Salt equivalence and temporal dominance of sensations of different sodium chloride substitutes in butter

Vanessa Rios de Souza*, Tassyana Vieira Marques Freire, Carla Gonçalves Saraiva, João de Deus Souza Carneiro, Ana Carla Marques Pinheiro and Cleiton Antônio Nunes

Department of Food Science, Federal University of Lavras, 37200-000, Lavras, MG, Brazil

Studies indicate a positive association between dietary salt intake and some diseases, which has promoted the tendency to reduce the sodium in foods. The objective of this study was to determine the equivalent amount of different sodium chloride replacements required to promote the same degree of ideal saltiness in butter and to study the sensory profile of sodium chloride and the substitutes using the analysis of Temporal Dominance of Sensations (TDS). Using the magnitude estimation method, it was determined that the potencies of potassium chloride, monosodium glutamate and potassium phosphate relative to the 1% sodium chloride in butter are 83·33, 31·59 and 33·32, respectively. Regarding the sensory profile of the tested salt substitutes, a bitter taste was perceived in the butter with potassium chloride, a sour taste was perceived in the butter with potassium phosphate and sweet and umami tastes were dominant in the butter with monosodium glutamate. Of all the salt substitutes tested calcium lactate, potassium lactate, calcium chloride and magnesium chloride were impractical to use in butter.

Keywords: TDS, potassium chloride, monosodium glutamate, potassium phosphate, butter.

Sodium chloride (NaCl) is one of the most important ingredients for many foods because of its low cost and several important properties (Albarracín et al. 2011). The salt plays an important role in food safety (Kremer et al. 2009) – as a direct consequence of reduced water activity – (Albarracín et al. 2011), in flavour enhancing (Rulikowska et al. 2012) – due the capacity to influence the enzymatic activity of some enzymes that are responsible for the development of different organoleptic parameters – (Albarracín et al. 2011) and it influences the nutritional value, composition and functionality of the foods (Guo et al. 2011).

Epidemiological studies indicate that the dietary salt intake has positive association with blood pressure and hypertension, been directly related to the development of cardiovascular disease (Dahl, 1972; Weinsier, 1976; Law 1997; SACN, 2003; WHO, 2003). For these reasons, there is great consumer demand for low-salt products (Katsiari et al. 2001; Matthews & Strong, 2005; Ruusunen & Puolanne, 2005; Guàrdia et al. 2006; Albarracín et al. 2011). According to Appel & Anderson (2010), 75% of dietary salt comes from processed foods, so the aim of the food

industry should be focused on the reduction of the salt content in these products.

According to Al-Otaibi & Wilbey (2006), 0·2 g sodium/day (approximately 0·5 g NaCl) is the minimum quantity required by a healthy adult, and according to World Health Organisation (WHO), the healthy limit is 5 g sodium chloride/day (approximately 2000 mg of sodium) (WHO, 2007). Research by the Brazilian Health Ministry (2011) noted that the Brazilians consume an average of 12 g sodium chloride/day (4800 mg NaCl/day). Because of concerns about excess sodium intake, the Health Ministry and the Brazilian food industry reached an agreement to reduce the sodium content of various categories of processed foods by 2016. The UK Food Standards Agency also revised its salt reduction targets for food processors, and Food and Drug Administration (FDA) are working with the US food industry to increase salt reduction in foods (Food and Drugs Administration Press Release, 2010).

The development of low-salt products can be possible using different sodium chloride substitutes, such as other chloride salts (e.g., KCl, $CaCl_2$ and $MgCl_2$) (Gou et al. 1996; Aliño et al. 2010), phosphates (Ruusunen & Poulanne, 2005), transglutaminase (Romero de Ávila et al. 2010) or flavour enhancers such as monosodium glutamate (Desmond, 2006).

*For correspondence; e-mail: vanessardsouza@gmail.com

For the salt substitutes to successfully replace sodium chloride in food formulations it is necessary to carry out initial studies to obtain knowledge regarding the appropriate concentration of sodium substitutes and their salt equivalence compared with sodium chloride. According to Souza et al. (2011) to obtain this information the most common method, widely used for sweeteners, is the estimation of the magnitude and a graphic representation of standardised results through the Law of Stevens, or the 'Power Function' (Stone & Oliver, 1969; Moskowitz, 1970).

The sodium chloride substitutes may have unpleasant taste (Cruz et al. 2011), thus it is also important to know sensory characteristics of sodium chloride replacements to determine the salt substitute or blend that has a sensory profile more similar to NaCl.

Temporal dominance of sensations (TDS), proposed by Pineau et al. (2003), is a recent methodology that provides the sequence of sensory attributes perceived over time. Tasters assess which sensation is dominant over time until the sensation ends or another appears as dominant (Labbe et al. 2009; Pineau et al. 2009). According to Albert et al. (2012), the sensory profile obtained by this technique can be related to acceptance.

