the most representative terms, the final vocabulary consisted of 17 attributes: four for aroma, two for taste, eight for texture and three for persistence (Table 3). We used the term 'odour' to refer to orthonasal olfactory perception and 'aroma' to refer to retronasal olfactory perception when eating. Persistence was evaluated after swallowing.

One product was systematically replicated during a profile session, conducting to 12 tested products (five non-flavoured model cheeses and one non-flavoured doubled product, five flavoured model cheeses and one doubled flavoured model cheese). To limit the boredom of subjects, only six non-flavoured products were tested in one session, and three flavoured products in one session, leading to a total of six sessions. The samples were presented in a monadic way and were distributed using a Latin Square design for each subject. Within a session, the subjects were asked to use one sample to score odour (overall intensity) and texture (by touch), and one sample to evaluate texture in the mouth, aroma and taste.

Table 2
Physicochemical properties of aroma compound used to flavour model cheeses and final concentrations.

Aroma compound	Formula	Molecular weight ($g.mol^{-1}$)	Concentration in mg/kg in model cheese	log$P$[a]	Sensory aroma attribute	$K_{gas/water}$ (25 °C)[a]
Diacetyl	$C_4H_6O_2$	86	130	−1.34	Butter	$0.072 * 10^{-2}$
Ethyl hexanoate	$C_8H_{16}O_2$	144	9	2.83	Fruity, pineapple	$3.35 * 10^{-2}$
Heptan-2-one	$C_7H_{14}O$	114	6	1.98	Blue (cheese)	$0.57 * 10^{-2}$

[a] Log$P$ = Logarithm of the ratio of the compound concentration in octanol and in water calculated values (EPI, 2000, estimation Programs Interface V3,10: database).

Table 3
Definition of sensory attributes selected by trained panel for descriptive quantitative analysis.

Sensory properties	Attributes	Definitions and references
Texture with finger	F-Moist	Surface textural attribute which describes the perception of humidity at the surface of the model cheese
	F-Shiny	Attribute describing a glossy surface showing bright reflection
	F-Springy	Mechanical textural attribute related to: (i) the rapidity of shape recovery after the application of a deforming force, (ii) the degree to which a deformed material returns to its undeformed condition after the deforming force is removed
	F-Firm	Mechanical textural attribute related to the penetration force required to achieve a given deformation
Taste	T-Salty	Basic taste produced by aqueous solutions of sodium chloride
	T-Sweet	Basic taste produced by aqueous solutions of sweet substances such as sucrose
Texture in-mouth	M-Crumbly	Attribute describing the extent to which the cheese structure breaks up in the mouth
	M-Firm	Mechanical textural attribute related to the force required to achieve a given deformation of the model cheese by teeth penetration
	M-Fragmentable	Attribute describing the ability of the model cheese to break down to smaller versions of itself
	M-Sticky	Mechanical textural attribute related to the force required to remove materials that adhere on oral mucosa and teeth
Odour	Overall odour intensity	Overall odour intensity of model cheese (orthonasal stimulation)
Aroma	A-Overall aroma intensity	Overall aroma intensity of model cheese (retronasal stimulation)
	A-Blue	Aroma attribute related to the perception of heptan-2-one during mastication
	A-Butter	Aroma attribute related to the perception of diacetyl during mastication
Persistence	P-Blue	Aroma attribute related to the perception of heptan-2-one after swallowing
	P-Butter	Aroma attribute related to the perception of diacetyl after swallowing
	P-Salty	Salty perception after swallowing

2.3. Texture analysis

The evaluation of textural properties of the model cheese was carried out by Texture Profile Analysis (TPA) on a TA-XT2 texture analyser (Stable Micro Systems Ltd., Godalming, UK) equipped with a 10-mm-diameter cylindrical probe made of ebonite. After storage at 4 °C, slice samples of model cheeses were equilibrated at room temperature (20 ± 2 °C) for 30 min before measurements were made. A double-bite compression cycle was carried out, with a rest period of 0.09 s between bites. Samples were compressed at a distance of 5 mm with a test speed of 2 mm/s during the first bite and at a distance of 5 mm with a test speed of 2 mm/s during the second one (Fig. 1). Model cheeses were characterised in terms of firmness, adhesiveness, cohesiveness, springiness and gumminess (parameters defined in Table 4). These parameters were defined according to the study of Szczesniak (1963) and Pons and Fiszman (1996). Three replicates for each product were performed. The study of TPA parameters shows a low variation of results (5% variation).

