Manufacture of reduced-sodium Cheddar-style cheese with mineral salt replacers

J. Grummer, M. Karalus, K. Zhang, Z. Vickers, and T. C. Schoenfuss¹

Department of Food Science and Nutrition, University of Minnesota, Saint Paul 55108

ABSTRACT

The use of mineral salt replacers to reduce the sodium content in cheese has been investigated as a method to maintain both the salty flavor and the preservative effects of salt. The majority of studies of sodium reduction have used mineral salt replacers at levels too low to produce equal water activity (a_w) in the finished cheese compared with the full-sodium control. Higher a_w can result in differences in cheese quality due to differences in the effective salt-to-moisture ratio. This creates differences in biochemical and microbial reactions during aging. We hypothesized that by targeting replacer concentrations to produce the same a_w as full sodium cheese, changes in cheese quality would be minimized. Stirred-curd Cheddar-style cheese was manufactured and curd was salted with NaCl or naturally reduced sodium sea salt. Reduced-sodium cheeses were created by blends of NaCl or sea salt with KCl, modified KCl, $MgCl_2$, or $CaCl_2$ before pressing. Sodium levels in reduced-sodium cheeses ranged from 298 to 388 mg of sodium/100 g, whereas the control full-sodium cheese had 665 mg/100 g. At 1 wk of age, a_w of reduced-sodium cheeses were not significantly different from control, which had an a_w of 0.96. The pH values of all reduced-sodium cheeses, excluding the treatment that combined sea salt and $MgCl_2$, were lower than those of full-sodium cheese, indicating that the starter culture was possibly less inhibited at the salting step by the replacers than by NaCl. Instrumental hardness values of the treatments with sea salt were higher than in cheeses containing NaCl, with the exception of the NaCl/ $CaCl_2$ treatment, which was the hardest. Treatments with $MgCl_2$ and modified KCl were generally less hard than other treatments. In-hand and first-bite firmness values correlated with the instrumental texture profile analysis results. Both $CaCl_2$ and $MgCl_2$ produced considerable off-flavors in the cheese (bitter, metallic, unclean, and soapy), as measured by descriptive sensory analysis with a trained panel. Bitterness

ratings for cheese with KCl and modified KCl were not significantly different from the full-sodium control. Potassium chloride can be used successfully to achieve large reductions in sodium when replacing a portion of the NaCl in Cheddar cheese.

Key words: sodium reduction, cheese, water activity, salt replacer

INTRODUCTION

Dietary sodium contributes to the development of hypertension, which can be a precursor to conditions such as cardiovascular disease and increases the risk for heart attacks and stroke in some individuals (Appel et al., 2006; Cotugna and Wolpert, 2011). At approximately 615 to 620 mg of sodium/100 g of cheese (Agarwal et al., 2011; USDA, 2011), Cheddar cheese contains approximately 8% of the US Food and Drug Administration's daily recommended value per serving (FDA, 2011). Cheese was reported to be the second largest contributor in the US diet of known sources of dietary sodium (almost 60% was from unknown sources) in one report, and dairy products were listed as the fourth largest contributor and reported to contribute 8.2% of the sodium in the US diet in another report (Jacobson, 2005; Anderson et al., 2010). Therefore, reducing the sodium content of cheese could have significant health benefits for some individuals.

Sodium reduction in natural cheese is inherently difficult due to the desirable effects of salt (NaCl) on flavor, culture activity, syneresis, and enzymatic activity (Guinee, 2004). Replacement salts containing potassium, magnesium, and calcium have been investigated in various cheeses (Lindsay et al., 1982; Fitzgerald and Buckley, 1985; Aly, 1995; Reddy and Marth, 1995; Katsiari et al., 1997, 2001; Johnson et al., 2009; Ayyash and Shah, 2011a,b). The purpose of these mineral salt replacers is to maintain the salty taste as well as enzymatic and microbial stability by maintaining water activity (a_w) of the cheese. However, most studies that examined salt replacers did not use them at a high enough concentration to equal the a_w of full-sodium cheese made with the same make procedure. This could have been because salt replacers have been implicated

Received August 20, 2011.

Accepted December 20, 2011.

¹Corresponding author: tschoenf@umn.edu

in causing bitter and metallic off-flavors (Lindsay et al., 1982; Fitzgerald and Buckley, 1985). However, clear conclusions about the effect of the salt replacers on taste cannot be made because varying the a_w could result in bitterness due to differences in biochemical reactions during aging.

Water activity in young cheese is driven by the salt-to-moisture ratio (S/M), which has numerous other significant effects on cheese aging (Guinee, 2004). However, because of differences in molecular weight, the traditional S/M calculation does not apply when using salt replacers. Biochemical reactions can likely be maintained between full- and reduced-sodium cheese by maintaining the a_w between treatments due to the close relationship between a_w and S/M . Similar biochemical reactions would allow for a clear evaluation of the salt replacers in cheese. Deviations in a_w from control would be equivalent to deviations in the S/M and, therefore, reactions during cheese aging.

We hypothesized that reduced-sodium Cheddar-style cheese could be made with mineral salt replacers, and that by maintaining the a_w of full-sodium control cheese, the effect of the S/M would be simulated and result in similar biochemical reactions during cheese aging. This would eliminate the difference in the reaction rates of microorganisms and enzymes, and the unadulterated effect of the salt replacers could be observed. To test this hypothesis, stirred-curd Cheddar-style cheese was manufactured, and curd was salted with NaCl or a naturally reduced-sodium sea salt, and reduced-sodium cheeses were created with blends of NaCl or sea salt with KCl, modified KCl, $MgCl_2$, or $CaCl_2$ before pressing. Salt and salt replacers were applied at concentrations to achieve an equivalent a_w to that of full-sodium cheese, and the cheese was evaluated for chemical, physical, and sensory differences.

MATERIALS AND METHODS

Cheese Making Materials

Lactococcus lactis ssp. *cremoris* and *Lc. lactis* ssp. *lactis* (CHOOZIT Superstart direct-to-vat-set strain M30, Danisco USA Inc., Madison, WI), annatto (AFC W/S 1X 70463, Chr. Hansen Inc.), 45% (wt/vol) calcium chloride (CAL-SOL 71257, Chr. Hansen Inc.), and liquid chymosin (CHY-MAX 73863, Chr. Hansen, Inc., Milwaukee, WI) were used to manufacture the cheese.

