Utilization of temporal dominance of sensations and time intensity methodology for development of low-sodium Mozzarella cheese using a mixture of salts

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ABSTRACT

Evidence has linked excessive salt consumption to the development of chronic degenerative diseases. Therefore, special attention has been given to the consumption of healthier products with reduced sodium contents. This study aimed to develop a Mozzarella cheese with a reduced sodium content using a mixture of salts through acceptance testing and temporal sensory evaluation. The following 3 formulations of Mozzarella cheese were prepared: formulation A (control), which was produced only with NaCl (0% sodium reduction), formulation B (30% sodium reduction), and formulation C (54% sodium reduction). Every formulation was produced using a mixture of salts consisting of NaCl, KCl, and monosodium glutamate at different concentrations. The products underwent sensory acceptance tests, and the time intensity and temporal dominance of sensations were evaluated. The proportions of salts used did not cause strange or bad tastes but did result in lower intensities of saltiness. Mozzarella with low sodium content (B and C) had a sensory acceptance similar to that of traditional Mozzarella (A). Therefore, the use of a mixture of salts consisting of NaCl, KCl, and monosodium glutamate is a viable alternative for the production of Mozzarella, with up to a 54% reduction in the sodium content while still maintaining acceptable sensory quality.

Key words: KCl, monosodium glutamate, temporal dominance of sensations, time intensity

INTRODUCTION

Sodium chloride is traditionally used as a food additive in food processing. In addition to its influence on the taste of products, it has an important role with regard to texture and storage. However, due to the high sodium content, NaCl has also been associated with an increased risk of hypertension, the development of

cardiovascular disease, osteoporosis, and the incidence of kidney stones (Weinsier, 1976; Sihufe et al., 2003; Heaney, 2006; WHO, 2007). Therefore, special attention has been paid to the consumption of foods containing sodium because of its role in increasing the risk of chronic diseases (Roberfroid, 2000; Menrad, 2003) and, consequently, the emerging need for low-sodium product development (Katsiari et al., 2001; Matthews and Strong, 2005; Ruusunen and Puolanne, 2005; Guàrdia et al., 2008; Albarracín et al., 2011).

Because of concerns about excess sodium intake, the Ministry of Health and the Brazilian food industry reached an agreement to reduce the sodium content of various categories of foods by 2016. The Food Standards Agency in the United Kingdom has also revised its targets for reducing salt (NaCl) in processed foods, and the Food and Drug Administration (FDA) is working with the US food industry to reduce sodium content in foods (FDA, 2010). However, the reduction in sodium content in food products is a challenge for the food industry because it is often reported that a decrease in NaCl content is associated with a decrease in product acceptance (Sofos, 1983; Breslin and Beauchamp, 1997; Toldrá, 2006).

Several substitutes for NaCl have been studied. One is KCl due to its similar physical properties, but complete replacement of NaCl by KCl is not recommended because of the bitter taste the latter gives to products, which is generally only somewhat acceptable (Nascimento et al., 2007). Thus, using a combination of salts for the preparation of products with reduced sodium and good sensory acceptance is an interesting option.

In addition to the use of KCl, an interesting alternative to promote the reduction of sodium content in foods is the use of flavor enhancers such as monosodium glutamate (MSG; Brandsma, 2006; Desmond, 2006). The umami taste allows the MSG to be used as a substitute for NaCl, reducing its usage between 30 and 40% in food (Yamaguchi and Takahashi, 1984). This additive contains approximately 13% sodium, leading to less than half of the sodium intake of NaCl, where the sodium ion is approximately 40% of the molecular

Received January 7, 2014.

Accepted April 16, 2014.

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mass. However, when the goal is to reduce the sodium concentration to prevent cardiovascular problems, it cannot be overlooked that MSG, even if at a lower concentration, is also an important source of sodium (Sugita, 2002). Mojet et al. (2004) showed that the umami taste of MSG helps the perception of saltiness in food and predicted that the NaCl content may be reduced in foods that contain a lot of umami without decreasing consumer acceptance. Therefore, it would be interesting to use a combination of NaCl, KCl, and MSG in the production of products with reduced sodium content.