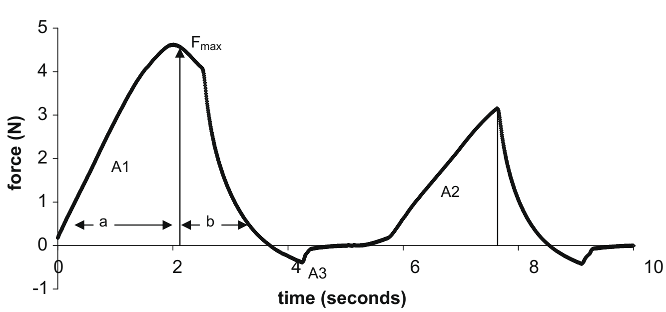

Fig. 1. Schematic representation of the texture profile (time-evolution of the force) obtained during a two-bite compression test. with Firmness = Fmax (N), Adhesiveness = A3 (N.mm), Cohesiveness = A2/A1 (dimensionless), Springiness = b/a (dimensionless), Gumminess = Fmax * A2/A1 (N).

2.4. Aroma release analysis

The analysis of the aroma compound release in the vapour phase above the model cheeses was performed by SPME (solid-phase microextraction) with a gas chromatograph equipped with a flame-ionisation detector (GC-FID HP6890, Germany) and an automatic headspace sampler (CombiPal, CTC Analytics, Switzerland). Glass vials (22.4 mL, Chromacol, France) were filled with 5 g/vial of product. After an overnight storage period at 13 °C, they were placed in the headspace sample tray and thermostated at 13 °C. This temperature was chosen with regard to the temperature of products for sensory analysis. Vials were then stirred for 10 min at 13 °C to allow the contact between the headspace and the SPME fibre (polydimethylsiloxane (PDMS) with a 100 µm-thick film). Aroma compounds were then desorbed by inserting the fibre into the injector set heated at 250 °C for 1 min. Aroma compounds were separated in an HP-INNOWax polyethylene glycol semi-capillary column (30 m × 0.53 mm, with a 1 µm-thick film) before being detected with the flame-ionisation detector. The carrier gas was helium at a flow rate of 8.4 mL/min. For the FID detector, N_2 and air flow rates were 20 and 450 mL/min, respectively. The oven programme was 10 min long, starting at 40 °C, 5 °C/min up to 60 °C, and 10 °C/min up to 120 °C. Results obtained from the SPME method were expressed as area units. Each headspace analysis was done in triplicate. This method made it possible to control the flavouring step in sample preparation. Moreover, this SPME method shows a low variation of results (1–8% variation).

Table 4
Significant effect of salt content, fat content and dry matter content and interactions by ANOVA with associated probabilities on averaged values of TPA parameters.

		Firmness (Fmax)			Adhesiveness (A3)			Cohesiveness (A2/A1)			Springiness (b/a)			Gumminess (F * A2/A1)		
	Variation	*P* value	Mean	1	*P* value	Mean	1	*P* value	Mean	1	*P* value	Mean	1	*P* value	Mean	1
Dry matter [a]	370	**<.0001**	2.82	b	0.257	0.14		**0.0015**	0.45	b	0.055	0.79		**<.0001**	1.29	b
	440		6.13	a		0.09			0.54	a		0.69			3.35	a
Fat (at 0.5% NaCl)[b]	20	**<.0001**	5.3	a	**0.0172**	0.07	b	**0.0005**	0.53	a	**0.0211**	0.69	b	**<.0001**	2.83	a
	40		2.82	b		0.14	a		0.45	b		0.79	a		1.29	b
Fat (at 1.5% NaCl) [c]	20	**<.0001**	3.82	a	0.167	0.31		0.597	0.44		**0.002**	0.74	b	**<.0001**	1.68	a
	40		2.53	b		0.45			0.43			0.89	a		1.11	b
Salt (at 20% Fat)[d]	0.5	**<.0001**	5.3	a	**0.0004**	0.07	b	**<.0001**	0.53	a	0.107	0.69		**<.0001**	2.83	a
	1.5		3.8	b		0.31	a		0.44	b		0.74			1.68	b
Salt (at 40% Fat)[e]	0.5	0.132	2.8		**0.001**	0.14	b	0.065	0.45		**0.035**	0.79	b	0.065	1.29	
	1.5		2.5			0.45	a		0.43			0.89	a		1.11	