Sodium chloride (Top-Flo Evaporated Salt, Cargill Inc., Minneapolis, MN) and the salt replacers KCl (Premier Potassium Chloride 8799, Cargill Inc.), a modified KCl (Modified Potassium Chloride 14510, Nu-Tek Products Inc., Minnetonka, MN), $MgCl_2$ (magnesium chloride 6-Hydrate 5956-06, Mallinckrodt Baker Inc.,

Phillipsburg, NJ), $CaCl_2$ (calcium chloride dihydrate, granular 4616-06, Mallinckrodt Baker Inc.), and a 45% reduced-sodium sea salt (SS45, A&B Ingredients, Fairfield, NJ) were used to salt the cheese curd. The percentage composition of the sea salt listed on the ingredient specification was as follows: sodium 22.0 ± 0.6 , chloride 34.0 ± 0.9 , sulfate 23.0 ± 0.7 , potassium 9.0 ± 0.3 , magnesium 2.0 ± 0.1 , trace elements 0.3, and moisture 10.0 ± 1.5 . The percentage of salts present in the chloride or sulfate form was not specified. All were Food Chemicals Codex (FCC) or United States Pharmacopeia (USP) grade.

Figure 1. Flow diagram of the cheese making procedure.

Table 1. Percentage of salt and salt replacers applied to drained curd (wt/wt)¹

Ingredient, %	Control		Reduced sodium ²						
	NaCl ³	Sea salt	NaCl + KCl ⁴	NaCl + mod. KCl ⁵	NaCl + MgCl ₂	NaCl + CaCl ₂	Sea salt + KCl	Sea salt + mod. KCl	Sea salt + MgCl ₂
NaCl	2.50	0	1.21	1.21	1.21	1.21	0	0	0
Sea salt	0	3.33	0	0	0	0	2.16	2.16	2.16
KCl	0	0	1.69	0	0	0	1.31	0	0
Modified KCl	0	0	0	1.69	0	0	0	1.31	0
MgCl ₂ ⁶	0	0	0	0	3.92	0	0	0	3.05
CaCl ₂ ⁷	0	0	0	0	0	2.57	0	0	0

¹Target amounts took into account expected loss during salting and pressing.

²Target: 300 mg of sodium/100 g.

³Target: 640 mg of sodium/100 g.

⁴Premier Potassium Chloride 8799 (Cargill Inc.).

⁵Modified Potassium Chloride 14510 (Nu-Tek Products Inc., Minnetonka, MN).

⁶Magnesium chloride 6-hydrate.

⁷Calcium chloride di-hydrate.

Cheddar-Style Cheese Manufacture

Cheddar-style cheese was manufactured at the University of Minnesota's Joe Warthesen Food Processing Center (St. Paul, MN). Raw whole milk was pasteurized at 74°C for 20 s on a Cherry-Burrell 1800 kg/h plate and frame-style milk pasteurizer (SPX, Delavan, WI) and pumped into a Damrow 2,260-kg rectangular vat (Tetra Damrow, Vernon Hills, IL) at 31.1°C. Cheese making proceeded as described in Figure 1. The majority of the remaining whey was drained once the titratable acidity reached 0.16 to 0.17 (lactic acid basis); enough whey was maintained in the vat to prevent the curd from drying. Curd was stirred until the titratable acidity reached 0.21 to 0.23, at which point the drained curd was weighed into individual plastic bins with drain holes and salted in 3 additions. The percentages of salt and salt replacers applied to the drained curd are shown in Table 1. These amounts were determined by calculation (taking account the hydration state of the minerals), and confirmed and adjusted using a model system on a water activity meter as described in Grummer and Schoenfuss (2011). A final sodium chloride concentration of 1.6% and moisture of 37% were the targets for the equivalent a_w we wanted to achieve (target was our full-sodium control cheese). The sea salt used had less sodium and a higher use rate was needed to achieve the same a_w , as shown in Table 1. The blends of salts were added in 3 additions spaced 5 min apart, and curd was stirred continuously by hand. Curd was transferred to cheesecloth-lined, 9.1-kg Wilson-style cheese hoops and pressed overnight at 276 kPa. Blocks were vacuum packaged and stored at 4 to 5°C. Cheese making was replicated on 2 d with different lots of milk. These replicates will be referred to as batches.

Compositional and Chemical Analysis

Fat and ash were determined by standard methods 18.8A2c and 18.4A, respectively (Richardson, 1985). Moisture was determined by vacuum oven following standard method 15.111 (Wehr and Frank, 2004). Water activity was measured at 23°C on an Aqua Lab 3TE a_w meter (Decagon Devices, Pullman, WA). The pH was measured with an Acorn pH 6 Meter (Oakton Instruments, Vernon Hills, IL) with an Orion Ross Sure-Flow pH electrode (Thermo Fisher Scientific Inc., Waltham, MA). Total protein (total nitrogen $\times$ 6.38) was determined using a TruSpec N (Leco Corp., St. Joseph, MI) based on the Dumas method of combustion. Sodium, potassium, magnesium, and calcium content were measured by atomic absorption spectrometry using a Perkin Elmer AAnalyst 100 using IDF method 119:2007(E) (IDF, 2007) with the exception of using the hot plate wet ashing digestion time and temperature of Kira et al. (2004). All measurements were performed in duplicate, at minimum.

Texture Profile Analysis

Instrumental texture profile analysis (TPA) was performed on a TA.XTPlus texture analyzer (Texture Technologies Corp., Scarsdale, NY). Instrumental hardness, springiness, cohesiveness, adhesiveness, resilience, and chewiness were calculated according to Bourne (1978). Cheese was equilibrated to 7°C for 16 h before cylinders (11.75 mm in diameter, 50–60 mm high) were cut with a steel cork borer and placed in an air-tight bag. Multiple samples of 12 mm height were cut from the cylinders, excluding 5 mm on each end, using a guided blade and returned to the bag. Samples were individually removed from the refrigerator, and a thin

layer of light white mineral oil (151694, MP Biomedicals LLC, Solon, OH) was applied to both ends. Within 20 s of removal, samples were compressed twice, with 2 s between compressions, to 20% of original height at a crosshead speed of 1 mm/s between a 25-mm-diameter polycarbonate probe (TA11, Texture Technologies Corp.) and a polycarbonate stage; room temperature was 23°C. A minimum of 5 replicates per cheese sample was analyzed.

