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Nano spray-dried sodium chloride and its effects on the microbiological and sensory characteristics of surface-salted cheese crackers

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ABSTRACT

Reducing particle size of salt to approximately 1.5 μm would increase its surface area, leading to increased dissolution rate in saliva and more efficient transfer of ions to taste buds, and hence, perhaps, a saltier perception of foods. This has a potential for reducing the salt level in surface-salted foods. Our objective was to develop a salt using a nano spray-drying method, to use the developed nano spray-dried salt in surface-salted cheese cracker manufacture, and to evaluate the microbiological and sensory characteristics of cheese crackers. Sodium chloride solution (3% wt/wt) was sprayed through a nano spray dryer. Particle sizes were determined by dynamic light scattering, and particle shapes were observed by scanning electron microscopy. Approximately 80% of the salt particles produced by the nano spray dryer, when drying a 3% (wt/wt) salt solution, were between 500 and 1,900 nm. Cheese cracker treatments consisted of 3 different salt sizes: regular salt with an average particle size of 1,500 μm; a commercially available Microsized 95 Extra Fine Salt (Cargill Salt, Minneapolis, MN) with an average particle size of 15 μm; and nano spray-dried salt with an average particle size of 1.5 μm, manufactured in our laboratory and 3 different salt concentrations (1, 1.5, and 2% wt/wt). A balanced incomplete block design was used to conduct consumer analysis of cheese crackers with nano spray-dried salt (1, 1.5, and 2%), Microsized salt (1, 1.5, and 2%) and regular 2% (control, as used by industry) using 476 participants at 1 wk and 4 mo. At 4 mo, nano spray-dried salt treatments (1, 1.5, and 2%) had significantly higher preferred saltiness scores than the control (regular 2%). Also, at 4 mo, nano spray-dried salt (1.5 and 2%) had significantly more just-about-right saltiness scores than control (regular 2%). Consumers' purchase intent increased by 25% for the nano spray-dried salt at 1.5% after they were notified about the 25% reduction in sodium content of the cheese cracker. We detected significantly lower yeast counts for nano spray-dried salt treatments (1, 1.5, and 2%) at 4 mo compared with control (regular) salt (1, 1.5 and 2%). We detected no mold growth in any of the treatments at any time. At 4 mo, we found no significant differences in sensory color, aroma, crunchiness, overall liking, or acceptability scores of cheese crackers using 1.5 and 1% nano spray-dried salt compared with control. Therefore, 25 to 50% less salt would be suitable for cheese crackers if the particle size of regular salt was reduced 3 log to form nano spray-dried salt. A 3-log reduction in sodium chloride particle size from regular salt to nano spray-dried salt increased saltiness, but a 1-log reduction in salt size from Microsized salt to nano spray-dried salt did not increase saltiness of surface-salted cheese crackers. The use of salt with reduced particle size by nano spray drying is recommended for use in surface-salted cheese crackers to reduce sodium intake.

Key words: nano spray drying, salt, cheese

INTRODUCTION

High sodium consumption has been linked to the increase in cardiovascular disease and stroke cases in the United States (American Heart Association, 2013). Strokes have resulted in 130,000 deaths in the United States (CDC, 2015) and 6 million deaths worldwide (World Heart Federation, 2015). Strokes cost the United States $34 billion annually in health care services, medications, and lost productivity (CDC, 2015). The Institute of Medicine (2015) reports that the tolerable upper intake level for salt is 5.8 g (or 2.3 g of sodium) per day. Healthy 19- to 50-yr-old adults should consume 3.8 g of salt or 1.5 g of sodium per day (Institute of Medicine, 2015). It is estimated that reducing dietary salt by 3 g per person per day would reduce the incidence of high blood pressure (11 million cases annually), coronary heart disease (120,000 cases), and

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strokes (66,000 cases), and would save up to 392,000 quality-adjusted life-years and $10 billion to $24 billion in health care costs (Palar and Sturm, 2009). Sodium levels, especially in processed foods, remain high. The tastes and flavors associated with historical salt use are expected, and the relatively low cost of enhancing the palatability of processed foods has become a key rationale for the use of salt in food.