1 – Labels a, b, c indicate means that significantly differ at $P < 0.05$ (SNK test).
Bold characters indicate a significant *P* value.
[a] Between (370-40-0.5) and (440-40-0.5).
[b] Between (370-40-0.5) and (370-20-0.5).
[c] Between (370-40-1.5) and (370-20-1.5).
[d] Between (370-20-1.5) and (370-20-0.5).
[e] Between (370-40-1.5) and (370-40-0.5).

2.5. Data analysis

All data analyses were performed using the SAS software package, version 9.1 (SAS® User's Guide: Statistics 1990). Panel performance was monitored and assessed by: (i) its intersession repeatability and its homogeneity based on the repetition and product * repetition effects of the two-way analysis of variance (product, random subject) with interaction of the general linear model procedure of the SAS programme, and (ii) its intrasession repeatability measured by a Student's *t*-test between the two replicated samples of one product in the profile. The level of significance was established at $P < 0.05$. Product effect (salt, fat and dry matter contents) was assessed by the two-way analysis of variance (ANOVA). When the product effect was significant ($P < 0.05$), revealing a significant difference between the five products, a Student-Newman-Keuls (SNK) multiple comparison test was performed to compare the product mean intensities.

The effect of flavouring on texture and taste attributes was analysed by ANOVA (product, subject, flavouring and product * flavouring) on the five products. The level of significance was established at $P < 0.05$. When the interaction was significant, a *t*-test was performed for each product.

The percentage of variation (x) between the average intensity at the lowest level of each factor (Int.x) and the average intensity at the highest level of each factor (Int.y) was calculated according to the following formula: $x(\%) = \left(\frac{\text{Int}.x - \text{Int}.y}{\text{Int}.y}\right) * 100$.

The effects of composition on texture parameters and aroma release were analysed using a one-way ANOVA of the general linear model procedure of the SAS programme. The level of significance was established at $P < 0.05$. When significant differences were observed, mean intensities were compared using SNK.

The linear relationship between sensory and instrumental texture parameters was investigated by calculating the correlation coefficients (r) between attributes after averaging the scores over subjects and replications.

3. Results

After analysis of panel performance, the results of the evaluation of the influence of the studied parameters on sensory properties and on physicochemical properties are presented. All these results are then discussed in the last part in order to determine the respective role of physicochemical and sensory interactions induced by salt reduction and other parameters at the origin of perception.

3.1. Panel performance

Intersession repeatability evaluated on repetition effect between the session by ANOVA was performed on flavoured model cheeses. Among the 17 attributes, a significant repeatability effect was only observed for two attributes: F-moist and F-shiny. This illustrated a difference of notation of products between two sessions, which could be explained by the presentation of samples in Petri dishes (contact between the model cheese and the dish cap that could modify the surface aspect of the product). On the basis of these results, data concerning these two sensory descriptors (F-moist and F-shiny) were not considered. Concerning product * repeatability interaction, panel performance was constant, regardless of the evaluated attribute.

Intrasession repeatability was performed on the two replicated samples of 370-20-0.5 in the profile. *T*-test results showed that subjects similarly evaluated all the attributes, except crumbly in the mouth. Subjects were therefore globally homogeneous and repeatable in their notation.