Statistical Analysis of Compositional, Chemical, and Texture Profile Analyses

We used an ANOVA (Linear Mixed Model analysis, SPSS Statistics ver. 17.0.2, IBM SPSS, Chicago, IL) to determine whether cheese treatments differed in any of these measurements. We used Fisher's Least Significant Difference to determine whether specific cheese treatments differed from each other.

Descriptive Sensory Analysis

Subjects. Nine members of the trained panel from the Sensory Center at the University of Minnesota (St. Paul) participated in these tests. All were 6-*n*-propylthiouracil (PROP) tasters or supertasters and were compensated for participating. Each had at least 20 h of training before starting this study. All recruiting and experimental procedures were approved by the University of Minnesota's Institutional Review Board.

Training. Panelists participated in five 1-h training sessions in which a lexicon of sensory attributes and references (Supplemental Table 1; <http://www.journalofdairyscience.org/>) was collectively developed and refined. Taste, flavor, aroma, and texture attributes and references used for the descriptive sensory analysis are listed in the lexicon. Cheese samples used for this training were a subset of cheeses used in this study, selected to represent the range of differences the subjects would find during the testing. Food Chemicals Codex or United States Pharmacopeia grade. Panelists practiced evaluating the cheeses on SIMS Sensory Evaluation Software (Sensory Computer Systems, Morristown, NJ), which was used during testing. Results were discussed as a group. Practice sessions were repeated to finalize the lexicon.

Products and Testing. Fourteen cheeses were included: 7 treatments from 2 cheese batches. Panelists received 3 cubes (1.5 cm³) of each cheese at room temperature (22°C) in a random 3-digit-coded 120-mL plastic cup with a lid.

Panelists participated in 4 test sessions. Panelists evaluated a complete set of the samples from the first batch in the first 2 sessions (the second session served as

Table 2. Compositional analysis of Cheddar-style cheese

Measurement	Control			Reduced sodium ¹							SE ²	P-value
	NaCl ³	Sea salt		NaCl + KCl	NaCl + mod. KCl	NaCl + MgCl ₂	NaCl + CaCl ₂	Sea salt + KCl	Sea salt + mod. KCl	Sea salt + MgCl ₂		
Moisture, %	36.87 ^{bcd}	34.56 ^d		35.81 ^{cd}	38.28 ^{bc}	39.33 ^{ab}	34.59 ^d	35.26 ^d	36.65 ^{cd}	40.89 ^a	1.05	<0.01
Fat, %	35.3 ^{abc}	36.6 ^a		35.8 ^{ab}	34.4 ^{bcd}	33.4 ^{cd}	36.6 ^a	36.3 ^{ab}	35.1 ^{abc}	32.7 ^d	0.7	0.02
Protein, %	23.90 ^{ab}	24.68 ^a		24.33 ^{ab}	22.38 ^c	22.62 ^c	24.55 ^{ab}	24.19 ^{ab}	23.61 ^b	22.12 ^c	0.32	<0.001
Total ash, %	3.838 ^{bc}	3.989 ^{abc}		4.133 ^a	4.051 ^{ab}	3.748 ^c	4.242 ^a	4.122 ^a	4.094 ^{ab}	4.190 ^a	0.082	0.03
Sodium, mg/100 g	664.7 ^a	508.4 ^b		358.3 ^c	386.6 ^c	355.0 ^c	298.4 ^d	348.8 ^{cd}	356.9 ^c	387.7 ^c	19.1	<0.001
Potassium, mg/100 g	89.1 ^e	202.2 ^d		707.0 ^a	665.1 ^{ab}	90.2 ^c	86.5 ^c	597.2 ^{bc}	554.9 ^c	162.9 ^d	24.3	<0.001
Calcium, mg/100 g	225.2 ^b	225.7 ^b		210.0 ^b	205.0 ^b	196.3 ^b	991.1 ^a	222.0 ^b	218.6 ^b	204.4 ^b	58.2	<0.001
Magnesium, mg/100 g	10.6 ^c	16.6 ^c		8.9 ^c	11.4 ^c	183.7 ^a	18.8 ^c	14.5 ^c	21.5 ^c	146.1 ^b	11.7	<0.001

^{a-c}Means within a row with different superscripts differ ($P < 0.05$).

¹Target: 300 mg of sodium/100 g.

²Largest standard error of all treatments is shown for each row.

³Target: 640 mg of sodium/100 g.

⁴Measured at 1 mo of age.

a sensory replicate) and a complete set of the samples from the second batch in the third and fourth sessions (the fourth session served as the sensory replicate). Within a session, serving order was balanced for order and carryover effects. During the testing sessions, each panelist evaluated each sample by rating the intensity of the attributes on a 20-point line scale labeled “none” at the left end and “intense” at the right end. Intensity ratings of flavor and taste were made on the standard citric acid scale (Pontet et al., 2010). Ratings of odors were made on the standard butanol scale (ASTM, 2010). Texture ratings were made on a 20-point scale anchored with references. Panelists were instructed to wear nose clips when evaluating the taste attributes.

Data Analysis. We used ANOVA (SAS PROC GLM ver. 9.1 (SAS Institute Inc., Cary, NC) to determine which sensory attributes differed significantly among the products. The sensory attribute intensities were dependent variables; judge, cheese, batch, cheese $\times$ batch, and replicate were predictors.

Comparison of Compositional, Chemical, and Texture Profile Analyses to Descriptive Sensory Analysis

To summarize the data, we conducted a principal components analysis (PCA) with Varimax rotation (XLSTAT; Addinsoft USA, New York, NY) using the mean attribute scores for each cheese. We selected sensory attributes that differed significantly among the cheeses and that had at least one mean score greater than 1.0 for inclusion in the PCA. Instrumental texture and chemical measurements that differed significantly among the cheeses were included as supplemental variables. Correlations between the means of compositional and chemical measurements with significant differences between treatments and descriptive sensory attributes were determined using Pearson correlation ($\alpha = 0.05$) in XLSTAT version 2011.1.04 (Addinsoft USA).

