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The salt and lipid composition of model cheeses modifies in-mouth flavour release and perception related to the free sodium ion content

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ABSTRACT

Reducing salt and lipid levels in foodstuffs without any effect on acceptability is a major challenge, particularly because of their interactions with other ingredients. This study used a multimodal approach to understand the effects of changes to the composition of model cheeses (20/28, 24/24, 28/20 lipid/protein ratios, 0% and 1% added NaCl) on sodium ion mobility (^{23}Na NMR), in-mouth sodium release and flavour perception. An increase in the salt content decreased cheese firmness and perceived hardness, and increased sodium ion mobility, *in vivo* sodium release and both saltiness and aroma perception. With the same amount of salt, a lower lipid/protein ratio increased the firmness of the cheeses, perceived hardness, and decreased sodium ion mobility, *in vivo* sodium release, saltiness and aroma perception. These findings suggest on one hand that it could be possible to increase saltiness perception by varying cheese composition, thus inducing differences in sodium ion mobility and in free sodium ion concentration, leading to differences in in-mouth sodium release and saltiness perception, and on the other hand that the reformulation of foods in line with health guidelines needs to take account of both salt content and the lipid/protein ratio.

1. Introduction

National, European and global regulatory bodies have all issued warnings that an excess intake of salt and lipids can lead to the onset of life-threatening pathologies. Sodium-rich diets have been widely demonstrated as promoting hypertension, which is a risk factor associated with cardiovascular diseases (Campbell, Correa-Rotter, Neal, & Cappuccio, 2011; Strazzullo, D'Elia, Kandala & Cappuccio, 2009). In order to reduce the risks of hypertension and the healthcare expenditure associated with it, many countries and health organisations have encouraged the food industry to lower salt levels in processed foods (WHO, 2007). Saturated fats are a precursor for cholesterol and their consumption is positively associated with serum cholesterol levels (Hunter, Zhang, & Kris-Etherton, 2010). Recently, dietary fat of animal origin was associated with an elevated risk of pancreatic cancer. In France, cheese is one of the principal sources of salt and lipid consumption. Cheeses contain appreciable quantities of sodium chloride, ranging from 0.5% in Emmental cheese to more than 3% in Roquefort cheese, although there is considerable variability; this salt is added during the cheese-making process, mainly to ensure preservation and drainage (Guinee & O'Kennedy, 2007). A reduction in salt content can affect not only saltiness perception but also other cheese properties, such as structure, texture and crusting, as the functionality of sodium chloride is multidimensional. Previous studies showed that saltiness perception was governed by the amount of sodium present in saliva, which varied not only as a function of the salt content but also as a function of cheese composition, and more precisely the lipid/dry matter ratio (Lawrence et al., 2012), suggesting either an effect of cheese microstructure on salt release or a fat/salt sensory interaction effect. It is therefore necessary to better understand the effects on reducing salt and lipid levels on cheese structure and then on flavour release and perception. In a previous paper, we observed that cheese composition and microstructure modified the mobility of sodium ions as measured by ^{23}Na NMR, as well as sodium release and partitioning between the food matrix and water phases (Boisard et al., 2013a). This study showed that ^{23}Na NMR was a good method to investigate sodium ion mobility in complex matrices such as model cheeses, and that this mobility was highly correlated with *in vitro* measurements of sodium release from the food matrix to the water phase. The next step is now to validate the hypothesis that sodium ion mobility can

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explain sensory perception. Only a few publications have studied the links between saltiness perception and the measurement of sodium (quantity, mobility) using ^{23}Na NMR. In particular, Na^+ binding measured with ^{23}Na NMR highlighted a reduction in the saltiness perception of xanthan and κ-carrageenan (ionic gums) by comparison with guar and locust bean (non-ionic gums), while ionic gums contained endogenous sodium (Rosett, Shirley, Schmidt, & Klein, 1994). These authors explained the reduction in perceived saltiness as resulting from the binding of sodium ions to negatively charged groups on the ionic gums. In a second study on soups containing the same types of gelling agents, no direct relationship was found between saltiness perception and the transversal relaxation time (T_2 value) determined by NMR (Rosett, Kendregan, Gao, Schmidt, & Klein, 1996). In smoked salmon containing restricted levels of salt, the saltiness perception of salmon was not correlated with the quantity of bound Na^+ ions but it was correlated with salt content ($r^2 = 0.70$) (Foucat, Donnat, Joffraud, Cardinal, & Renou, 2004). More recently, a more appropriate ^{23}Na NMR method for the quantification of bound and free sodium ions using a double-quantum filtering method (DQF) was applied to determining both the distribution and mobility of salt in bread, where sodium could be bound to gluten. They observed a lower concentration of bound sodium when encapsulated salt was used during baking, and they concluded that this could affect saltiness perception (Guodjonsdottir, Traoré, & Renou, 2013).

Moreover sodium chloride has also been found to act as a flavour enhancer. For example, an increase in the salt content of model cheeses enabled a higher intensity of overall aroma (Saint-Eve, Lauverjat, Magnan, Deleris, & Souchon, 2009).

In different dairy products, a reduction in lipid levels can affect not only fat perception but also salt release and perception (Lawrence et al., 2012), aroma release (Repoux et al., 2012) and aroma perception (Saint-Eve et al., 2009). It was found that the kinetics of aroma release were strongly dependent on both the amount of lipid and the hydrophobic nature of the aroma compound. In the context of strategies designed to reduce both salt and lipid contents, a clearer understanding of the effects on flavour (salt and aroma) release and perception is needed because the acceptability of foods by consumers is mainly due to sensory perception. As reductions in both salt and lipid levels seem to induce a decrease in aroma release and perception, a modification to the structure of a product may constitute an alternative means of limiting this decrease. The findings of these studies could then help to optimise product formulation from a sensory perspective so as to ensure the acceptance by consumers of cheeses with low salt/lipid contents.