3.2. Effects of product composition on sensory properties

3.2.1. Influence of salt content

Model cheeses with different NaCl contents showed obvious differences in terms of texture, but more subtle differences in terms of olfactory properties (Fig. 2a). Model cheeses with the highest salt content (1.5%-salt) were significantly perceived as being less springy and less firm to the touch than model cheeses with the lowest salt content (0.5%-salt). For in-mouth evaluation, model cheeses with the highest salt content (1.5%-salt) were the stickiest, the least crumbly, the least firm and the least fragmentable. However, springy and sticky differences induced by salt variation were significantly observed only for model cheeses with a low fat content. In addition, for 20%-fat model cheese, overall odour in 0.5%-salt model cheese was perceived as being significantly less intense than in 1.5%-salt model cheese, contrary to "butter" aroma and "butter" persistence, which were evaluated as being more intense in 0.5%-salt model cheeses than in 1.5%-salt model cheeses. Model cheeses with high-salt content presented the highest salty perception in the mouth and in persistence, as expected. Variations in sensory properties when salt content was modified were quite high, from 33% to 144% variation (mean of 76%). In general, a less significant effect of salt content was observed for 40%-fat model cheese than for 20%-fat model cheese.

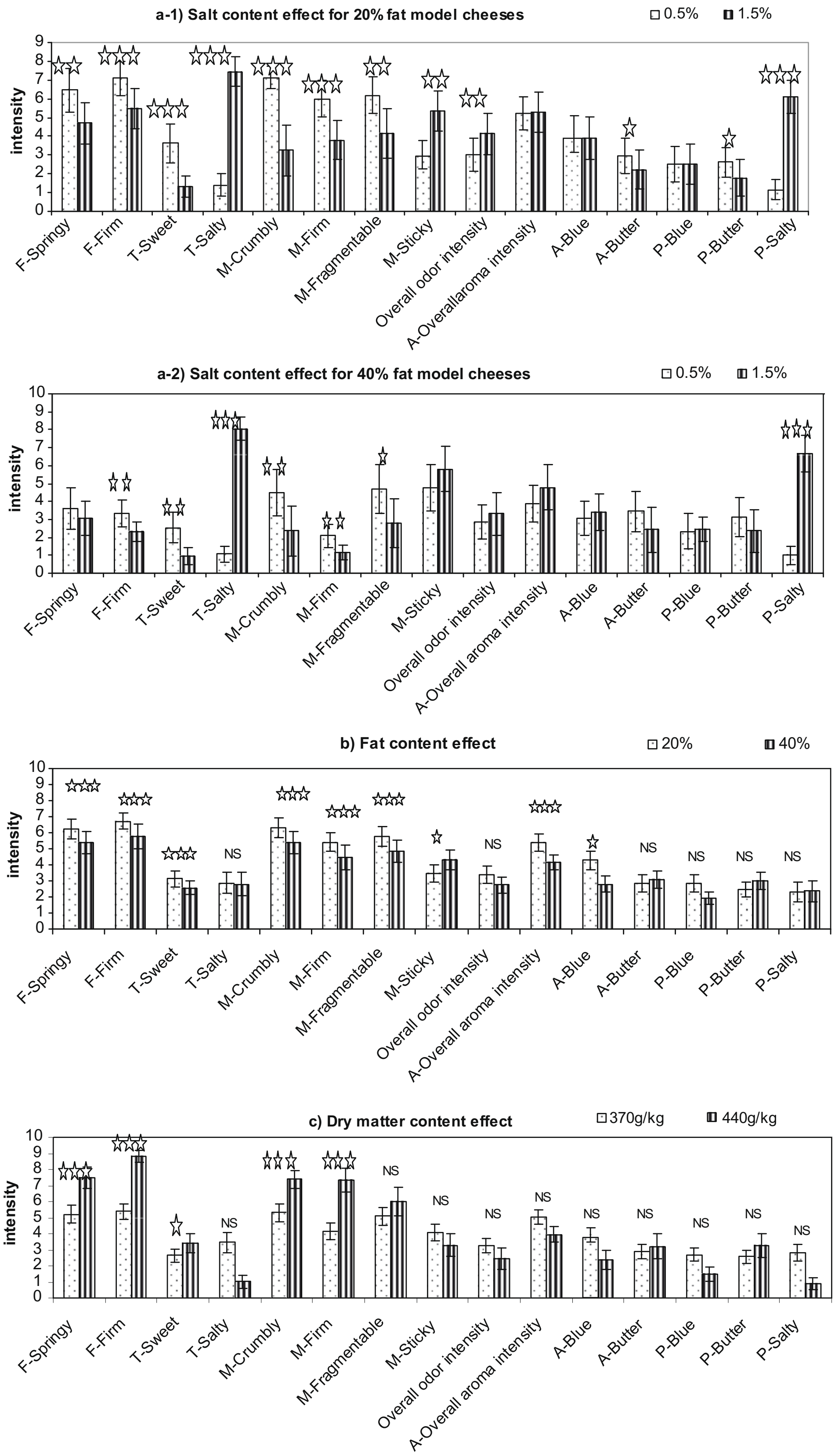

Fig. 2. Effect of salt content, fat content and dry matter content on the average perceived intensities of sensory attributes of the model cheeses. Means across subjects and repetitions are represented with standard deviation. The number of stars indicate the level of significancy: means significantly different at $P < 0.05$ (1 asterix), at $P < 0.01$ (2 asterixs) and $P < 0.001$ (3 asterixs) or not significantly different (NS). (a-1) salt content effect for 20%-fat model cheeses, (a-2) salt content effect for 40%-fat model cheeses, (b) fat content effect, (c) dry matter content effect.

3.2.2. Influence of fat content

According to ANOVA (Fig. 2b), the fat level significantly discriminated model cheeses on the basis of nine attributes characterising texture, taste and olfactory perception. Low-fat level model cheeses (20%-fat) were visually judged to be springier and firmer than high-fat level model cheeses (40%-fat). In the mouth, the 20%-fat model cheeses appeared to be sweeter, more crumbly, firmer, more fragmentable and less sticky than the 40%-fat model cheeses. Concerning the olfactory properties, overall aroma and "blue" aroma intensities were perceived as being more intense in 20%-fat model cheeses than in 40%-fat model cheeses. However, "butter" odour and "butter" persistence were not significantly modified by the fat content. We can observe that these variations remained quite low, ranging between 16% and 22% with a mean of 19%.