RESULTS AND DISCUSSION

Compositional, Chemical, and Texture Profile Analyses

Moisture tended to be lower in treatments containing sea salt compared with analogous treatments containing NaCl, with the exception of the treatment sea salt + MgCl₂ (Table 2). Correspondingly, treatments lower in moisture were higher in fat and protein because of less dilution from the moisture. Treatments sea salt + MgCl₂ and NaCl + MgCl₂ contained more than 39% moisture, which is above the legal maximum for Cheddar cheese in the United States. The differences in moisture indicated that less syneresis occurred in cheeses salted with MgCl₂, and consequently they had higher moisture contents in the finished cheese. Fitzgerald and Buckley (1985) also found that Cheddar cheese salted with MgCl₂ only and an NaCl + MgCl₂ mixture (1:1 mixture) had higher moisture contents than full-sodium control. Higher moisture contents can be explained by an increased hydration of casein proteins due to the effect of replacement salts. Arakawa and Timasheff (1984) reported the effect of MgCl₂ on protein solubility was strongly affected by pH, whereas this effect was not observed with NaCl, indicating that hydration was also related to a preferential interaction of MgCl₂ with proteins. According to the Hofmeister series, both Mg²⁺ and Ca²⁺ should tend to increase the solubility of proteins more than Na⁺, and could result in more moisture in the cheese and less syneresis (Creighton, 1984). However, increased moisture was not observed in cheeses with CaCl₂ in our study. In addition, in a study on the effect of divalent cations on cheese production, Solorza-Feria (2001) found variation in the effect of 2 divalent cations, Ca²⁺ and Cd²⁺. Both resulted in more whey expulsion than controls (resulting in cheese with less moisture) and both reduced renneting time, but they noted an inhibitory effect of Cd on starter cultures. In a study that included the calculation of

Table 3. Water activity (a_w) and pH of Cheddar-style cheese

Measurement ¹	Control		Reduced sodium ²							SE ³	P-value
	NaCl ⁴	Sea salt	NaCl + KCl	NaCl + mod. KCl	NaCl + MgCl ₂	NaCl + CaCl ₂	Sea salt + KCl	Sea salt + mod. KCl	Sea salt + MgCl ₂		
a _w	0.956	0.957	0.955	0.957	0.953	0.959	0.954	0.957	0.956	0.002	0.07
pH	5.17 ^a	4.97 ^b	5.07 ^{ab}	4.96 ^b	4.99 ^b	4.97 ^b	5.00 ^b	4.97 ^b	5.19 ^a	0.04	0.02

^{a,b}Means within a row with different superscripts differ ($P < 0.05$).

¹Measured at 1 wk of age (a_w) or 1 mo of age (pH).

²Target: 300 mg of sodium/100 g.

³Largest standard error of all treatments is shown for each parameter.

⁴Target: 640 mg of sodium/100 g.

Table 4. Mean values from instrumental texture profile analysis (TPA) of Cheddar-style cheese at 2 mo of ripening

TPA attribute	Control			Reduced sodium ¹							P-value
	NaCl ³	Sea salt	NaCl + KCl	NaCl + mod. KCl	NaCl + MgCl ₂	NaCl + CaCl ₂	Sea salt + KCl	Sea salt + mod. KCl	Sea salt + MgCl ₂	SE ²	
Hardness, g	6,045 ^{cde}	7,715 ^{ab}	6,230 ^{cd}	4,535 ^f	5,580 ^{def}	8,495 ^a	7,415 ^{abc}	6,930 ^{bcd}	4,665 ^{ef}	480	<0.001
Springiness	0.375 ^{bed}	0.433 ^b	0.304 ^{cd}	0.257 ^d	0.477 ^{ab}	0.567 ^a	0.382 ^{bc}	0.384 ^{bc}	0.489 ^{ab}	0.041	<0.001
Cohesiveness	0.207 ^{ab}	0.136 ^c	0.175 ^{cd}	0.159 ^{de}	0.233 ^a	0.189 ^{bc}	0.150 ^{de}	0.141 ^e	0.175 ^{cd}	0.014	<0.001
Adhesiveness, g × s	198.8 ^b	90.7 ^{bc}	436.5 ^a	393.7 ^a	107.2 ^{bc}	15.6 ^c	170.3 ^b	175.9 ^b	47.0 ^c	41.3	<0.001
Resilience	0.0437 ^{bc}	0.0382 ^{bc}	0.0344 ^c	0.0292 ^c	0.0674 ^a	0.0625 ^a	0.0363 ^{bc}	0.0341 ^c	0.0527 ^{ab}	0.0058	<0.001
Chewiness, g	473 ^{bc}	454 ^{bc}	325 ^c	181 ^c	731 ^{ab}	925 ^a	432 ^{bc}	365 ^c	413 ^c	104	<0.01

^{a-f}Means within a row with different superscripts differ ($P < 0.05$).¹Target: 300 mg of sodium/100 g.²Largest standard error of all treatments is shown for each parameter.³Target: 640 mg of sodium/100 g.

the solubility and speciation of calcium and magnesium in milk, differences were noted in the effect of pH on solubility (solubility of magnesium did not decrease at pH above 4, whereas that of calcium did; Nelson et al., 1986). They also noted that complexing of calcium with citrate commenced at a lower pH and occurred over a broader range than that of magnesium. The differences observed between MgCl₂ and CaCl₂ observed in our study might be due to a combination of their differing effect on starter cultures, solubility, and interaction with casein in milk.