Replacement salts containing K, Mg, and Ca have been investigated in various cheeses (Katsiari et al., 2001; Johnson et al., 2009; Ayyash and Shah, 2011a,b; Gomes et al., 2011; Ortakci et al., 2012). Grummer et al. (2012) showed that KCl can be used successfully to achieve large reductions in sodium when replacing a portion of the NaCl in Cheddar cheese. It is possible to produce this low-sodium Cheddar cheese in a way that results in high consumer acceptance and low bitterness (Grummer et al., 2013). Another cheese that can be prepared by partial substitution (25%, wt/wt) of NaCl with KCl at the salting step is low-sodium Minas fresh cheese (Gomes et al., 2011). Kamleh et al. (2012) and Karimi et al. (2012) also demonstrated that Halloumi cheese and Feta cheese could be successfully manufactured using NaCl and KCl. Kamleh et al. (2012) further suggested using ingredients that would help mask this bitterness and thus improve the acceptability of Halloumi. Drake et al. (2011) studied the sodium reduction in cheese sauce, cottage cheese, and milk-based soup and they found that the complexity of the food matrix influenced salty taste perception and the percentage sodium reduction that was noticeable to consumers. Thus, further research for each product is necessary to further clarify salty taste perception in each product.

Among products with high sodium content, Mozzarella cheese, which, according to research from the National Brazilian Sanitary Surveillance (ANVISA), has an average sodium content of 577 mg/100 g, with results ranging from 309 to 1,068 mg (Brazilian Health Surveillance Agency, 2012), stands out. In addition, due to changes in eating habits, including the increased consumption of foods such as fast food and pizza, Mozzarella cheese is currently one of the most manufactured and consumed cheeses in Brazil and in the world (Santos, 2009). In addition, use of Mozzarella cheese as an ingredient in sandwiches and for other culinary applications, has increased, which has resulted in a natural tendency for these products to contain increased sodium contents (Cruz et al., 2011a). Cheeses enhance the taste of preparations to which they are added, including pies, stuffings, and pasta sauces. Recently, high sodium contents of several hot takeout meals in

the United Kingdom have been reported, with sodium contents varying from 1.32 to 1.65 g of salt/100 g across several pizzas, for which the main ingredient is Mozzarella cheese (Jaworowska et al., 2012), which makes reducing the sodium content of this cheese important.

Because the replacement of NaCl with other salts during the preparation of Mozzarella cheese raises several questions about the potential to reduce the saltiness and the possible introduction of metallic, bitter, and astringent tastes, it is necessary that, in addition to sensory acceptance tests, tests to characterize the sensory profile of the product during its consumption, such as the analysis of time-intensity (TI) and the analysis of temporal dominance of sensations (TDS), are also performed. Therefore, this study aimed to develop an accepted Mozzarella cheese with reduced sodium content, using a mixture of salts consisting of NaCl, KCl, and MSG in different concentrations, through acceptance testing and temporal sensory evaluation (TI and TDS).

MATERIALS AND METHODS

Ingredients

The materials used in the preparation of Mozzarella cheese were standardized and pasteurized milk (3% fat), mesophilic starter TCC-20, which is a starter culture for direct use that contains *Streptococcus salivarius* ssp. *thermophilus* (40%) and *Lactobacillus helveticus* (60%; Chr. Hansen A/S, Hørsholm, Denmark), 50% (wt/vol) calcium chloride solution, bovine rennet powder (Hansen Industries and Co., Valinhos-SP, Brazil), potassium chloride (99%; Vetec Química Fina Ltda, Duque de Caxias, RJ, Brazil), MSG (99%; Ajinomoto, São Paulo, SP, Brazil), and NaCl (99%; Vetec Química Fina Ltda).

Preparation of Mozzarella Cheese

The Mozzarella cheeses were manufactured according to the methodology described by Furtado (1990), with some modifications. Figure 1 shows a flowchart of the manufacturing process for Mozzarella cheese.

For the preparation of Mozzarella formulations, 40 L of homogenized, pasteurized, and standardized milk was tempered to $35 \pm 1^\circ\text{C}$ with mesophilic starter in the amount recommended by the manufacturer. Subsequently, the milk was subjected to preaging for a period of 40 min at the same temperature. After preripening, the milk was added to the 50% CaCl_2 solution (0.4 mL/L of milk) with rennet powder in an amount sufficient for clotting to occur in 50 min. The obtained curd was cut to obtain 1-cm³ edges.