3.2.3. Influence of dry matter

Model cheeses differing in their dry matter level presented obvious differences in their texture properties (Fig. 2c). Model cheeses with 370 g/kg of dry matter were significantly perceived as being visually less springy and less firm than model cheeses with 440 g/kg of dry matter. In the mouth, model cheeses were perceived as being sweeter, more crumbly and firmer for high dry matter content than for low-dry matter content. For significant attributes, sensory property intensities varied from 17% to 79% with a mean of 49%. However, aroma perceptions were not significantly modified by dry matter content.

3.2.4. Influence of flavouring

The effect of flavour addition was assessed by ANOVA on the six attributes concerning texture in the mouth and taste perceptions. No significant taste difference was observed among the five flavoured and non-flavoured model cheeses. Thickness perception was twice as high for the flavoured 370-20-0.5 model cheese. Concerning the other matrices, no effect of flavouring was observed (Fig. 3).

3.3. Effects of composition on physicochemical properties

3.3.1. Effect on TPA parameters

The mean values of the TPA parameters obtained for the different levels of the manufacturing parameters analysed by product are summarised in Table 4.

According to ANOVA, the salt level significantly discriminated the model cheeses on the basis of texture parameters. High-salt model cheeses presented greater adhesiveness and springiness but less firmness, cohesiveness and gumminess than low-salt level model cheeses.

A similar trend was observed for model cheeses with high-fat content compared to the ones with low fat content. A significant interaction between fat and salt was observed on firmness, cohesiveness and springiness parameters. The cohesiveness parameter was only significantly affected by fat content at low-salt levels and not at high-salt levels. At high-fat content (40%), more TPA parameters (firmness, adhesiveness, cohesiveness, springiness and gumminess) discriminated the products according to salt content than at low fat content (20%) (adhesiveness and gumminess).

Concerning the dry matter effect, firmness, cohesiveness and gumminess values significantly increased when dry matter content increased in model cheeses.

3.3.2. Effect on aroma volatility

The release of the three aroma compounds discriminated the model cheeses by ANOVA ($P < 0.05$) (Table 5).