The objective of this study was to determine the equivalent amount of different sodium chloride replacements (potassium chloride, monosodium glutamate, potassium phosphate, magnesium chloride, calcium chloride, calcium lactate and potassium lactate) required to promote the same degree of ideal saltiness in butter and to study the sensory profile of sodium chloride and the substitutes using Temporal Dominance of Sensations (TDS) analysis.

In commercial products the low or reduced sodium content of the products is achieved by reduction or partial replacement of sodium chloride by substitutes, in particular, potassium chloride. This study aimed to test different sodium chloride substitutes and to evaluate the possibility of reducing total sodium chloride in butter by these substitutes. Thus, this research provides novel scientific information to the dairy industry and research fields, to expand the knowledge of the salting potency and sensory characteristics of different sodium chloride replacement, often still not used, and also to provide information of the feasibility of the total replacement of sodium chloride in butter.

Materials and methods

Materials

The following is a list of materials used in the food preparations in this study: milk cream with 38% fat, potassium chloride – 99% (Vetec®), monosodium glutamate – 99% (Aji-no-moto®), potassium phosphate – 99% (CRQ®), magnesium chloride – 99% (Vetec®), calcium chloride – 99% (Doremus®, calcium lactate – 99% (Purac®), potassium lactate – 99% (Purac®) and sodium chloride – 99% (Vetecc®).

Preparation of butter

The cream with 38% fat, which was standardised with skim milk, was pasteurised at 80 °C for 20 min. It was then cooled and subjected to physical aging at 10 °C for 24 h, followed by churning for 50 min. The butter was washed with chilled drinking water at 2 to 4 °C, and the sodium chloride or a salt substitute was added to the butter. Immediately after the addition of the salt or salt substitute, the butter was whipped. Afterward, the butter was packaged in polypropylene plastic and stored at 4 °C until the time of analysis.

Sensory analysis

Equivalent salting. To reach the equivalent saltiness for the various salt replacements relative to the salt taste of sodium chloride in butter, sensory evaluations were conducted at various stages. The procedures followed in each stage was based on the work of Souza et al. (2011).

Selection of panellists. Were recruited 25 butter consumers who were interested in determining the equivalent salt of butter compared with sodium chloride and had available time and no restrictions as to the consumption of this product (Souza et al. 2011).

The sequential method proposed by Wald (Amerine et al. 1965) – where a number of tests triangular are applied – was used to select panellist with a good ability to discriminate samples (Meilgaard et al. 1999).

In the triangular tests two samples of butter were used with 1% significance difference, comparing the salty taste. The samples were: butter with 1·0% sodium chloride and butter with 1·25% sodium chloride.

From the defined parameters ($P = 0·30$, $p1 = 0·70$, $\alpha = 0·10$ and $\beta = 0·10$) the Wald graph was constructed and judges were selected or rejected according to the number of correct tests analysed in the triangular graph (Souza et al. 2011).

With 8 triangular tests, 12 judges were selected. The selected panellists were college students aged between 18 and 27 years and included 8 females and 4 males.

Training session. The panellists selected were trained to use magnitude scales according to Souza et al. (2011). In the training session the panellists received three samples of butter (0·5, 1 and 2% sodium chloride), and were asked to determine the potency of this samples with respect to a reference sample (butter with 1% sodium chloride). The ideal concentration of 1% sodium chloride was determined based on information regarding commercial butter and pretests.

Determination of the equivalent salt. The selected and trained panellists received a reference sample (with the optimal concentration of sodium chloride, 1%) with a *potency* designated by an saltiness value of 1, followed by

Table 1. The concentrations of sodium chloride and each sodium chloride substitute used to determine the equivalent saltiness in butter compared with 1% sodium chloride

Salts	Concentration (%)				
Sodium chloride	0·39	0·62	1·00	1·60	2·56
Potassium chloride	0·47	0·75	1·20	1·92	3·07
Monosodium glutamate	1·01	1·62	2·60	4·16	6·66
Potassium phosphate	1·17	1·87	3·00	4·80	7·68
Magnesium chloride	0·98	1·56	2·50	4·00	6·40
Calcium chloride	0·78	1·25	2·00	3·20	5·12
Calcium lactate	1·56	2·50	4·00	6·40	10·24
Potassium lactate	1·56	2·50	4·00	6·40	10·24

several butter samples that were coded and presented in a balanced manner (Macfie et al. 1989). Then, the panellists were asked to estimate the intensities of the salty taste of the butter samples compared with the reference.