Our aim was therefore to try and understand the effects of changes to salt and lipid contents on the ratio of bound/free sodium ions in well-characterised model cheeses, related to their mobility and availability for release in saliva during consumption and subsequent perception. The consequences regarding the overall perception of these model cheeses are then discussed.

2. Materials and methods

This study protocol was submitted to an ethics committee (RCB 2010-A00370-39) and was approved on 20 May 2010 by the Comité de Protection des Personnes Est-1 and on 10 June 2010 by Agence Française de Sécurité Sanitaire des Produits de Santé (AFSSAPS).

2.1. Model cheeses

The model cheeses were made using cheese technology processes described elsewhere (Boisard et al., 2013a). The ingredients used were: anhydrous milk fat (32 °C melting point; Cormans, Goe-Limbourg, Belgium), rennet casein (Eurial Poitouraine, Nantes, France), acid casein (BBA Lactalis, Retiers, France), melting salts (Kasomel 2185, Prayon, Europhos, Engis, Belgium), deionised water (MilliQ®, Bedford, MA) and sodium chloride (Sigma–Aldrich, Steinheim, Germany). The model cheeses were flavoured (1 g/kg) with a solution of six aroma compounds composed of 2.8 mg 2-3-butanedione, 3.5 mg ethyl butanoate, 6.3 mg ethyl hexanoate, 5.1 mg 2-heptanone, 5.1 mg 3-octanone, 5.4 mg 2-nonanone (Sigma–Aldrich), made up to 1 g with propylene glycol (Cooper, Melun, France). The model cheeses were then labelled according to their lipid/protein ratios (L/P (w/w): 28/20, 24/24 and 20/28) calculated from the dry matter contents of milk fat and caseins and their added salt contents (indicated with an 's' when 1 g/100 g salt was added). The total amount of sodium in the model cheeses without added NaCl mainly came from the melting salts (6.2 g per 1 kg model cheese) while only 0.51 g per kg came from caseins. Melting salts are blends of phosphates designed for the manufacture of processed cheese. The principal characteristics of the six model cheeses thus produced are shown in Table 1.

The sodium content, i.e. the concentration of total sodium, was determined by atomic absorption spectroscopy on ash residues treated with HCl (6 M), according to the standard method described by the International Dairy Federation (IDF) (FIL-27, 1964).

The texture of the six model cheeses was characterised by the uniaxial compression at constant speed of cylindrical samples

Table 1
Principal characteristics of model cheeses and ^{23}Na NMR data.

	Model cheeses[B]					
	L28P20	L28P20s	L24P24	L24P24s	L20P28	L20P28s
L/P ratio[A]	28/20	28/20	24/24	24/24	20/28	20/28
$[Na]_{total}$(g/100 g)	0.67 ± 0.02^{b}	1.06 ± 0.05^{a}	0.66 ± 0.01^{b}	1.06 ± 0.04^{a}	0.67 ± 0.01^{b}	1.06 ± 0.02^{a}
pH	6.75 ± 0.01^{b}	6.68 ± 0.04^{b}	6.85 ± 0.01^{a}	6.70 ± 0.04^{b}	6.85 ± 0.03^{a}	6.73 ± 0.01^{b}
Dry matter	53.0 ± 0.6^{a}	52.7 ± 0.6^{a}	52.8 ± 0.4^{a}	53.1 ± 0.4^{a}	52.7 ± 0.6^{a}	53.0 ± 0.5^{a}
W (kJ/m^3)[C]	231 ± 5.1^{d}	122 ± 8.3^{e}	361 ± 21.8^{c}	319 ± 32.3^{c}	522 ± 37.8^{a}	462 ± 29.5^{b}
T_1 (ms)	10.64 ± 0.17^{b}	11.93 ± 0.18^{a}	9.41 ± 0.11^{d}	10.73 ± 0.20^{b}	8.49 ± 0.17^{e}	9.71 ± 0.04^{c}
T_{2F}^{DQF} (ms)	0.36 ± 0.11^{c}	0.44 ± 0.02^{a}	0.28 ± 0.01^{d}	0.40 ± 0.03^{b}	0.26 ± 0.02^{e}	0.34 ± 0.01^{c}
T_{2S}^{DQF} (ms)	9.47 ± 0.11^{d}	9.90 ± 0.06^{e}	8.45 ± 0.05^{b}	8.98 ± 0.16^{c}	7.53 ± 0.21^{a}	8.30 ± 0.08^{b}
τ_{opt}	1.21 ± 0.02^{c}	1.43 ± 0.05^{e}	0.99 ± 0.02^{b}	1.31 ± 0.07^{d}	0.90 ± 0.06^{a}	1.14 ± 0.04^{c}
$[Na]_{bound}/[Na]_{total}$ (%)	8.33 ± 0.96^{a}	9.19 ± 0.42^{ab}	9.27 ± 0.77^{ab}	8.74 ± 1.52^{ab}	10.99 ± 0.6^{b}	9.42 ± 1.32^{ab}
$[Na]_{free}$ (g/100 g)	0.614 ± 0.006^{b}	0.963 ± 0.004^{a}	0.608 ± 0.005^{b}	0.967 ± 0.016^{a}	0.596 ± 0.014^{c}	0.960 ± 0.014^{a}

The value are presented as mean ± standard deviation (SD) ($n = 3$), except for sodium content and pH ($n = 2$).
[a–e]Values in the same line with different subscript letters were significantly different ($p < 0.10$).
[A] *L/P* ratio corresponding to the lipid/protein ratio and calculated from the dry matter content of milk fat and caseins.
[B] s for formulations with added salt.
[C] W: work at maximal deformation.