At a constant salt concentration, one would expect higher a_w in cheese with a higher moisture content. However, the reduced-sodium cheeses with higher moistures also had higher sodium levels, leading to almost equal sodium-to-moisture ratios. Also interesting was the finding that the sodium concentration of the sea salt control was almost 24% lower than that of the NaCl control, even though approximately 25% more sea salt was added, which should have brought the levels close to parity. During the salting process, moisture is expelled from the cheese and a percentage of salt is lost to the whey. Additional salt is lost when the curd is compressed to form blocks during the pressing step. Higher salting rates are associated with greater whey expulsion and less moisture in the final cheese, and with greater losses of added salt to the whey portion (Sutherland, 1974). Sutherland (1974) reported that salt lost to the whey increased from 33% of added salt to 50% when the salting rate was increased from 1.5 to 3.5% (based on the weight of the curd). Conversely, the moisture of the final cheese decreased from 37.5 to 35% in the same cheese. Because the amount of moisture expulsion was lower in the cheeses with higher moisture, the loss of salt was also lower.

The pH of the cheeses ranged from 4.96 to 5.19 at 1 mo of age (Table 3). The reduced-sodium cheeses were lower in pH than the full-sodium control, with the exception of NaCl + KCl and sea salt + MgCl₂ cheeses, indicating that the salt replacers and sea salt did not inhibit the starter cultures as much as NaCl did. The lower pH (compared with full-sodium control) in treatments NaCl + MgCl₂ and NaCl + CaCl₂ is supported by Fitzgerald and Buckley (1985), who observed a lower pH in Cheddar cheeses salted with MgCl₂ and CaCl₂, both with and without NaCl. The lower pH in cheese with KCl is also supported by Reddy and Marth (1995), who found the pH to be lower in 3-d-old Cheddar with various NaCl + KCl mixtures. Other studies in Cheddar (Lindsay et al., 1982; Fitzgerald and Buckley, 1985) and Mozzarella (Ayyash and Shah, 2011a) contradict our results, in that they report that cheese with various NaCl + KCl mixtures resulted in similar or higher pH compared with control.

Table 5. Mean values of descriptive sensory analysis of Cheddar-style cheese at 6 mo of age¹

Sensory attribute	Control		Reduced sodium ²							SE ³	P-value
	NaCl ⁴	Sea salt	NaCl + KCl	NaCl + mod. KCl	NaCl + MgCl ₂	NaCl + CaCl ₂	Sea salt + KCl	Sea salt + mod. KCl	Sea salt + MgCl ₂		
Aroma											
Overall	7.7	8.1	7.3	7.9	7.4	7.5	7.3	8.1	7.4	0.5	NS
Sour dairy	1.7	1.8	1.7	1.7	1.6	1.9	1.6	1.7	1.5	0.3	NS
Taste											
Sweet	1.3 ^a	0.7 ^{abc}	1.1 ^{ab}	0.8 ^{abc}	0.6 ^{abc}	0.3 ^c	1.0 ^{abc}	0.7 ^{abc}	0.4 ^{bc}	0.3	<0.001
Salty	4.5 ^a	3.9 ^a	4.5 ^a	4.5 ^a	3.3 ^a	3.1 ^a	3.9 ^a	3.9 ^a	4.6 ^a	0.6	0.04
Sour	2.3	2.7	2.7	3.3	4.1	3.4	2.5	3.3	3.5	0.6	NS
Bitter	1.1 ^c	1.7 ^c	1.6 ^c	2.3 ^c	6.3 ^b	8.0 ^a	1.7 ^c	2.2 ^c	5.6 ^b	0.7	<0.001
Umami	1.3	1.2	1.2	1.3	0.8	1.0	1.2	1.3	1.3	0.3	NS
Flavor											
Overall	8.4 ^c	7.9 ^c	8.9 ^{abc}	10.0 ^a	9.1 ^{abc}	9.7 ^{ab}	8.2 ^c	8.4 ^{bc}	10.0 ^a	0.6	<0.001
Diacytyl	5.4 ^a	4.7 ^{ab}	5.3 ^a	5.3 ^a	3.5 ^{bc}	2.9 ^c	4.2 ^{abc}	4.3 ^{abc}	3.9 ^{abc}	0.5	<0.001
Cooked	2.3 ^{abc}	2.1 ^{abc}	2.4 ^{ab}	1.8 ^{abc}	1.7 ^{bc}	1.1 ^c	1.8 ^{abc}	2.9 ^a	1.9 ^{abc}	0.8	<0.01
Metallic	0.7 ^c	1.1 ^c	0.9 ^c	1.7 ^c	3.8 ^{ab}	4.3 ^a	0.8 ^c	1.3 ^c	3.0 ^b	0.7	<0.001
Milky	1.2 ^a	0.8 ^{ab}	1.0 ^{ab}	1.2 ^a	0.7 ^{ab}	0.4 ^b	0.9 ^{ab}	0.7 ^{ab}	0.6 ^{ab}	0.2	<0.01
Whey	1.8	2.1	2.1	2.4	1.5	1.3	2.1	2.2	2.4	0.6	NS
Unclean	0.3 ^c	0.6 ^c	0.4 ^c	0.7 ^c	2.0 ^b	4.6 ^a	0.5 ^c	0.7 ^c	2.5 ^b	0.5	<0.001
Sour dairy	2.2	2.6	2.4	2.9	2.7	3.5	2.1	2.4	2.2	0.7	NS
Soapy	0.5 ^c	1.1 ^c	0.7 ^c	0.8 ^c	2.0 ^b	3.2 ^a	1.0 ^c	1.1 ^c	2.7 ^a	0.4	<0.001
Sensation											
Astringency	0.2 ^b	0.9 ^b	0.6 ^b	0.5 ^b	1.1 ^b	1.9 ^a	0.4 ^b	0.9 ^b	0.7 ^b	0.6	<0.001
Numbing	0.1 ^c	0.2 ^{bc}	0.3 ^{bc}	0.2 ^{bc}	1.0 ^a	0.7 ^{ab}	0.2 ^{bc}	0.3 ^{bc}	0.7 ^{ab}	0.2	<0.001
Pungent	0.4 ^a	0.5 ^a	0.5 ^a	1.0 ^a	1.3 ^a	1.5 ^a	0.4 ^a	1.0 ^a	1.1 ^a	0.5	0.03
In-hand texture											
Firmness	12.1 ^c	18.2 ^a	15.2 ^b	14.0 ^b	9.0 ^d	15.2 ^b	17.8 ^a	18.1 ^a	14.0 ^b	0.7	<0.001
Springiness	6.4	6.4	6.0	5.9	8.8	6.4	5.9	6.5	6.2	1.2	NS
Stickiness	3.7 ^{ab}	2.1 ^{cd}	3.2 ^{bc}	3.5 ^{ab}	4.3 ^a	2.9 ^{bcd}	1.8 ^d	2.2 ^{cd}	3.1 ^{bc}	0.5	<0.001
Cohesiveness	13.2	12.6	12.3	11.6	12.7	12.3	13.2	13.0	10.9	1.0	NS
Slipperiness	10.4 ^{bcd}	8.0 ^e	9.5 ^{cde}	10.6 ^{bcd}	11.6 ^b	11.4 ^{bc}	9.2 ^{de}	9.5 ^{cde}	13.6 ^a	0.8	<0.001
First-bite texture											
Firmness	4.8 ^e	12.8 ^a	6.1 ^e	5.5 ^e	3.4 ^f	9.7 ^c	11.2 ^b	12.1 ^{ab}	7.5 ^d	0.7	<0.001
Stickiness	12.8 ^a	5.4 ^c	12.9 ^a	13.3 ^a	12.1 ^a	7.6 ^{bc}	6.6 ^{bc}	6.4 ^{bc}	7.9 ^b	0.9	<0.001
Brittleness	2.2 ^c	10.1 ^a	3.3 ^c	3.6 ^c	2.0 ^c	7.4 ^b	7.9 ^b	9.0 ^{ab}	7.1 ^b	1.0	<0.001
Five-chew texture											
Firmness	5.9 ^{fg}	12.9 ^a	7.5 ^e	6.5 ^{ef}	4.9 ^g	10.4 ^c	11.4 ^{bc}	11.9 ^{ab}	8.8 ^d	0.6	<0.001
Stickiness	13.7 ^a	6.5 ^b	12.6 ^a	13.6 ^a	12.0 ^a	6.9 ^b	7.1 ^b	7.3 ^b	8.5 ^b	0.9	<0.001
Brittleness	2.1 ^c	10.7 ^a	3.0 ^c	3.1 ^c	2.8 ^c	8.1 ^b	8.5 ^b	9.5 ^{ab}	7.7 ^b	0.9	<0.001
Curdiness	1.6 ^b	7.9 ^a	2.3 ^b	2.2 ^b	2.5 ^b	7.4 ^a	5.9 ^a	7.3 ^a	6.9 ^a	0.9	<0.001