After the cutting step, the solution was allowed to clot at rest for 5 min; then, the curd was slowly stirred for 10 min. To enhance the desired Mozzarella cheese

Figure 1. Flowchart of the production of Mozzarella cheese. S1 = traditional brine containing 100% NaCl; S2 = brine with a 25% reduction in NaCl content; S3 = brine with a 50% reduction in NaCl content.

syneresis, the temperature was raised slowly to 40°C, and the curd was stirred in the tank for an additional 25 min, when it hit the mass point. Upon reaching this point, all the serum was removed, and the mass in the tank was maintained at a temperature of 40°C for 1 h to accelerate the acidification of the dough to

achieve a pH of 5.3. The mass was cut into slices of approximately 1.8 cm and manually worked into water at 78°C for approximately 5 min. The ratio of stretching water:mass used was 2:1. The masses were shaped and placed in plastic rectangular forms. The masses were then left to rest for 10 min (turned after 5 min). Afterward, these forms, which contained the Mozzarella cheese, were immersed in water at $8 \pm 1^\circ\text{C}$ for 1 h to promote cooling of the mass to be removed from the forms. Next, the 3 kg of Mozzarella cheese that was produced was divided into 3 equal parts, and each part was subjected to a different brine (S1, S2, and S3) in a cold chamber at a temperature of 10°C for 8 h to yield the following 3 Mozzarella cheese formulations: (A) traditional Mozzarella cheese salted in brine containing 100% NaCl (S1), (B) Mozzarella cheese salted in brine with a 25% reduction in NaCl content (S2), and (C) Mozzarella cheese salted in brine with a 50% reduction in NaCl content (S3).

The composition of the brine (Table 1) was determined using a mixture of salts (NaCl, KCl, and MSG) at different concentrations while maintaining the same salting power as the brine containing only NaCl to produce Mozzarella cheese with a 25 to 50% reduction in sodium content. In doing this, the mixture of salts was determined by pretesting and the salting power of KCl and glutamate in relation to NaCl determined by de Souza et al. (2013a) were taken into consideration.

The brine solutions used had a pH of 5.3 and were used in the ratio of 3 L of brine per pound of cheese to be salted. After salting, the Mozzarella cheese was removed and dried in the same chamber for 48 h. After this period, the cheeses were packaged in low-density polyethylene bags and subjected to chemical analysis and sensory tests.

Determination of the Sodium Content of Mozzarella Cheese

To determine the sodium content of the Mozzarella cheese, formulations A, B, and C were ground and subjected to digestion with perchloric and nitric acids (AOAC, 1990). The sodium content of the Mozzarella cheese was determined using flame photometry. The results were subjected to ANOVA and a mean comparison (Tukey) test using the statistical program Sisvar (Ferreira, 2002).

Table 1. Composition of brines used for the preparation of Mozzarella cheese formulations

Brine	NaCl (kg/L)	KCl (kg/L)	Monosodium glutamate (kg/L)	Reduction in NaCl content (%)
S1	0.3000	—	—	0
S2	0.2250	0.0646	0.0402	25
S3	0.1500	0.0430	0.1608	50

Temporal Evaluation of Mozzarella Cheese

TI Analysis. Time-intensity analysis was performed according to Cadena and Bolini (2011), Morais et al. (2013), and de Souza et al. (2013b). Thirty participants (15 men and 15 women; 24–56 yr of age) not allergic to dairy, with experience in sensory evaluation, who consumed Mozzarella cheese at least once per week and who had the interest and time availability were selected for the sensory panel analysis of TI through the use of questionnaires. For acquisition and data analysis, the program SensoMaker (Nunes and Pinheiro, 2012) was used. Through a graphical interface in the form of a 10-point scale, with 0 meaning no perception and 10 signifying an extreme perception of salty taste, each tester indicated the intensity of the attribute of the samples with a monadic presentation, using a balanced complete block design (Wakeling and MacFie, 1995) by computer mouse stimulus. In the course of the analysis, messages were presented at the beginning of each step of the analysis with instructions for the action to be performed (Cardello et al., 2003). First, the panelist clicked in the button “start” and took the full amount of the sample during 2 s, after, during 20 s using the mouse, indicated the intensity of the particular sensory attribute (salty flavor) on the scale. Finishing the analysis, a message indicated the end of the test and the panelist proceeded to another sample.