Cheese cracker sales were $817.1 million in 2012 in the United States (Malovany, 2013) and cheese crackers are among the most popular snack products in North America, with excellent acceptability (Whitaker, 2013). It would be beneficial commercially and from a health standpoint if the salt content of surface-salted cheese crackers could be reduced by modifying the physical aspects of salt, yet keeping the same level of saltiness. It has been speculated that decreasing the particle sizes of nutritional salts would enhance saltiness (Noort et al., 2012). This theory is based on the fact that reducing the size of salt grains leads to a faster dissolution rate of the salts in saliva. A faster dissolution rate would inherently lead to a more efficient transfer of ions to the taste buds and hence a saltier perception of the food product. According to Noyes and Whitney (1897), size reduction leads to an increased surface area and increased dissolution velocity. Therefore, particle size reduction is a suitable way to enhance the bioavailability of particles when dissolution velocity is the rate-limiting step. By reducing particle size by nano spray drying, particle surface area is further increased and thus the dissolution velocity increases (Junghanns and Müller, 2008). Additionally, solubility is a function of particle size. The solubility increases with decreasing particle size below 1,000 nm (Junghanns and Müller, 2008). Li et al. (2010) used 0.1 to 1% (wt/wt) concentrations of sodium chloride solution to calibrate the nanospray dryer B-90 (Büchi Labortechnik AG, Flawil, Switzerland). They observed a particle size distribution from 517 to 993 nm by increasing the concentration from 0.1 to 1% (wt/wt), but did not report use of higher percentages such as 3, 5, 10, and 20%, which would tend to have a greater salt yield.

It is not known whether 25 and 50% reductions in the amount of sodium chloride by using a nano spray-dried form of salt would alter the sensory and microbiological characteristics of surface-salted cheese crackers. Our objectives were (1) to study the influence of salt solution concentrations of 3, 5, 10, and 20% in the developments of nano spray-dried particles of sodium chloride, and (2) to use the best concentration identified in objective 1 to elucidate the effect of incorporating the developed nano spray-dried salt particles on the sensory and microbiological characteristics of surface-salted cheese crackers.

MATERIALS AND METHODS

Manufacture of Sodium Chloride Particles by Nano Spray Drying

Salt solutions in deionized water (3, 5, 10, and 20% wt/wt) were prepared, completely dissolved, filtered through a Whatman No. 2 filter paper (Clifton, NJ), and subsequently processed by nano spray drying (Nanospray dryer B-90, Büchi Labortechnik AG). The sodium chloride solutions were sprayed through a 4-μm nozzle. The air flow (125 L/min), pressure (0.0038 MPa), head temperature (95°C), and spray percentage (90%) were kept constant in all treatments. The resulting particle sizes were determined by dynamic light scattering, and particle shapes were observed by scanning electron microscopy.

Particle Size Determination

The size of the nano spray-dried salt particles was measured using a Microtrac S3500 laser diffraction particle size analyzer (Microtrac, York, PA) by wet measurement with isopropyl alcohol as the mobile phase. Nano spray-dried salt (50 mg) was added to 100 mL of isopropyl alcohol and sonicated for 180 s. Particle sizes were measured 3 times by detecting the low angle region to almost the entire angular spectrum (approximately zero to 160 degrees).

Scanning Electron Microscopy

A thin layer of nano spray-dried salt was placed on sticky tabs on aluminum scanning electron microscopy stubs, and coated with platinum in an EMS 550X sputter coater (Electron Microscopy Sciences, Hatfield, PA). A scanning electron microscope JSM-6610 (Jeol Ltd., Tokyo, Japan) with an acceleration voltage of 15 kV and a vacuum of 0.00001 MPa was used to observe samples and record images. Representative fields were recorded.

Experimental Design

For objective 1, 4 salt solution concentrations (3, 5, 10, and 20% wt/wt) were prepared 3 times to identify the concentration that would yield the smallest nano spray-dried salt. For objective 2, nano spray-dried salt was prepared for the rest of the experiment using the single concentration from objective 1 (3%) that yielded nano spray-dried salt. The treatments consisted of 3 salt sizes: regular salt with an average particle size of 1,500 μm; commercially available Microsized 95 Extra Fine Salt (Cargill Salt, Minneapolis, MN) with an average particle size of 15 μm; and nano spray-dried salt with an average particle size of 1.5 μm, manufactured in our laboratory) and 3 salt concentrations (1, 1.5, and 2% wt/wt). For sensory analysis of cheese crackers, nano spray-dried salt (1, 1.5, and 2%), Microsized salt (1, 1.5, and 2%), and regular 2% (control, as used by industry) were evaluated using 476 participants at 1 wk and 4 mo. The sensory test was conducted and analyzed as a balanced incomplete block design. For yeast and mold counts, the 9 (3 salt sizes × 3 salt concentrations) cheese cracker treatments were tested at wk 1 and 4 mo of storage. The experimental design for yeast and mold counts was completely randomized design with repeated measures.