^{a–g}Means within a row with different superscripts differ ($P < 0.05$).

¹Only attributes with significant differences between treatments ($\alpha = 0.05$) and means greater than 1 (for at least one treatment) at 1 or 6 mo of age are shown.

²Target: 300 mg of sodium/100 g.

³Largest standard error of all treatments is shown for each parameter.

⁴Target: 640 mg of sodium/100 g.

NS = No significant differences between treatments ($\alpha = 0.05$).

Differences in the response of bacteria to activity inhibition when exposed to sodium replacement salts have been investigated. Bautista-Gallego et al. (2008) found that CaCl₂ inhibited the growth of *Lactobacillus pentosus* similarly to NaCl, but KCl and MgCl₂ were less inhibitory. In a study on the effect of cations on the activity of β -galactosidases, including those from *Lactococcus lactis* ssp. *lactis*, Garman et al. (1996) found that equimolar concentrations of K⁺ stimulated the activity of the purified enzyme more than Na⁺ and Mg²⁺. Enzymes sourced from other lactic cultures they studied showed a similar effect in regards to K⁺ stimulating

the most, with the exception of β -galactosidase from *Lactobacillus delbrueckii* ssp. *bulgaricus*, where Na⁺ had the greatest stimulatory effect. This could account for differences observed in pH in our study as a result of acid production due to the utilization of lactose by the cultures.

The instrumental hardness values measured at 2 mo of ripening of the treatments with sea salt were higher than in cheeses containing NaCl, with the exception of NaCl + CaCl₂, which was the hardest, as shown in Table 4. The sea salt used in this study contained sodium, magnesium, and potassium as both chloride-

Figure 2. Sensory attributes (lowercase) and instrumental vectors (uppercase) from the principal components analysis (PCA) for components 1 (abscissa) and 2 (ordinate). The PCA was computed over all judges ($n = 9$), products, and sensory replicates for the cheese treatments. Only sensory attributes that had at least one mean score ≥ 1.0 and that discriminated significantly among the cheeses were included in the PCA. The first component (horizontal axis) correlated >0.9 with the following attributes: bitter, metallic, earthy, unclean, soapy, and numbing. Those attributes fall toward the right side of the plot. Component 1 explained 45% of the variability in the data set. Component 2 (vertical axis) was highly positively correlated (>0.9) with firmness, brittleness, and curdiness (those attributes fall toward the top of the plot), and negatively correlated with stickiness. Component 2 explained an additional 36% of the variability. To minimize clutter on this plot we removed some of the sensory attributes that correlated highly ($r > 0.9$) with others. Bitter represents metallic, earthy, unclean, soapy, and numbing; diacetyl represents milky; astringency represents fermented; bite firmness represents 5-chew hand firmness and firmness; bite brittleness represents 5-chew brittleness and curdiness; bite stickiness represents 5-chew stickiness. Color version available in the online PDF.

and sulfate-based salts. This different composition from straight NaCl could have been responsible for the difference in texture, because sulfate and chloride salts (in the case of Mg) differ in protein hydration properties (Arakawa and Timasheff, 1984). The increased hardness of treatment NaCl + CaCl₂ is supported by Pastorino et al. (2003), who found that the hardness of cheese similar to low-moisture part-skim Mozzarella increased with an increased concentration of calcium resulting from an injection with a 40% (wt/wt) CaCl₂ solution after pressing. The increased hardness we observed was not supported by the report of Fitzgerald and Buckley (1985), however. They observed lower hardness and firmness in Cheddar cheese salted with CaCl₂ only and with a NaCl + CaCl₂ mixture. Cheese made with NaCl + CaCl₂ in our study was also more springy, less adhesive, and more chewy than control cheese. Treatments with MgCl₂ were generally less hard than other treatments, with the exception of NaCl-modified KCl. The reduction in instrumental firmness corroborates reports by Lefier et al. (1987) and Chamba and Debry (1994) in reduced-sodium Gruyère and Emmental, when MgCl₂ was used to replace sodium in the brine solution. Treatments with KCl generally had similar in-

strumental texture values to controls, except for lower cohesiveness and higher adhesiveness in treatments NaCl + KCl and NaCl + modified KCl, respectively. The similarity in instrumental texture is in agreement with Fitzgerald and Buckley (1985) and Katsiari et al. (1997, 1998), who found no significant difference in instrumental textural properties due to KCl in Cheddar, feta, and Kefalograviera cheeses, respectively.