To determine the equivalent saltiness of the sodium chloride substitutes relative to sodium chloride, the series of concentrations presented in Table 1 was used. The central concentrations of the sodium chloride substitutes were based on pretests. To calculate the other concentrations, a multiplication factor of 1·6 was used, following Cardoso et al. (2004) and Marcellini et al. (2005).

During the pretests, it was found that the calcium lactate and potassium lactate have very low salting power. The pretests found that the intermediate concentration (4%) was not sufficient to salt the butter, but we chose this concentration because the resulting highest concentration is exceptionally high (10·24%).

After appropriate treatment of the data, as described by Souza et al. (2011), the 'Power Function' for sodium chloride and each sodium chloride substitute were obtained. The power function ('Power Function') has the following characteristic:

$$S = aC^n \tag{1}$$

S: sensation perceived, *C*: concentration of the stimulus, *a*: antilog of the y-intercept of the linear function and *n*: slope of the linear function

Based on the power function of sodium chloride and each substitute and from the ideal concentration of sodium chloride in butter (1%), the equivalent concentration of each sodium chloride substitute was estimated, as described by Souza et al. (2011).

Determination of the potencies of the sodium chloride substitutes. The potency of each sodium chloride substitute was calculated by the ratio between the ideal concentration of sodium chloride (1%) and the equivalent concentration of the sodium chloride substitute in the butter (Souza et al. 2011).

Temporal dominance of sensations (TDS). We recruited ten participants from the panel of the salting equivalence test to participate in the TDS analysis. Two preliminary sessions

were conducted, as described by Albert et al. (2012). In the first session, the panellists were introduced to the notion of the temporality of sensations (TDS) and were introduced to the data acquisition program SensoMaker (Nunes & Pinheiro, 2012). In the second session, the panellists participated in a simulation of a TDS session with several samples of butter to answer any questions of the participants and so they could get used to the computer program and methodology. This session also defined the total duration time of the experiment to be 20 s, and the attributes selected by the panel were salty, bitter, sweet, umami, sour, spicy, astringent and off-taste.

Finally, the panel evaluated three replicates of each of the four samples of butter: the standard butter sample with sodium chloride (1%) and three samples of butter with sodium chloride substitutes (potassium chloride, monosodium glutamate and potassium phosphate) at the concentration that promoted the same degree of saltiness as sodium chloride, 1%.

The participants were requested to select the dominant taste over the time. To avoid possible misunderstandings, it was clearly explained that the dominant taste is the taste that is perceived with greater clarity and intensity among others. Then, the panellists were requested to put the sample of butter (around 5 g) in the mouth and immediately start the evaluation.

The samples were served one by one, and the assessors were asked to rinse their mouth with water between each sample. The presentation was made in monadic order (Macfie et al. 1989) in disposable white plastic cups coded with three-digit numbers.

The methodology of Pineau et al. (2009) was used in the software SensoMaker to compute the TDS curves. In brief, two lines are drawn in the TDS graphical display, the 'chance level' and the 'significance level'. The 'chance level' is the dominance rate that an attribute can obtain by chance and the 'significance level' is the minimum value this proportion should equal to be considered to be significantly (Pineau et al. 2009). It is calculated using the confidence interval of a binomial proportion based on a normal approximation, according Pineau et al. 2009 (2).

$$Ps = Po + 1 \cdot 645 \sqrt{\frac{Po(1-Po)}{n}} \tag{2}$$

Ps: lowest significant proportion value ($a = 0·05$) at any point in time for a TDS curve; *n*: number of subjects *replication.

Results

Equivalent saltiness

Of all the salt substitutes tested (potassium chloride, monosodium glutamate, potassium phosphate, magnesium chloride, calcium chloride, calcium lactate and potassium lactate), calcium lactate, potassium lactate, calcium chloride and magnesium chloride were impractical to use in butter. As expected, lactates (calcium lactate and potassium lactate)

Table 2. Antilog of the y-intercept (*a*), intercept on the ordinate (*n*), linear coefficient of determination (R^2) and power function (Power Function) of the results to determine the equivalent saltiness of sodium chloride, potassium chloride, monosodium glutamate and potassium phosphate relative to the 1% sodium chloride in butter. *S*: Salt sensation perceived