Cheese Cracker Manufacture

Freshly prepared, unsalted queso blanco cheese (61% wt/wt), unsalted butter (14% wt/wt), wheat flour (18% wt/wt), water (5% wt/wt), and cayenne pepper (2% wt/wt) were combined to form the dough, which was aged at 4°C overnight. Then, the dough was rolled into sheets 3 mm thick and trimmed into 25.4-mm rectangles; a hole was incorporated in the center of each rectangle for release of water vapor to prevent puffing during baking. Baking was conducted at 177°C for 25 min. The surface was very lightly sprayed with fine droplets of canola oil. Crackers were weighed and salt was added at 1, 1.5, and 2% by weight to the surfaces. Regular salt (kosher salt with an average particle size of 1,500 μm; Morton Salt, Chicago, IL) was obtained from a local grocery store. Commercially available Microsized 95 Extra Fine Salt, average particle size of 15 μm (Cargill, 2011), was obtained from Cargill Salt. Nano spray-dried salt, average particle size of 1.5 μm, was prepared using a 3% (wt/wt) salt solution as described above. The cheese crackers were packaged in modified-atmosphere packaging using a Koch UltraVac (Kansas City, MO) packaging machine and biaxially oriented polypropylene-plastics technology/cast polypropylene bags (BOPPT/VMCPP; Uline, Houston, TX) and stored at 22°C until analysis.

Yeast and Mold Counts

The cheese crackers were tested for yeast and molds before conducting the sensory evaluation. The enumeration of yeasts and molds was conducted at 1 wk and 4 mo. Serial dilutions were made in peptone water (0.1% wt/vol) and samples were plated in duplicate on 3M Petrifilms for yeasts and molds (3M Microbiology, St. Paul, MN). The Petrifilms were placed on a flat surface and 1 mL of each cheese cracker dilution was placed on the center of the bottom film containing dehydrated medium. The inoculum was covered by the top film and spread to an area of 20 cm^2 using the plastic spreader supplied. The 3M Petrifilms were incubated at 22°C for 5 d. After the incubation period, the colonies were counted. Salt particle sizes produced by this nano spray-drying method were in optimum, stable, nonclumping condition, for 4 mo. Hence, the surface-salted cheese crackers, a shelf-stable product, were evaluated at 1 wk (relatively soon after manufacture) and at 4 mo.

Sensory Study

The sensory study was approved by the Louisiana State University Institutional Review Board (exemption number HE13–15). A balanced incomplete block design was used to conduct the consumer analysis of cheese crackers using 476 participants in total at 1 wk and 4 mo. For significance, the target was that at least 100 participants evaluate each cracker treatment at each time point. To avoid the sensory overload of all 7 cracker treatments being evaluated by the same 100 participants, a balanced incomplete block was used (Hinkelmann and Kempthorne 2005). The 7 cracker treatments were assigned to the 7 blocks at 1 wk or 4 mo as cracker treatments 1, 2, and 4 in block 1; cracker treatments 2, 3, and 5 in block 2; cracker treatments 3, 4, and 6 in block 3; cracker treatments 4, 5, and 7 in block 4; cracker treatments 5, 6, and 1 in block 5; cracker treatments 6, 7, and 2 in block 6; and cracker treatments 7, 1, and 3 in block 7 (Hinkelmann and Kempthorne 2005). Each participant evaluated 3 cracker treatments at each time point. Each block, at each time point, was evaluated by 34 participants; hence, 102 participants evaluated each cracker treatment at each time point (Hinkelmann and Kempthorne 2005). The cheese crackers were placed on plastic plates, and a 3-digit random number code was used to label the plastic plates. Samples were provided to each participant along with the evaluation questionnaire, which consisted of a 9-point rating scale (1 = dislike extremely to 9 = like extremely) for color, aroma, crunchiness, saltiness, and overall liking. The evaluation questionnaire also included saltiness rating as not enough, just about right (**JAR**), and too much. Acceptability and purchase intent (**PI**) questions (as yes/no questions) were included. Participants were also asked if they would buy the product knowing that it was 25 or 50% lower in table salt. The sensory study was advertised by mass e-mails and colored printouts periodically posted on the entrance doors of university buildings. The sensory evaluations were conducted by students (between ages of 18 and 30 yr) and staff and they received a treat (cookie and soft drink) for their participation.