Descriptive Sensory Analysis

Numerous sensory differences were observed between treatments, as shown in Table 5. Two principal components defined most (81%) of the variation in sensory attributes among the cheeses (Figure 2). The first component (horizontal axes in Figures 2 and 3) correlated positively with bitter, metallic, earthy, unclean, soapy, and numbing. Samples with CaCl₂ and MgCl₂ scored highly on this component (Figure 3). The first component correlated negatively with diacetyl, milky, and cooked flavor; samples with sea salt, NaCl, and KCl scored negatively on this first component. The second principal component correlated highly with firmness, brittleness, and curdiness. Samples with sea salt scored

Figure 3. Principal component analysis (PCA) for components 1 and 2 over all judges ($n = 9$), products, and sensory replicates. Only sensory attributes that had at least one mean score ≥ 1.0 and that discriminated significantly among the cheeses were included in the PCA. This plot shows the location of the treatments: NaCl, NaCl + CaCl, NaCl + KCl, NaCl + MgCl₂, NaCl + modified KCl, sea salt, sea salt + KCl, sea salt + MgCl₂, and sea salt + modified KCl. The first component (horizontal axis) correlated >0.9 with the following attributes: bitter, metallic, earthy, unclean, soapy, and numbing. Component 1 explained 45% of the variability in the data set. Component 2 (vertical axis) was highly positively correlated (>0.9) with firmness, brittleness, and curdiness, and negatively correlated with stickiness. Component 2 explained an additional 36% of the variability. Color version available in the online PDF.

high on this component. The second principal component correlated negatively with stickiness; samples containing NaCl scored negatively on this second component. Cheeses containing NaCl + KCl and NaCl + modified KCl positioned closest to the control NaCl in Figure 3, indicating that they had sensory attributes more similar to those of the control than did the other cheeses. These findings agree with those reported by Fitzgerald and Buckley (1985) concerning MgCl₂ and CaCl₂. Cheddar cheese salted only with MgCl₂ or CaCl₂ was not included in their sensory evaluation due to a reported extreme bitterness, and cheese salted with a 1:1 molar ratio mixture of NaCl and MgCl₂ or CaCl₂ was found to be bitter and metallic.

Cheeses containing KCl and modified KCl, as described in the principal component plot, did not vary significantly from controls in terms of bitter and salty flavor intensities. This is in contrast to the study of Lindsay et al. (1982), which reported that reduced- and low-sodium Cheddar cheese with KCl was less salty and more bitter than reduced- and low-NaCl cheese that

did not have KCl at 6 mo of age. The reduced and low NaCl cheese in the latter study had both less NaCl and less KCl than cheese in our study. Thus, the a_w of the cheeses between the 2 studies, as well as cheese ripening characteristics, would be expected to differ.

CONCLUSIONS

Despite achieving equivalent a_w among treatments, the various salt and salt replacers had different effects on cheese properties. Differences observed in moisture and pH indicate different effects on cheese culture growth and metabolism and on the solubility of milk proteins. The use of CaCl₂ and MgCl₂ to reduce sodium in Cheddar-style cheese resulted in flavor differences compared with the full-sodium control, and these flavors (bitter, metallic, earthy, unclean, soapy, and numbing) would not be desirable in high-quality cheese. The reduced-sodium sea salt used in this study resulted in firmer, more brittle, and less sticky cheese compared with NaCl. Cheese made with NaCl + KCl and NaCl +

modified KCl were similar to cheeses made with NaCl in most respects. This indicates that KCl can be used successfully to achieve large reductions in sodium when replacing a portion of the NaCl in Cheddar cheese.

ACKNOWLEDGMENTS

Funding was provided by the Dairy Research Institute, managed by Dairy Management Inc. (Rosemont, IL). We thank the funder and companies who supplied salt replacer and cheese making ingredients. The use of trade names in this publication neither implies endorsement by the funding organization, the University of Minnesota or the researchers, nor criticism of ones we did not evaluate.