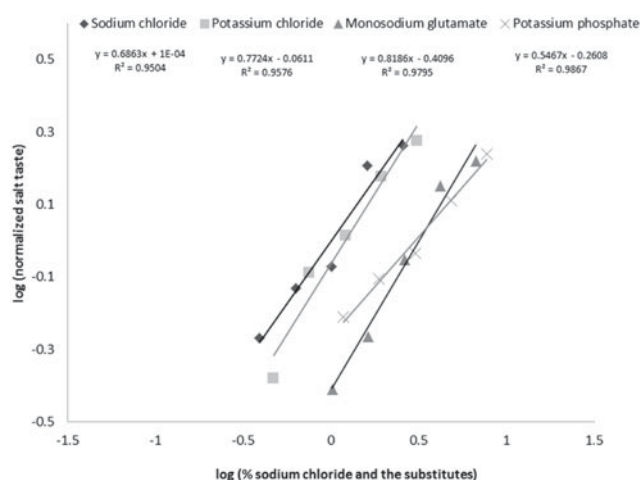| Salts	*A*	*n*	R^2	Power function
Sodium chloride	1·0002	0·6863	0·9504	$S = 1{\cdot}0002 C^{0{\cdot}6863}$
Potassium chloride	0·8688	0·7724	0·9576	$S = 0{\cdot}8688 C^{0{\cdot}7724}$
Monosodium glutamate	0·3894	0·8186	0·9795	$S = 0{\cdot}3894 C^{0{\cdot}8186}$
Potassium phosphate	0·5485	0·5467	0·9867	$S = 0{\cdot}5467 C^{0{\cdot}5467}$

Fig. 1. Linearised power function for butter salted with sodium chloride, potassium chloride, monosodium glutamate and potassium phosphate The x-axis shows the logarithm of the concentration of the sodium chloride and the substitutes (%), while the y-axis shows the logarithmic values of the estimated magnitudes, appropriately normalised.

Table 3. Equivalent concentrations and potencies of potassium chloride, monosodium glutamate and potassium phosphate relative to the 1% sodium chloride in butter

Salts	Concentration	Potency
Potassium chloride	1·2001	83·33
Monosodium glutamate	3·1659	31·59
Potassium phosphate	3·0010	33·32

rejection since they are characterised by bitter tastes, producing metallic, astringent and irritating sensations.

Thus, it was possible to determine the equivalence of salt with only the substitutes potassium chloride, monosodium glutamate and potassium phosphate. A linear regression of the points obtained for sodium chloride and its substitutes was then made, and a straight-line equation was obtained for each of the salts and their combinations (Fig. 1).

From the equations for sodium chloride and each sodium chloride substitute (Fig. 1), a simple power function was obtained (Table 2). From the power functions obtained for sodium chloride and each substitute, the equivalent amount of saltiness required to provide the same salty taste as 1% sodium chloride in butter was calculated; the potency was also calculated (Table 3).

Temporal dominance of sensations

Figures 2–5 show the TDS profiles for the four butters evaluated in the study. Each curve represents the change in the dominance rate of an attribute over time. The TDS analyses show that in the butter with sodium chloride (Fig. 2), the salty taste was the dominant taste throughout the measured time. In the butter with potassium chloride (Fig. 3), the salty taste and bitter taste are dominant, and salty was perceived with greater dominance rate than bitter up to approximately 8 s, but after that time, the bitter taste dominated.

In the butter with potassium phosphate (Fig. 4), a sour taste was significantly noticed beyond the salty taste. A bitter taste was also noted above the chance level, but it did not exceed the significance level. The salty taste was perceived with high dominance rate to an approximate time of 7 s. After that time, the sour taste dominated.

In the butter with monosodium glutamate (Fig. 5), the dominant tastes were salty and almost insignificantly sweet and umami tastes were perceived. A similar number of participants evaluated sweet and umami as dominant at
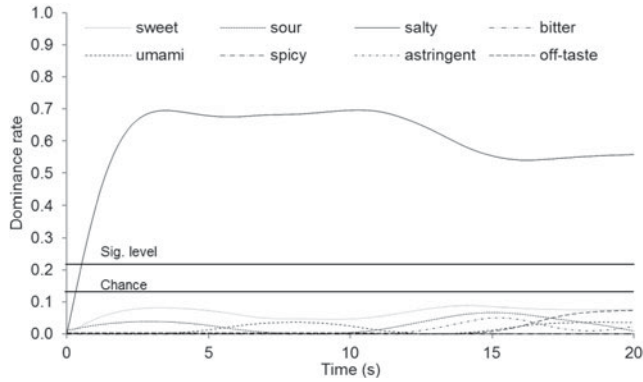
did not salt the products. As the scores of all of the panellists for all of the concentration levels used for these salts were below 1, the mean salty taste was less than the standard (butter with 1% sodium chloride). Therefore, for both lactates, concentrations of up to 10·24% (an extremely high concentration) in the butter were not sufficient to salt it.