Statistical Analysis

The cheese cracker data from the microbiological analysis were analyzed using Proc Mixed and the data from the sensory analysis were analyzed using Proc Glimmix (SAS Institute Inc., Cary, NC). The analysis of change of PI was performed using McNemar's test in SAS 9.3 (SAS Institute Inc.). Differences of least squares means were used to determine significant differences at $P < 0.05$ for main effects (treatment and time) and their interaction effects (treatment × time). Data are presented as means ± standard deviation of the means. Significant differences were determined at $\alpha = 0.05$. Significant differences ($P < 0.05$) among the main effects were analyzed using Tukey's adjustment and Macro program to determine differences between treatments.

RESULTS AND DISCUSSION

The particle size distributions obtained for salt particles from different concentrations (3, 5, 10, and 20% wt/wt) of salt solutions that were nano spray dried are shown in Figure 1. The nano spray-dried salt particles of 3% salt (Figure 1A) had approximately 80% of the particles in the size range of 0.5 to 1.9 μm. Over 90% of the particles obtained from the 5% concentration ranged from 0.8 to 13.1 μm (Figure 1B). The nano spray-dried salt particles from the 10% salt concentration (Figure 1C) had 91% of the particles in the size range between 2.8 and 26.2 μm (Figure 1C), and over 90% of the particles obtained from the 20% concentrations were between 3 and 74 μm (Figure 1D). Size distribution curves tended to be bell shaped. At the lower concentrations of 3 and 5%, taller bell curves were obtained. As the concentration increased, particle size increased. The smallest particle size was obtained at the lowest concentration (3%).

Scanning electron microscopy was used to observe the structure of nano spray-dried salt (Figure 2). All nano spray-dried salts from the different concentrations were irregular in shape (Figure 2). The 3% salt concentration (Figure 2A) had the smallest size range for particles and an average particle size of 1.5 μm. Its particles were slightly agglomerated compared with particles from the other salt concentrations (Figure 2B, C and D). During the first or constant drying stage in nano spray drying, hot air causes an increase in droplet