REFERENCES

- Agarwal, S., D. McCoy, W. Graves, P. D. Gerard, and S. Clark. 2011. Sodium content in retail Cheddar, Mozzarella, and process cheeses varies considerably in the United States. *J. Dairy Sci.* 94:1605–1615.
- Aly, M. E. 1995. An attempt for producing low-sodium feta-type cheese. *Food Chem.* 52:295–299.
- Anderson, C. A. M., L. J. Appel, N. Okuda, I. J. Brown, Q. E. Chan, L. C. Zhao, H. Ueshima, H. Kesteloot, K. Miura, J. D. Curb, K. Yoshita, P. Elliott, M. E. Yamamoto, and J. Stamler. 2010. Dietary sources of sodium in China, Japan, the United Kingdom, and the United States, women and men aged 40 to 59 years: The INTERMAP study. *J. Am. Diet. Assoc.* 110:736–745.
- Appel, L. J., M. W. Brands, S. R. Daniels, N. Karanja, P. J. Elmer, and F. M. Sacks. 2006. Dietary approaches to prevent and treat hypertension—A scientific statement from the American Heart Association. *Hypertension* 47:296–308.
- Arakawa, T., and S. N. Timasheff. 1984. Mechanism of protein salting in and salting out by divalent cation salts: Balance between hydration and salt binding. *Biochemistry* 23:5912–5923.
- ASTM. 2010. ASTM Standard E544: Standard practices for referencing suprathreshold odor intensity. ASTM International, West Conshohocken, PA.
- Ayyash, M. M., and N. P. Shah. 2011a. The effect of substitution of NaCl with KCl on chemical composition and functional properties of low-moisture Mozzarella cheese. *J. Dairy Sci.* 94:3761–3768.
- Ayyash, M. M., and N. P. Shah. 2011b. Proteolysis of low-moisture Mozzarella cheese as affected by substitution of NaCl with KCl. *J. Dairy Sci.* 94:3769–3777.
- Bautista-Gallego, J., F. N. Arroyo-Lopez, M. C. Duran-Quintana, and A. Garrido-Fernandez. 2008. Individual effects of sodium, potassium, calcium, and magnesium chloride salts on lactobacillus pentosus and *Saccharomyces cerevisiae* growth. *J. Food Prot.* 71:1412–1421.
- Bourne, M. C. 1978. Texture profile analysis. *Food Technol.* 32:62–66.
- Chamba, J. F., and G. Debry. 1994. Caractéristiques et acceptabilité d'émulsions hyposodées. *Sci. Aliments* 14:335–348.
- Cotugna, N., and S. Wolpert. 2011. Sodium recommendations for special populations and the resulting implications. *J. Community Health* 36:874–882.
- Creighton, T. E. 1984. *Proteins: Structures and Molecular Properties*. 2nd ed. W. H. Freeman and Company, New York, NY.
- FDA. 2011. Nutrition labeling of food. 21 CFR 101.9(c)(9) <http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=101.9>.
- Fitzgerald, E., and J. Buckley. 1985. Effect of total and partial substitution of sodium chloride on the quality of Cheddar cheese. *J. Dairy Sci.* 68:3127–3134.
- Garman, J., T. Coolbear, and J. Smart. 1996. The effect of cations on the hydrolysis of lactose and the transferase reactions catalysed by beta-galactosidase from six strains of lactic acid bacteria. *Appl. Microbiol. Biotechnol.* 46:22–27.
- Grummer, J., and T. C. Schoenfuss. 2011. Determining salt concentrations for equivalent water activity in reduced-sodium cheese by use of a model system. *J. Dairy Sci.* 94:4360–4365.
- Guinee, T. P. 2004. Salting and the role of salt in cheese. *Int. J. Dairy Technol.* 57:99–109.
- IDF. 2007. Milk and milk products: Determination of sodium, potassium, calcium and magnesium contents—Method by flame atomic absorption spectrometric method. Joint Standard IDF 119/ISO 8070. International Dairy Federation, Brussels, Belgium, and International Organisation for Standardisation, Geneva, Switzerland.
- Jacobson, M. F. 2005. *Salt: The forgotten killer*. Center for Science in the Public Interest, Washington, DC.
- Johnson, M. E., R. Kapoor, D. J. McMahon, D. R. McCoy, and R. G. Narasimmon. 2009. Reduction of sodium and fat levels in natural and processed cheeses: Scientific and technological aspects. *Comp. Rev. Food Sci. Food Saf.* 8:252–268.
- Katsiari, M. C., E. Alichanidis, L. P. Voutsinas, and I. G. Roussis. 2001. Proteolysis in reduced sodium Kefalograviera cheese made by partial replacement of NaCl with KCl. *Food Chem.* 73:31–43.
- Katsiari, M. C., L. P. Voutsinas, E. Alichanidis, and I. G. Roussis. 1997. Reduction of sodium content in feta cheese by partial substitution of NaCl by KCl. *Int. Dairy J.* 7:465–472.
- Katsiari, M. C., L. P. Voutsinas, E. Alichanidis, and I. G. Roussis. 1998. Manufacture of Kefalograviera cheese with less sodium by partial replacement of NaCl with KCl. *Food Chem.* 61:63–70.
- Kira, C. S., F. D. Maio, and V. A. Maihara. 2004. Comparison of partial digestion procedures for determination of Ca, Cr, Cu, Ce, K, Cg, Mn, Na, P, and Zn in milk by inductively coupled plasma-optical emission spectrometry. *J. AOAC Int.* 87:151–156.
- Lefter, D., R. Grappin, G. Grosclaude, and G. Curtat. 1987. Sensory properties and nutritional quality of low-sodium Gruyere cheese. *Lait* 67:451–464.
- Lindsay, R. C., S. M. Hargett, and C. S. Bush. 1982. Effect of sodium-potassium (1:1) chloride and low sodium-chloride concentrations on quality of Cheddar cheese. *J. Dairy Sci.* 65:360–370.
- Nelson, L. S., F. A. Jacobs, J. G. Brushmiller, and R. W. Ames. 1986. Effect of pH on the speciation and solubility of divalent metals in human and bovine milks. *J. Inorg. Biochem.* 26:153–168.
- Pastorino, A. J., N. P. Ricks, C. L. Hansen, and D. J. McMahon. 2003. Effect of calcium and water injection on structure-function relationships of cheese. *J. Dairy Sci.* 86:105–113.
- Pontet, C., M. Murray, and Z. Vickers. 2010. Experimentally created intensity scales for the five basic tastes: Sweet, sour, salty, bitter and umami. Abstract 160–12, Page 101 in Book of Abstracts, IFT Annual Meeting, Chicago, IL. Institute of Food Technologists, Chicago, IL.
- Reddy, K. A., and E. H. Marth. 1995. Microflora of Cheddar cheese made with sodium-chloride, potassium-chloride, or mixtures of sodium and potassium-chloride. *J. Food Prot.* 58:54–61.
- Richardson, G. H. 1985. *Standard Methods for the Examination of Dairy Products*. 15th ed. American Public Health Association, Washington, DC.
- Solorza-Feria, J. 2001. Study of the changes in cheese making parameters of skim milk with divalent cations addition. *Food Technol. Biotechnol.* 39:115–121.
- Sutherland, B. J. 1974. Control of salt absorption and whey drainage in Cheddar cheese manufacture. *Aust. J. Dairy Technol.* 29:86–93.
- USDA. 2011. National Nutrient Database for Standard Reference. USDA Agricultural Research Service Nutrient Data Laboratory. Accessed Jan. 28, 2011. <http://www.nal.usda.gov/fnic/foodcomp/search/>.
- Wehr, H. M., and J. F. Frank. 2004. *Standard Methods for the Examination of Dairy Products*. 17th ed. American Public Health Association, Washington, DC.