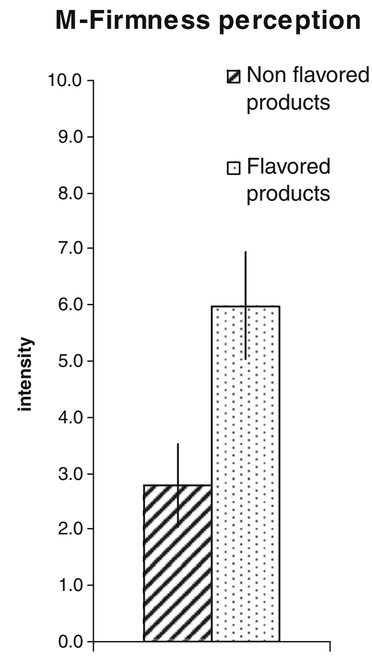

Fig. 3. Sensory intensity of M-firmness attribute perceived by the subjects for the flavoured and unflavoured model cheeses with the same composition (370-20-0.5). Means with standard deviations (ANOVA).

Concerning the effect of salt content, differences in aroma release were only observed at low-fat levels for the three aroma compounds. In this case, 2-heptanone and ethyl hexanoate were more highly released from 1.5%-salt matrices than from 0.5%-salt matrices, contrary to diacetyl, which was more highly released from 0.5%-salt matrices than from 1.5%-salt matrices.

Fat content influenced the release of the three aroma compounds, depending on their physicochemical properties: the release of the most hydrophobic molecules (2-heptanone and ethyl hexanoate) was higher in low-fat model cheeses than in high-fat model cheeses. This effect was more pronounced for model cheeses with 0.5% NaCl than for the ones with 1.5% NaCl. On the contrary, the most hydrophilic molecule (diacetyl) had a higher volatility in high-fat products than in low-fat products.

Dry matter content did not significantly affect aroma compound volatility.

4. Discussion

The perception of sensory properties of a food product results from the integration of physicochemical and sensory signals by consumers. In order to address the challenge related to salt decrease in model cheeses, it seems necessary to identify and quantify the respective roles of sensory interactions (sensory levers) and composition (formulation levers) induced during the perception process.

4.1. Physicochemical interactions at the origin of perception

Salt has been shown to have a high impact on the perception and the physicochemical characteristics of model cheeses. In the present study, the decrease in cohesiveness when salt content increased was in agreement with other studies (Cervantes, Lund, & Norman, 1983; Mistry & Kasperson, 1998; Pastorino, Hansen, & McMahon, 2003). This decrease in cohesiveness could be due to a decrease in protein–protein interactions. An increase in salt leads to an increase in protein–water interactions and, therefore, to a de-

Table 5
Significant effect of salt content, fat content and dry matter content and interactions by ANOVA with associated probabilities on averaged peak area by SPME.

	Variation	Heptan-2-one			Diacetyl			Ethyl hexanoate		
		P value	Mean peak area	1	*P* value	Mean peak area	1	*P* value	Mean peak area	1
Dry matter [a]	370	0.56	248		0.78	14.8		0.5	277	
	440		231			14.45			264	
Fat (at 0.5% NaCl)[b]	20	**<.0001**	480.5	a	**0.0006**	10.7	b	**<.0001**	609.9	a
	40		248.8	b		14.8	a		277	b
Fat (at 1.5% NaCl) [c]	20	0.064	390.9		**0.0049**	9.1	b	**0.0009**	518.4	a
	40		312.1			17.4	a		332.9	b
Salt (at 20% Fat)[d]	0.5	**0.0464**	507.5	b	**0.0053**	12.8	a	**0.0363**	632.2	b
	1.5		564.6	a		10.1	b		670.7	a
Salt (at 40% Fat)[e]	0.5	0.08	248		0.18	14.8		0.1	277	
	1.5		312			17.4			332	

1 – Labels a, b, c indicate means that significantly differ at $P < 0.05$ (SNK test).
Bold characters indicate a significant *P* value.
[a] Between (370-40-0.5) and (440-40-0.5).
[b] Between (370-40-0.5) and (370-20-0.5).
[c] Between (370-40-1.5) and (370-20-1.5).
[d] Between (370-20-1.5) and (370-20-0.5).
[e] Between (370-40-1.5) and (370-40-0.5).