The software SensoMaker analyzed the data collected during each sensory evaluation session and furnished the following parameters: maximum intensity recorded by the assessor and time in which the maximum intensity was recorded (Palazzo and Bolini, 2009). The data are presented in graphical form (through calculation parameters) using Microsoft Excel 2012 software (Microsoft Corp., Redmond, WA). In the graph, the values represented on the horizontal axis are time, and intensity values are on the vertical axis.

TDS. The TDS analysis was performed according to Sokolowsky and Fischer (2012), Dinnella et al. (2012), and de Souza et al. (2013a). We recruited 30 participants not allergic to dairy for the TDS analysis. To recruit participants, questionnaires were administered that considered the frequency of consumption of Mozzarella cheese (at least once per week) and experience with sensory analysis. The panelists were trained on the concept of TDS and were introduced to the data acquisition program SensoMaker (Nunes and Pinheiro, 2012). The total duration of the experiment was 20 s, and the attributes selected by the panel, as determined by the conventional method, were salty, bitter, sweet, umami, sour, spicy, astringent, and off-flavor.

After the instructions, the panelists were asked to click in the button “start” and during 2 s put the sample of Mozzarella cheese (approximately 5 g) in their mouth and immediately start the evaluation. During 20 s, using the mouse, the participants were requested to select the dominant taste over that time. They were told that the dominant taste is the taste that is perceived with the greatest clarity and intensity. For each of these 8 descriptors, a button on the computer screen was presented for evaluation.

The presentation of the samples was made in monadic order (Macfie et al., 1989) in disposable white plastic cups coded with 3-digit numbers. The samples were served one by one, and the assessors were asked to rinse their mouth with water between each sample.

The methodology of Pineau et al. (2009) was used with the SensoMaker software to compute the TDS curves. The curves were plotted (smooth = 0.5) and used for visual interpretation. In brief, 2 lines were 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 that the dominance rate should equal to be considered to be significant (Pineau et al., 2009). The significance level was calculated using the confidence interval of a binomial proportion based on a normal approximation according to Pineau et al. (2009):

$$Ps = Po + 1.645 \sqrt{\frac{Po(1 - Po)}{n}}, \quad [1]$$

where Ps = lowest significant proportion value ($\alpha = 0.05$) at any point in time for the TDS curve, $Po = 1/p$, with p being the number of attributes, and n = number of subjects per replication.

Analogous to the parameters of the TI curves, 3 parameters of the TDS curves for the attribute salty were extracted: namely, maximum dominance rate, duration of the salty dominance, and area under the curve. Duration of the salty dominance and TDS area were calculated only above the “chance level” ($P = 1/\text{number of attributes}$; here, $P = 12.5\%$) to exclude interference. Calculation of the dominance rates was conducted using SensoMaker software. For further analyses, the data were exported to Microsoft Excel and the graphs were plotted. The evaluation process according to Pineau et al. (2009) suggested summarizing the data for all evaluations.

For analysis, the results of the curves were considered significant sensations (i.e., above the line “significance level”). Curves were analyzed through the maximum rate

of dominance, time of the maximum rate of dominance, and area under the curve.

Sensory Acceptance Evaluation of Mozzarella Cheese

The Mozzarella cheese formulations (A, B, and C) were analyzed by a sensory test of acceptance. The samples were served in a monadic in 4 sections, and the order of presentation was balanced according to the proposal by Wakeling and MacFie (1995). The test was conducted in individual booths. The panelists received approximately 20 g of each sample in plastic cups coded with 3-digit numbers at room temperature. The test was performed in cabins with proper lighting and with absence of interferences such as noise and odors (Bowles and Demiate, 2006).

The 60 panelists not allergic to dairy evaluated the samples in terms of the acceptance of salty taste and overall impression of the samples using a 9-point hedonic scale ranging from “extremely dislike” to “extremely like,” according to the methodology described by Sidel and Stone (1993).

The results of the acceptance test were subjected to ANOVA using the statistical program SISVAR (Ferreira, 2002). To better visualize the acceptance of the samples, a histogram of the frequency distribution of the values obtained for each sample was also constructed. The histograms make it possible to visualize the segmentation of the hedonic values of each sample, revealing the acceptance level and allowing for the comparison of the performance of 2 or more samples in the study (Behrens et al., 1999).