Calcium chloride and magnesium chloride were infeasible due to an extreme undesirable taste that masked the possible perception of a salty taste. In addition to all of the panellists scoring these salts below 1 (salty taste less than the standard) at all concentrations used, as the concentration of these salts increased, the panellists further decreased the scores compared with the standard. According to these panellists, this occurred because the higher concentration of these salts resulted in more intense 'bitter', 'acid' and 'astringent' tastes, which makes the perception of salty taste even more difficult. The panellists classified the addition of these salts, even at lower levels, as 'unsuitable for consumption'. According to Grummer et al. (2012), $CaCl_2$ and $MgCl_2$ produced significant off-flavours (bitter, metallic, unclean and soapy) in cheese. According to Armenteros et al. (2012), divalent cations, may contribute to the sensory

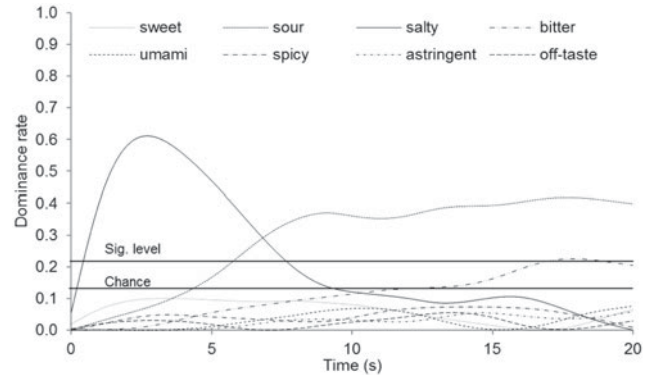**Fig. 2.** A graphical TDS representation for the butter with sodium chloride.

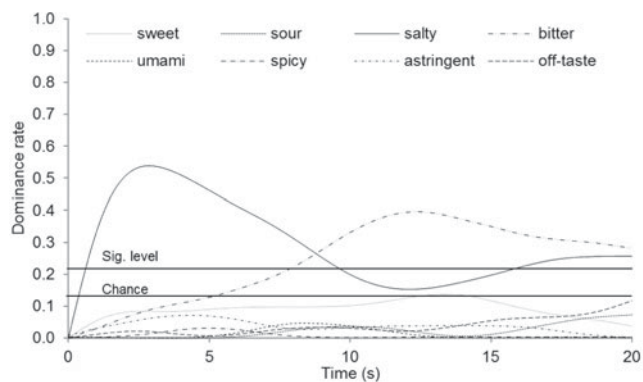**Fig. 4.** A graphical TDS representation for the butter with potassium phosphate.

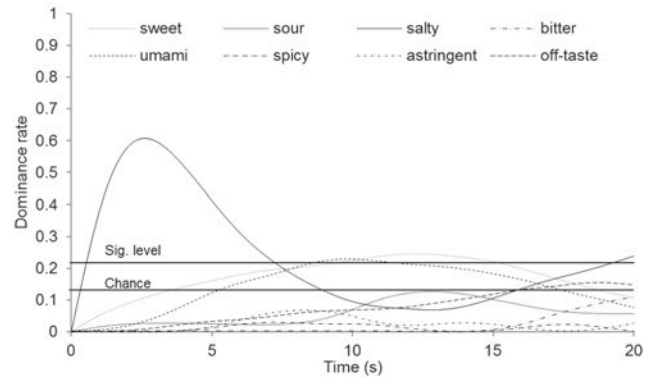**Fig. 3.** A graphical TDS representation for the butter with potassium chloride.

Fig. 5. A graphical TDS representation for the butter with monosodium glutamate.

the same time period. The salty taste dominated with high dominance rate until approximately 7 s. The sweet and umami tastes had low intensities between approximately 8 and 14 s.

The TDS curves also show that the butter with sodium chloride achieved a maximum dominance rate of 0·7 (the maximum of testers who selected saltiness as dominant was 70%) for saltiness, and the other sodium chloride substitutes reached a maximum saltiness dominance rate of 0·6. The duration and the maximum dominance rate of the salty taste was greater in the butter with sodium chloride than for the other substitutes.

Discussion

Equivalent saltiness

Comparing the sodium chloride substitutes (Fig. 1), it was observed that a higher concentration of monosodium glutamate and potassium phosphate was needed to reach the same salty taste sensation, and these two salt substitutes appear to have similar salting power. Sodium chloride and potassium chloride have a similar salting power, which means that a similar concentration of these salts produces the same sensation of salty taste.

The potassium chloride required a lower concentration and consequently had a high potency, but was the closest substitute to that of sodium chloride. The two other salts, monosodium glutamate and potassium phosphate, showed similar equivalent concentrations/power, but both salts were only capable of saltiness of approximately 65–70% lower than that of sodium chloride, i.e., to achieve the same level of saltiness as sodium chloride, it is necessary to use approximately three times the amount to achieve the same salty taste sensation.