crease in protein–protein interactions. However, contrary to these studies, we observed a decrease in model cheese firmness with the increase in salt concentration. This decrease could be due to coagulation time during the preparation of the matrices. This coagulation time increases with salt addition, especially beyond a salt content of 100 mM (0.5%) (Gaucheron & Famelart, 2004). This increase is explained by the inhibitory effect of NaCl on chymosin activity responsible for casein hydrolyse and milk coagulation (van Hooydonk, Hagedoorn, & Boeriigter, 1986). Since the duration of the coagulation step was the same for all of the model matrices, a high-salt content may be responsible for a reduction of coagulation efficiency, leading to a decrease in cheese firmness. An increase in salt content can also reduce the firming-up kinetics leading to less firm gels.

Concerning the effect of salt on aroma release and perception, high-salt model cheeses were perceived as being more intense in overall odour than low-salt model cheeses, and this result was only observed for 20%-fat matrices. The 1% increase of sodium chloride content (from 0.5% to 1.5%) increased the headspace concentration of 2-heptanone and ethyl hexanoate from 6% to 10%. This result was in agreement with the odour perception and can be explained by a salting out effect of hydrophobic aroma compounds due to sodium chloride. This headspace enrichment in volatile compounds resulting from salt addition has already been reported in the literature for aqueous solutions (Guichard, 2002) and for dry-cured meat products (Flores, Gianelli, Perez-Juan, & Toldra, 2006; Perez-Juan et al., 2007) and seems to be dependent on the physicochemical properties of the studied compounds. This dependence could explain the results concerning diacetyl release and its perception. In fact, in 20%-fat model cheeses, the highest intensity of "butter" note for low-salt matrices was confirmed by diacetyl release. The decrease in diacetyl release when salt content increases could be attributed to an increased number of caseins available for protein–diacetyl interactions since salt increase leads to the decrease of protein–protein interactions. Concerning 40%-fat matrices, no influence of salt content was observed for the three molecules released. This could be explained, on the one hand, by the high affinities between ethyl hexanoate and 2-heptanone for fat (hydrophobic interactions), which prevail on the salting out effect and, on the other hand, by a lack of proteins to bind the diacetyl due to reduced protein content. Contrary to overall odour perception, no impact of salt level on overall aroma perception in the mouth was observed. The 1% increase in salt content induced small variations of flavour release (from 6% to 20%). Such small variations are certainly lower than the differential olfactory threshold in these complex products and, thus, could be not perceived by panellists. The subjects could therefore not significantly discriminate these products on the basis of overall aroma and "blue" aroma perceptions.

Salt content differences consequently induced large differences in rheological properties and texture perception of model cheeses and small differences in aroma release and olfactory perception, in particular for matrices with low fat content. This result could be explained by eventual differences in mastication conditions induced by the firmness of matrices. These differences could induce some differences in aroma and salt release at the origin of sensory stimuli.

Fat content is one of the main influential experimental parameters in this study since a majority of sensory and physicochemical characteristics were significantly modified by this parameter. Concerning texture properties, low-fat samples were perceived as being springier, firmer, more crumbly, more fragmentable and less sticky than high-fat samples. These modifications of texture properties could be explained by changes in functional properties of matrices, presumably due to the loss of the plasticising action of fat and increased cross-linking within the curd (Gunasekaran Sundaram, 2002). Fat breaks up the protein matrix and plays the role of a lubricant to provide smoothness, typically found in full-fat cheese. In reduced-fat cheeses, there are fewer fat globules available to break up the protein matrix, which results in a denser structural matrix and leads to firm and dry cheese (Madadlou, Khosroshahi, & Mousavi, 2005; Mistry & Anderson 1993).