RESULTS

Sodium Content of Mozzarella Cheese

A significant difference ($P \leq 0.05$) was detected in the sodium content of the different formulations of Mozzarella cheese. Table 2 lists the average sodium content of the Mozzarella cheese formulations (A, B, and C). Table 2 shows that the use of the NaCl, KCl, and MSG salt mixture resulted in cheeses with 30 and 54% reductions in the sodium content compared with the traditional formulation (A).

TI

Figure 2 represents the intensity of the salty taste with the passage of time for the Mozzarella cheese formulations analyzed and Table 3 shows the parameters obtained while analyzing the intensity over time for the salty taste of Mozzarella cheese. Figure 2 and Table 3 show that all Mozzarella cheese profiles were similar

Figure 2. Graphic representation of the intensity of the salty taste with the passage of time for traditional Mozzarella cheese and reduced-sodium Mozzarella cheese. A = traditional Mozzarella cheese (control); B = Mozzarella cheese with 30% sodium content reduction; C = Mozzarella cheese with 54% sodium content reduction.

with respect to the occurrence of the salty taste, but at different intensities. The formulation prepared only with NaCl (A) showed a maximum intensity of saltiness equal to 6.80, and it took approximately 18 s of chewing to achieve this. The Mozzarella cheese with 30% (B) and 54% sodium content reduction (C) had a maximum intensity of salty flavor of 4.3 and 3.21 over the course of approximately 14.2 and 12.4 s, respectively.

TDS

Figures 3, 4, and 5 show the dominant temporal profile of sensations (TDS) of the 3 formulations of Mozzarella cheese studied. Each curve represents a particular attribute of dominance over the course of time. In the graphical representation of the TDS analysis, 2 lines are shown: the “chance level” and “significance level.” The “chance level” is the dominance rate that an attribute can obtain by chance, and the “significance level” is the minimum value the dominance rate should equal to be considered significant (Pineau et al., 2009).

Analysis of the TDS for the Mozzarella cheese sample containing only NaCl (Figure 5) showed that the per-

Table 2. Sodium content in Mozzarella cheese

Mozzarella cheese ¹	Sodium content (mg/100 g)	Sodium reduction ² (%)
A	630 ± 15.5 ^a	0
B	440 ± 16.3 ^b	30
C	290 ± 14.4 ^c	54

^{a-c}Values within a column followed by the same superscript letter are not significantly different from each other ($P < 0.05$; by Tukey test).

¹A = traditional Mozzarella cheese (control); B = Mozzarella cheese with 30% sodium content reduction; C = Mozzarella cheese with 54% sodium content reduction.

²Calculated according to formulation A, which was considered 0% sodium reduction.

ception of the salty taste was significant at all times. The same is true for sample B, with a 30% sodium content reduction (Figure 4). As for the Mozzarella cheese with a 54% sodium content reduction (formulation C), a significant occurrence of salty and umami tastes was present, which occurred over the course of 10 and 12 s, respectively.

The TDS curves also show that formulation A (traditional Mozzarella) reached a maximum salinity dominance rate of approximately 0.65, meaning that at most 65% of the panelists selected salinity as the dominant taste), whereas formulations B (30% sodium content reduction) and C (54% content sodium reduction) reached a maximum of 0.55 and 0.35 salinity, respectively.

Acceptance Test

The ANOVA applied to the data for acceptance testing indicated that no significant difference ($P > 0.05$) existed in relation to the acceptance of the attributes of the different formulations of Mozzarella cheese. Table 4 lists the average scores given for acceptance of the salty taste and the overall impression of the Mozzarella cheeses evaluated.

Note that in both attributes, the acceptance grades given to all formulations ranged between “like slightly” and “like moderately,” indicating good acceptance of the products. Therefore, a reduction in sodium con-

Table 3. Parameters obtained in the analysis of time-intensity for the Mozzarella cheese formulations

Formulation ¹	Imax ²	TImax ³
A	6.80	18.00
B	4.30	14.20
C	3.21	12.40

¹A = traditional Mozzarella cheese (control); B = Mozzarella cheese with 30% sodium content reduction; C = Mozzarella cheese with 54% sodium content reduction.

²Maximum intensity of saltiness.