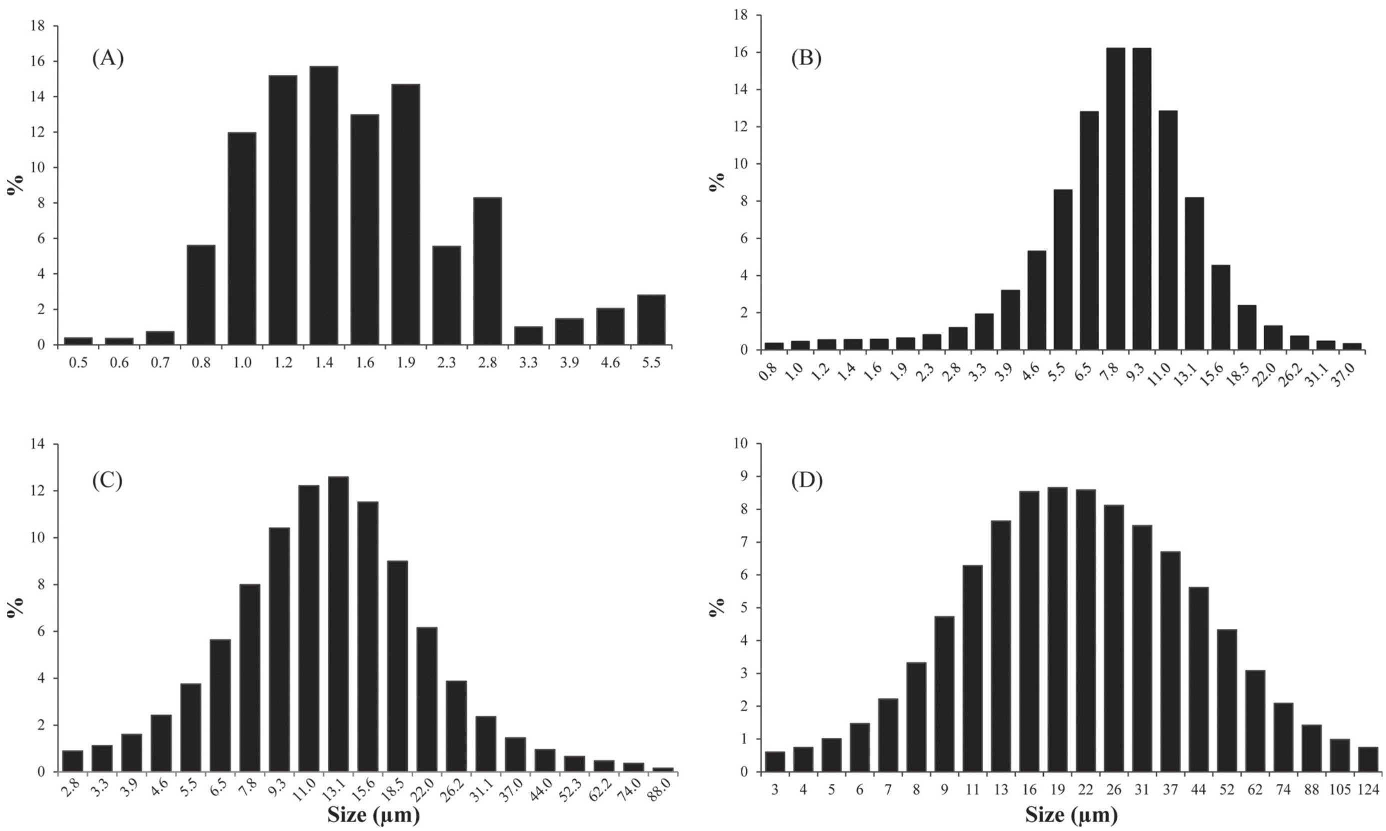

Figure 1. Salt particle size distributions of nano spray-dried salt solutions: (A) 3%, (B) 5%, (C) 10%, and (D) 20% (wt/wt).