In the present study, low-fat samples were perceived as being the most intense in overall aroma and in "blue" aroma. Moreover, the release of 2-heptanone, a volatile compound responsible for "blue" aroma, was higher in 20%-fat products than in 40%-fat products. Hydrophobic interactions that occurred between 2-heptanone and matrices with different fat levels could explain the variation in "blue" perception. On the contrary, diacetyl release was enhanced with fat increase. This could be explained by the hydrophilic nature of diacetyl. However, fat content did not significantly influence butter perception and butter persistence. These results are concomitant with the work of de Roos (de Roos, 1997). In conclusion, fat reduction induced major changes in physical properties and flavour, in agreement with sensory properties.

The influence of dry matter content is directly linked to the moisture content. The high dry matter model cheeses were perceived as being firmer and more crumbly than the low-dry matter model cheeses, which was in agreement with the work of Everard et al. (2006). In their study, they showed that an increase in moisture content, e.g., lowering the dry matter, significantly decreased firmness and fragmentable perception. Their results were confirmed by TPA data and were attributed to a looser matrix that allowed more structural movements. We can also note in the present study that the high dry matter model cheeses were perceived as being sweeter than those with a lower dry matter content. This could be explained by the amount of lactose available in the matrix (222 and 264 g/L of lactose for low-dry matter and high dry matter model cheeses, respectively). Since the model cheeses were not inoculated with lactic starters, this molecule was not consumed, and the panellists' perception threshold was therefore capable of perceiving the sensory differences between these two levels of lactose.

Dry matter is also known to influence aroma release. Several authors studied the influence of whey protein or casein content on aroma perception and release (Guichard, 2002; Hansen & Heinis, 1992; Reiners, Nicklaus, & Guichard, 2000) and they all agreed that an increase in milk proteins leads to a decrease in aroma release and perception. This effect is due to specific interactions between proteins and aroma compounds. Contrary to these studies, no difference in aroma release or in sensory perception was observed in this study. With regard to the high amount of proteins, it is possible that all the binding sites between proteins and aroma compounds are already unavailable.

Regardless of the factor studied, all the present results showed some high correlations between sensory and instrumental texture properties. These correlations have been widely investigated in the literature (Drake, Gerard, Truong, & Daubert, 1999), but presented some variations between authors. Firmness is the easiest parameter to be measured by instrumental and sensory analysis, probably because the human mouth and mechanical property-testing instruments are very good at measuring force (Foegeding & Drake, 2007). This could explain the high correlation ($r = 0.97$) between firmness perception and firmness TPA parameters in the present study.

4.2. Sensory interactions at the origin of perception

When eating, a multitude of sensations such as taste, aroma and texture, as well as temperature, sound and irritation are experienced. These sensations could interact at perceptual and at physical levels. The results of the present study showed the effect of olfactory perception on texture perception: the flavouring of model cheeses appeared to enhance thickness, whereas no effect on instrumental texture properties was observed between the products. A dumping effect could explain this increase of thickness intensity: in the mouth, flavoured products were perceived as being more complex by the panellists than non-flavoured products. A transfer of these complex sensations of flavoured products on the thickness texture scale may thus be induced. This cognitive interaction was not negligible and was responsible for approximately 50% of the increase in thickness intensity. We can however note that this sensory effect between olfactory and texture perceptions was only observed when model cheeses presented low-fat, low-salt and low-dry matter contents. This study led to the conclusion that sensory interactions could thus act as levers in the sensory process of model cheese perception only in the case of products formulated with low contents of fat, salt and dry matter.

5. Conclusion

This study is further evidence of the influence of composition (NaCl, fat and dry matter contents) on the sensory and physicochemical properties of complex dairy matrices. The first result is that salty perception was not influenced by the texture characteristics of model cheeses. The main effects that we observed were that fat played a major role in aroma release and olfactory perception, whereas NaCl played a preponderant role in texture perception as well as in the instrumental texture of products. Furthermore, salt reduction had an impact on aroma release, particularly for low-fat model cheeses, and olfactory perception modified texture perception but only for model cheeses with low-fat and low-dry matter contents. Variations in salt content and sensory interactions therefore seem to have a greater impact on products with low fat content than on those with high-fat content.

Thus, for the formulation of flavoured food products with reduced-fat and salt content, it will be necessary to take both physicochemical interactions between aroma compounds and matrices and sensory interactions into account.

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