³Elapsed time to reach the maximum intensity of saltiness.

tent of 30% (formulation B) and 54% (formulation C) in Mozzarella cheese promoted the development of products with the same sensory acceptability as the traditional cheese (formulation A). Figures 6 and 7 show histograms obtained from the data for acceptance testing of Mozzarella cheese for a better view of the acceptance of the formulations.

Analysis of the histograms shows slight differences in the frequency distribution of hedonic values assigned to different samples of Mozzarella cheese. In both histograms, the frequency distributions of the responses for all samples skewed toward the region of the highest scores, ranging from “like slightly” (note 6) and “like extremely” (note 9), indicating good acceptance of the products. Formulation C (54% sodium reduction) had a sensory acceptance slightly superior to that of the other products.

Figure 3. Graphical representation of the temporal dominance of sensations (TDS) profile of traditional Mozzarella cheese. Sig. = significance.

Figure 4. Graphical representation of the temporal dominance of sensations (TDS) profile of Mozzarella cheese with 30% sodium content reduction. Sig. = significance.

DISCUSSION

Sodium Content of Mozzarella Cheese

In a survey of the sodium content of processed foods made by the National Brazilian Sanitary Surveillance (ANVISA) in 2012, it was found that in Brazil, the

average content of sodium Mozzarella cheese is 577 mg/100 g (Brazilian Health Surveillance Agency, 2012). Felicio et al. (2013) also found a similar sodium intake for samples of Mozzarella cheese (574.5 mg/100 g). They also found that 75% of the samples evaluated, according to Brazilian legislation, were classified as high

Figure 5. Graphical representation of the temporal dominance of sensations (TDS) profile of Mozzarella cheese with 54% sodium content reduction. Sig. = significance.

Figure 6. Histogram of frequencies of hedonic values for acceptance in relation to the salty taste of traditional Mozzarella cheese and reduced-sodium Mozzarella cheese. A = traditional Mozzarella cheese (control); B = Mozzarella cheese with 30% sodium content reduction; C = Mozzarella cheese with 54% sodium content reduction.

sodium. Both showed that different cheese categories presented elevated variability with respect to their sodium contents, suggesting the considerable diversity of processing methods used by manufacturers, which can directly affect the amount of added sodium. Table 2 shows that traditional Mozzarella cheese (formulation A) had an average sodium content of 630 mg/100 g,

Figure 7. Histogram of frequencies of hedonic values for acceptance in relation to the overall impression of traditional Mozzarella cheese and reduced-sodium Mozzarella cheese. A = traditional Mozzarella cheese (control); B = Mozzarella cheese with 30% sodium content reduction; C = 54% Mozzarella cheese with sodium content reduction.

Table 4. Acceptance means in relation to the salty taste and overall impression for the formulations of Mozzarella cheese¹

Treatment ²	Salty taste	Overall impression
A	5.92	6.12
B	6.23	6.40
C	6.43	6.48

¹Sixty panelists not allergic to dairy evaluated the samples in terms of the acceptance of salty taste and overall impression of the samples using a 9-point hedonic scale ranging from “extremely dislike” to “extremely like,” according to the methodology described by Sidel and Stone (1993).

²A = traditional Mozzarella cheese (control); B = Mozzarella cheese with 30% sodium content reduction; C = Mozzarella cheese with 54% sodium content reduction.

which is above the Brazilian average. However, bringing Mozzarella cheeses with 25% (S2) and 50% (S3) sodium brine to reduce the NaCl and KCl content and using MSG during the preparation of the cheeses (formulations B and C) resulted in products with 30 and 54% reductions in sodium content, respectively; both samples showed below-average sodium levels (440 and 290 mg/100 g, respectively).

A higher percentage of sodium content reduction was found for Mozzarella cheeses B and C in relation to the predicted theoretical reductions of 25 and 50% NaCl content, respectively. This greater reduction in sodium levels can be justified due to the difference in the diffusion coefficients of salts in brines. According to Cussler (1976) and Onsager (1945), Fick’s laws of diffusion are assumed when various solutes diffuse simultaneously. Thus, besides the diffusion coefficient of each solute in relation to its own concentration gradient, crossed diffusion coefficients are included, representing the influence of a solute on the solute flux of the other solutes (Bona et al., 2005). Typically, the cross terms for highly dissociated solutes, such as NaCl and KCl, are orders of magnitude lower than the main terms (Medina-Vivanco et al., 2002; Gerla and Rubiolo, 2003).