The salty perception of sodium chloride is attributed to the cation (70–85%) and to the anion (30–15%) (Formaker & Hill, 1988; Mattes, 2001) and involves the passage of the ions through a narrow ionic channel. According to Mccaughy (2007), this passage through these channels is a specificity of the ions of sodium chloride, being difficult to find other substances with this capability, except toxic ions. Thus, the salting capacity depends on the type of cation/anion present in the substance (Ye et al. 1991, 1993). Compared with sodium chloride, other cations (potassium, magnesium and calcium) and other anions (phosphates and citrates) may have off taste and have less salty perception (Mooster, 1980).

According to Albarracín et al. (2011), the diffusion of larger ions through a narrow ionic channel is limited.

Therefore, salts with larger anions are less effective stimuli (Delwiche et al. 1999), so when the cation or anion of NaCl is substituted with a higher molecular weight compound, it results in a less intense salty taste (Guàrdia et al. 2006).

Temporal dominance of sensations

As already mentioned, the salty perception of NaCl is attributed either to the cation (70–85%) and the anion (30–15%) (Formaker & Hill 1988; Mattes 2001), and according to Albarracín et al. (2011), cations and anions have an effect on the taste properties of different types of salt. Compared with sodium chloride, other cations (potassium, magnesium and calcium) and other anions (phosphates and citrates) interfere in the taste, resulting in a perception of unpleasant taste, as sourness and residual metallic taste (Mooster, 1980). According to Horita et al. (2011), potassium chloride is widely used in low-sodium products but in high concentration produces a bitter and metallic taste, resulting in sensory rejection (Seman et al. 1980; Askar et al. 1994; Guàrdia et al. 2008; Armenteros et al. 2012).

In butter with monosodium glutamate, there were no undesirable tastes (bitter, sour or off-taste). In this salt, the predominant tastes were umami, sweet and salty. Considering the dominant profile sensations of the salts studied, glutamate appears to have the greatest potential for use as a substitute for sodium chloride. According to Brandsma (2006) the flavour enhancers – compounds that activate the receptors in the mouth and throat – may be of great interest to the food industry, because it can help in the reduction of the levels of sodium chloride. However, considering that the glutamate salty power (31·59) is well below the sodium chloride, the use of this sodium chloride substitute alone probably will not significantly reduce the level of sodium. In addition, the use of glutamate to specifically replace chloride sodium even if combination with other salt substitutes may not be relevant for consumers expecting only salty taste in butter and not sweet and umami tastes.

According to the results of TDS analysis, the total replacement of sodium chloride by potassium chloride, monosodium glutamate or by potassium phosphate in butter is not recommended, because these substitutes have undesirable tastes and/or low salty power in this product.

The sensory characteristics, functional properties and shelf life, are the characteristics most affected by reducing salt in foods (Guinee & O'Kennedy, 2007). In the development of products with sodium reduction, it is important to consider: the nature and the composition of the product, the type of processing and the conditions of manufacturing (Ruusunen & Puolanne, 2005). Although there are many salt substitutes in the market, according to Cruz et al. (2011) only sodium chloride is really recognised as a pure salty taste.

It is important to emphasise that recent studies have been able to develop products with reduced sodium and good acceptability, but in all cases, the partial substitution of sodium chloride was used and even the replacement of sodium chloride with different blends of sodium (Katsiari et al. 2001; Guinee & O'Kennedy, 2007; Reps et al. 2009; Horita et al. 2011; Ayyash et al. 2013, Gomes et al. 2011). In the present work, sodium chloride was completely replaced to obtain the salting power and the sensory characteristics of each particular sodium chloride substitute in butter. Thus, it would be extremely important to evaluate these salts in butter at different levels of substitution of sodium chloride and even in different combinations to mitigate/reduce unwanted tastes, especially bitter, sour and off-tastes.

References

Albarracín W, Sánchez IC, Grau R & Barat JM 2011 Salt in food processing; usage and reduction: a review. *International Journal of Food Science and Technology* **46** 1329–1336

Albert A, Salvador A, Schlich P & Fiszman S 2012 Comparison between temporal dominance of sensations (TDS) and key-attribute sensory profiling for evaluating solid food with contrasting textural layers: fish sticks. *Food Quality and Preference* **24** 111–118

Aliño M, Grau R, Toldrá F, Blesa E, Pagán MJ & Barat JM 2010 Physicochemical properties and microbiology of dry-cured loins obtained by partial sodium replacement with potassium, calcium and magnesium. *Meat Science* **85** 580–588

Al-Otaibi MM & Wilbey RA 2006 Effect of chymosin reduction and salt substitution on the properties of white salted cheese. *International Dairy Journal* **16** 903–909

Amerine MA, Pangborn RM, Roessler EB 1965 Principles of sensory evaluation of food. New York: Academic Press

Appel LJ & Anderson CAM 2010 Compelling evidence for public health action to reduce salt intake. *New England Journal of Medicine* **362** 650–652