TI

The evaluation of the salty taste through TI analysis is very important in the development of products with reduced sodium content, because the use of other salts to replace NaCl can promote less perception of the salty taste in the product. By this test, it is possible to find what the best substitutes are for NaCl and what the best concentrations are of each substitute.

Upon comparing the TI curves (Figure 2), we observed that higher concentrations of MSG and KCl were required to achieve the same salty taste sensation as achieved with NaCl. The same was observed by de Souza et al. (2013a) and Teodoro et al. (2013) in their

experiment with sodium reduction in butter and cream cheese. However, those studies showed that KCl salt is more similar to NaCl than MSG. Therefore, according to Guinee and O'Kennedy (2007), the substitution up to 40% of the NaCl by KCl is a good alternative to reduce the sodium content and maintain the characteristic flavor of cheeses. The lower intensity of saltiness in the C formulation (54% sodium reduction) is likely the result of a higher content of MSG.

Furthermore, the lower perception of salty taste found for samples B (30% sodium reduction) and C (54% sodium reduction) may be related to the type of cations or anions present in the substance (Ye et al., 1991, 1993) because the salty taste of NaCl is attributed to both the cations (70–85%) and the anions (30–15%; Formaker and Hill, 1988; Mattes, 2001) and is the result of the passage of ions through an ion channel specific for NaCl ions (McCaughey, 2007). It is difficult to find other substances with this capability, with the exception of toxic ions. Thus, according to Mooser (1980), other cations, such as potassium, present a less savory flavor compared with NaCl, as observed in this experiment.

Calculations to determine the compositions of brine were performed according to the powers of curing salts found by de Souza et al. (2013a) in butter. Thus, the lower perception of saltiness in Mozzarella cheeses B and C can also be justified by the different food matrices of the products.

TDS

Temporal dominance of sensations analysis is also relevant for the development of reduced-sodium-content products, because the use of other salts as substitutes for NaCl can promote unpleasant tastes, such as metallic, bitter, and astringent (Nascimento et al., 2007; de Souza et al., 2013a; Teodoro et al., 2013;). Furthermore, the temporal analysis TDS and TI allow descriptive evaluating of the products throughout the chewing time.

According to Horita et al. (2011), KCl is widely used in products with reduced sodium content, but in high concentrations it produces a bitter and metallic taste, resulting in sensory product rejection (Seman et al., 1980; Askar et al., 1994; Armenteros et al., 2012). However, in the current study, Mozzarella cheese containing KCl (B and C) did not result in the perception of a bitter and metallic taste. This may be due to the combined use of KCl and MSG because it is postulated that the effect of the flavor enhancer MSG may result from its interaction with taste receptors that minimize the perception of bitter taste (Dutcosky, 2007). Therefore, the use of the combination of these salts as partial sub-

stitutes for NaCl is a good alternative for the production of Mozzarella cheese with reduced sodium content and good consumer acceptance.

In addition to minimizing strange tastes, MSG can be used as a food additive because it is able to confer a distinctive taste to foods recognized as umami, a Japanese expression meaning tasty (Solms, 1969; Kawamura and Kare, 1987). However, its salting power (31.59%) is well below that of NaCl (de Souza et al., 2013a). This is consistent with the results found in the TDS curves (Figure 7). Formulation C (54% sodium reduction), which was prepared with the highest concentration of MSG, exhibited umami and salty flavors, and the salty flavor presented to a lesser extent than in the other samples (A and B). The same taste was noticeable in the studies by de Souza et al. (2013a) and Teodoro et al. (2013) with butter and cream cheese.

Sensory characteristics, functional properties, and shelf life are the features most affected by the reduction of salt in food (Guinee and O'Kennedy, 2007). Thus, in the development of products with reduced sodium content, it is important to consider the nature and composition of the product, the type of treatment, and the manufacturing conditions (Ruusunen and Puolanne, 2005). Although many salt substitutes are on the market, according to Cruz et al. (2011a), NaCl is the only salt that promotes the manifestation of a pure salty taste. However, this experiment showed that it is possible to prepare Mozzarella cheese with 30% less sodium using a mixture of NaCl and KCl salts and MSG that has a salty taste similar to that made with NaCl (Figure 4).

Acceptance Test

Several recent studies have developed products with reduced sodium content and good acceptability, but in all cases, partial substitution of NaCl was used, and the NaCl was replaced with different mixtures of salts (Katsiari et al., 2001; Guinee and O'Kennedy, 2007; Cruz et al., 2011a; Horita et al., 2011; Ayyash et al., 2013). In the current study, the use of a mixture of NaCl, KCl, and MSG was a good alternative for the preparation of products with reduced sodium content. This combination enabled the preparation of Mozzarella cheese with up to 54% reduction in sodium (formulation C), which maintained good acceptability and similar acceptance relative to the salty taste and the overall impression of the traditional Mozzarella cheese.

Except in products intended for children less than 1 yr old, requiring further studies, MSG is considered a safe additive in concentrations commonly used and its use is governed by leading regulatory agencies (Carvalho et al., 2011). However, it is important to highlight

that MSG contains 13% sodium. Therefore, it cannot be used in large proportions when the objective is to reduce the sodium content of the product. In the case of the production of Mozzarella cheese, as the salts, including MSG, were added to the brine and had different diffusion coefficients, MSG could be added in larger quantities without contributing significantly to the sodium content of the final cheese. Therefore, the replacement of NaCl by MSG is a good alternative to reduce the sodium content in cheeses salted in brine.

Results obtained in acceptance testing show that the consumers did not require a high intensity of salty taste in Mozzarella cheese, being able to accept and appreciate a product with a lower intensity of salt. Møller et al. (2013) showed the same during the production of Cheddar cheese with a 50% reduction in salt content. Thus, another alternative to promote the reduction of sodium content in Mozzarella cheese is the simple reduction of NaCl content used during its preparation. This is possible, as consumers have been increasingly concerned with the concept of well-being (Ares et al., 2014) and human health risk factors. Consequently, they have sought healthier products with lower salt content (Drake et al., 2011).

According to Grimes et al. (2009), few studies have examined the consumer's ability to interpret nutrition information regarding salt labels on food products. Consistently across studies, consumers criticize the use of the scientific terminology "sodium" on nutrition food labels (Grunert and Wills, 2007). Thus, according to Petersen et al. (2013), it is necessary to educate the consumers to read food labels to choose low-sodium products. Similarly, salt awareness campaigns are needed (Kenten et al., 2013) and strategies to reduce salt intake must raise interest in engaging in salt reduction through improving understanding of intake levels and dietary sources of salt. Strategies have been suggested by Mendoza et al. (2014).

For better characterization of Mozzarella cheese, future studies should cover sensory profiling of sodium-reduced Mozzarella cheese using quantitative descriptive analysis and consumer profiling methodologies (Albenzio et al., 2013; Cadena et al., 2013; Cruz et al., 2013; Pimentel et al., 2013; Sant'Ana et al., 2013; Santos et al., 2013; Morais et al., 2014).

CONCLUSIONS

It is possible to produce Mozzarella cheese with up to a 54% reduction in sodium content and good acceptability using the following mixture of salts: 42.40% NaCl, 12.15% KCl, and 45.45% MSG, although the products have lower intensities of saltiness and umami taste manifestation. Temporal dominance of sensations

and TI analysis are important tools in the development of products with reduced sodium content. Through this analysis, it was possible to describe the sensorial profile of the products and to optimize the formulations. For better characterization of the new product reduced-sodium Mozzarella cheese, future studies using descriptive sensorial analysis and physical and chemical analysis should be done. Furthermore, as NaCl has an important role in cheese conservation, the cheese shelf life should be investigated. This work paves the way for future studies, supporting the development of new products with reduced sodium content, taking into account the desires and needs of consumers.

ACKNOWLEDGMENTS

We thank the postgraduate program in food science from the Federal University of Lavras (Lavras, MG, Brazil), funders, and companies who supplied salt replacer and Mozzarella cheese-making ingredients. The financial support by Fundação de Amparo a Pesquisa de Minas Gerais (FAPEMIG, São Pedro, MG, Brazil) is gratefully acknowledged. The use of trade names in this publication does not imply endorsement by the funding organization, the University of Lavras, or the researchers, nor does it imply criticism of materials we did not evaluate.

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