Armenteros M, Aristoy MC, Barat JM & Toldrá F 2012 Biochemical and sensory changes in dry-cured ham salted with partial replacements of NaCl by other chloride salts. *Meat Science* **90** 361–367

Askar A, El-Samahy SK & Tawfik M 1994 Pasterna and beef bouillon. The effect of substituting KCl and K-lactate for sodium chloride. *Fleischwirtschaft* **73** 289–292

Ayyash MM, Sherkat F & Shah NP 2013 Effect of partial NaCl substitution with KCl on the texture profile, microstructure, and sensory properties of low-moisture mozzarella cheese. *Journal of Dairy Research* **80** 7–13

Brandsma I Reducing sodium 2006 A European perspective attitudes and regulations regarding sodium in foods pose challenges for the food industry. *Food Technology* **60** 24–29

Brazil 2011 Ministry of Health. www.saude.gov.br/

Cardoso JMP, Battochio JR & Cardello HMAB 2004 Equi-sweetness and sweetening power of sweetening agents in differents different temperatures of consumption of tea drink soluble in power. *Ciência e Tecnologia de Alimentos* **24** 448–452

Cruz AG, Faria JAf, Pollonio MAR, Bolini HMA, Celeghini RMS, Granato D & Shah N 2011 Cheeses with reduced sodium content: effects on functionality, public health benefits and sensory properties. *Trends in food Science and Technology* **22** 276–291

Dahl LK 1972 Salt and hypertension. *American Journal of Clinical Nutrition* **25** 231–244

Delwiche JF, Halpern BP & DeSimone JA 1999 Anion size of sodium salts and simple taste reaction times. *Physiology and Behavior* **66** 27–32

Desmond E 2006 Reducing salt: a challenge for the meat industry. *Meat Science* **74** 188–196

Food & Drugs Administration Press Release 2010 FDA issues statement on IOM sodium report. http://www.fda.gov/NewsEvents/Newsroom/PressAnnouncements/ucm209155.htm

Formaker BK & Hill DL 1988 An analysis of residual NaCl taste response after amiloride. *American Physiological Society* **255** 1002–1007

Gomes AG, Cruz AG, Cadena RS, Caleghini RMS, Faria JAF, Bolini HMA, Pollonio MAR & Granato D 2011 Manufacture of low-sodium Minas fresh cheese: Effect of the partial replacement of sodium chloride with potassium chloride. *Journal of Dairy Science* **94** 2701–2706

Gou P, Guerrero L, Gelabert J & Arnau J 1996 Potassium chloride, potassium lactate and glycine as sodium chloride substitutes in fermented sausages and in dry-cured pork loin. *Meat Science* **42** 37–48

Grummer J, Karalus M, Zhang K, Vickers Z & Schoenfuss TC 2012 Manufacture of reduced-sodium Cheddar-style cheese with mineral salt replacers. *Journal of Dairy Science* **95** 2830–3839

Guàrdia MD, Guerrero L, Gou P & Arnau J 2006 Consumer attitude towards sodium reduction in meat products and acceptability of fermented sausages with reduced sodium content. *Meat Science* **73** 484–490

Guàrdia MD, Guerrero L, Gelabert J, Gou P & Arnau J 2008 Sensory characterisation and consumer acceptability of small calibre fermented sausages with 50% substitution of NaCl by mixtures of KCl and potassium lactate. *Meat Science* **80** 1225–1230

Guinee TP & O'Kennedy BT 2007 Mechanisms of taste perception and physiological controls. In *Reducing Salt in Foods: Practical Strategies*, pp. 246–287 (Eds Guinee TP & O'Kennedy BT). Boca Raton, LA, USA: CRC Press

Guo L, Hekken DLV, Tomasula PM, Shieh J & Tunic MH 2011 Effect of salt on the chemical, functional, and rheological properties of Queso Fresco during storage. *International Dairy Journal* **21** 352–357

Horita CN, Morgano MA, Celeghini RMS & Pollonio MAR 2011 Physico-chemical and sensory properties of reduced-fat mortadella prepared with blends of calcium, magnesium and potassium chloride as partial substitutes for sodium chloride. *Meat Science* **89** 426–433

Katsiari MC, Alichannidis E, Voutsinas LP & Roussis IG 2001 Proteolysis in reduced sodium Kefalograviera cheese made by partial replacement of NaCl with KCl. *Food Chemistry* **73** 31–43

Kremer S, Mojet J & Shimojo R 2009 Salt reduction in foods using naturally brewed soy sauce. *Journal of Food Science* **74** S255–S262

Labbe D, Schlich P, Pineau N, Gilbert F & Martin N 2009 Temporal dominance of sensations and sensory profiling: a comparative study. *Food Quality and Preference* **20** 216–221

Law MR 1997 Epidemiologic evidence on salt and blood pressure. *American Journal of Hypertension* **10** 42S–45S

Macfie HJ, Bratchell N, Greenhoff K & Vallis LV 1989 Designs to balance the effect of order of presentation and first-order carry-over effects in hall tests. *Journal of Sensory Studies* **4** 129–148

Marcellini PS, Chainho TF & Bolini HMA 2005 Ideal sweetness and acceptance analysis of pineapple juice concentrate reconstituted sweetened with sucrose and different sweeteners. *Food Nutrition* **16** 177–182

Mattes RD 2001 The taste of fat elevates postprandial triacylglycerol. *Physiological Behavior* **74** 343–348

Matthews K & Strong M 2005 Salt – its role in meat products and the industry's action plan to reduce it British. *Nutrition Foundation Nutrition Bulletin* **30** 55–61

Mccaughy S 2007 Mechanisms of taste perception and physiological controls. In *Reducing Salt in Foods: Practical Strategies*, pp. 77–98 (Eds Guinee TP & O'Kennedy BT). Boca Raton, LA, USA: CRC Press

Meilgaard M, Civille GV & Carr BT 1999 *Sensory Evaluation Techniques*, p. 390, 3rd edition. Boca Raton: CRC

Mooster G 1980 Membrane transitions in taste receptor cell activation by sodium salts. In *Biological and Behavioural Aspects of Salt Intake*, pp. 275–287 (Eds Kare MR, Fregly MJ & Bernard RA). New York: Academic Press Inc

Moskowitz HR 1970 Ratio scales of sugar sweetness. *Perception and Psychophysics* **7** 315–320

Nunes CA & Pinheiro ACM 2012 SensoMaker, version 1.0. UFLA, Lavras, 2012

Pineau N, Cordelle S, Imbert A, Rogeaux M & Schlich P 2003 Dominance temporelle des sensations. Codage et analyse d'un nouveau type de données sensorielles. In *XXXVèmes Journées de Statistiques*, pp. 777–780 Lyon

Pineau N, Schlich P, Cordelle S, Mathonnière C, Issanchou S, Imbert A, Rogeaux M, Etiévant P & Koster E 2009 Temporal dominance of sensations: construction of the TDS curves and comparison with time-intensity. *Food Quality and Preference* **20** 450–455

Reps A, Wisniewska K & Kuzmicka M 2009 Possibilities of increasing the potassium content of cheese spread. *Milchwissenschaft* **64** 176–179

Romero de Ávila MD, Ordóñez JA, de la Hoza L, Herrero AM & Cambero MI 2010 Microbial transglutaminase for cold-set binding of unsalted/salted pork models and restructured dry ham. *Meat Science* **84** 747–754

Rulikowska A, Kilcawley KN, Doolan IA, Alonso-Gomez M, Nongonierma AB, Hannon JA & Wilkinson MG 2013 The impact of reduced sodium chloride content on Cheddar cheese quality. *International Dairy Journal*, **28** 45–55

Ruusunen M & Puolanne E 2005 Reducing sodium intake from meat products. *Meat Science* **70** 531–541

SACN 2003 Salt and health. *Scientific Advisory Committee on Nutrition*. Norwich, UK: The Stationary Office

Seman DL, Olson DG & Mandigo RW 1980 Effect of reduction and partial replacement of sodium on bologna characteristics and acceptability. *Journal of Food Science* **45** 1116–1121

Souza VR, Pinheiro ACM, Carneiro JDS, Pinto SM, Abreu LR & Menezes CC 2011 Analysis of various sweeteners in petit Suisse cheese: determination of the ideal and equivalent sweetness. *Journal of Sensory Studies* **26** 339–345

Stone H & Oliver SM 1969 Measurement of the relative sweetness of selected sweeteners and sweetener mixtures. *Journal of Food Science* **34** 215–222

Weinsier RL 1976 Overview: salt and the development of essential hypertension. *Preventive Medicine* **5** 7–14

WHO/FAO (World Health Organisation/Food and Agriculture Organisation) 2003 Diet, nutrition and the prevention of chronic diseases. WHO Technical Report Series 916. Geneva, World Health Organisation

[WHO]World Health Organisation. 2007 Reducing salt intake in populations. Report of a WHO Forum and Technical Meeting. Geneva: WHO Document Production Services

Ye Q, Heck GL & DeSimone JA 1991 The anion paradox in sodium taste reception: resolution by voltage-clamp studies. *Science* **254** 726–742

Ye Q, Heck GL & DeSimone JA 1993 Voltage dependence of the rat chorda tympani response to Na+ salts: implications for the functional organization of taste receptor cells. *Journal of Neurophysiology* **70** 167–178.