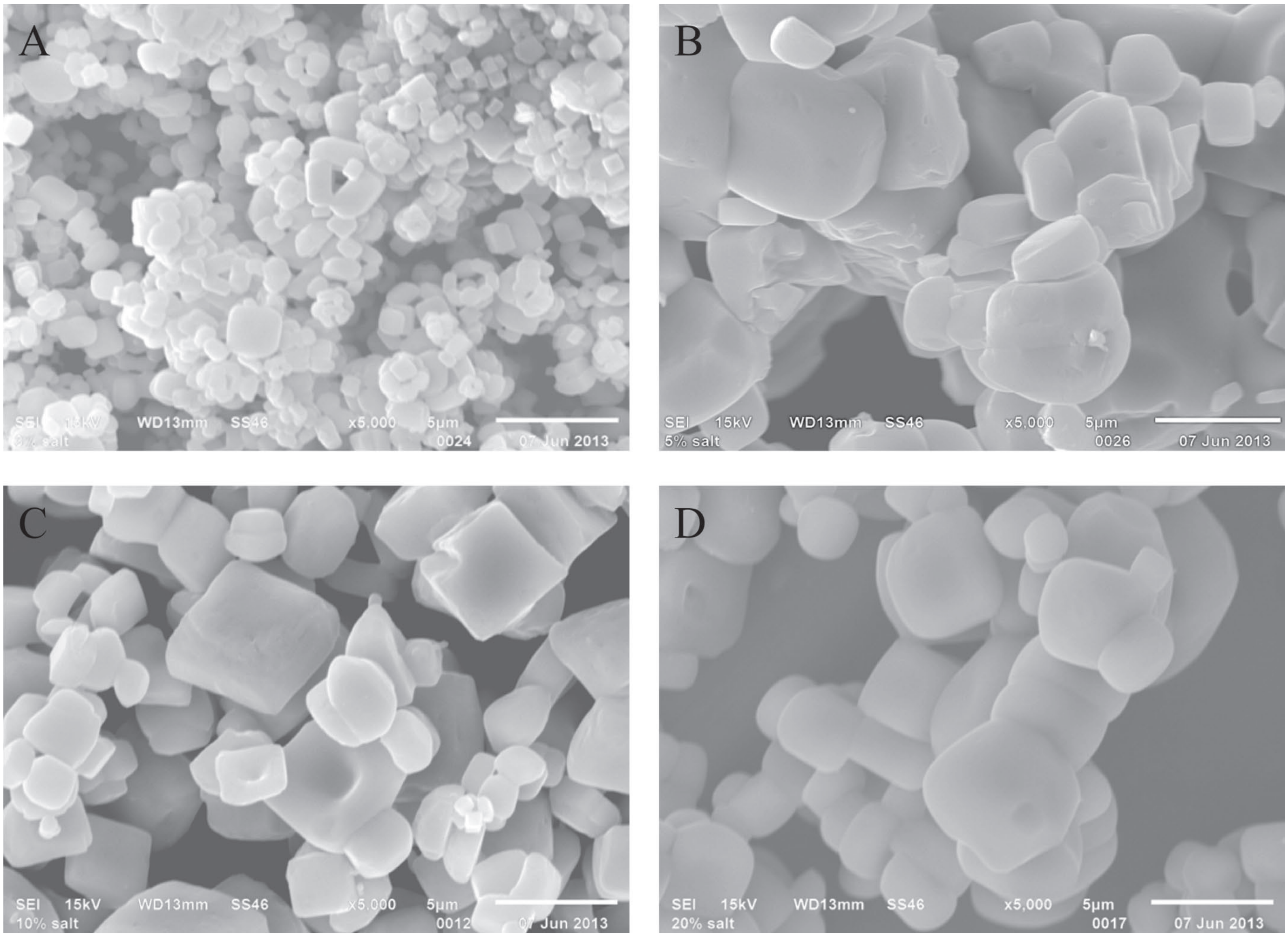

Figure 2. Scanning electron photomicrographs of salt particles obtained from nano spray-dried salt solutions at (A) 3%, (B) 5%, (C) 10%, and (D) 20% (wt/wt). Scale bar = 5 μm.

temperature, which promotes rapid liquid evaporation from the droplet surface and a corresponding reduction in droplet size, and subsequently results in dry particles (Buchi, 2012). Hence, the dry particle size tended to be larger with higher salt concentrations within the droplet compared with particles obtained from low concentration (3%) salt solutions.

Yeast Counts

The yeast counts of surface-salted cheese cracker as influenced by different salt particle sizes and concentrations are shown in Table 1. We detected significant ($P < 0.0001$) treatment × time interaction, treatment ($P < 0.0001$), and time ($P < 0.0001$) effects. Yeast counts in all treatments increased significantly ($P < 0.05$) from 1 wk to 4 mo (Table 1). Nano spray-dried salt 2% and Microsized salt 2% at 4 mo had significantly ($P < 0.05$) lower yeast counts than regular 2% at 4 mo (Table 1). Yeast counts for nano spray-dried salt 1.5% at 4 mo were significantly ($P < 0.05$) lower than regular 1.5% at 4 mo (Table 1). Nano spray-dried salt 1% at 4 mo had significantly ($P < 0.05$) lower yeast counts compared with Microsized salt 1% and regular 1% at 4 mo (Table 1). These results indicated that the nano spray-dried salt treatments (1, 1.5, and 2%) had positive effects on yeast reduction at 4 mo compared with regular salt (1, 1.5, and 2%).

Having nano spray-dried salt crystals on the surface of the cheese crackers increased the surface area 1,000-fold compared with regular salt crystals, leading to a reduced area available for yeast growth. The direct effects of the chloride ion, the reduced oxygen tension, and interference with the action of enzymes contribute to the preservative action of salt (Dams and Moss, 2000). All organisms with a semipermeable membrane

Table 1. Least squares means for yeast counts of surface-salted cheese crackers at 1 wk and 4 mo

Salt type and concentration (wt/wt)	Yeast (Log cfu/mL) 1 wk	4 mo
Regular, 2%	0^{e}	2.254^{a}
Regular, 1.5%	0^{e}	2.238^{a}
Regular, 1%	0^{e}	2.202^{ab}
Microsized,[1] salt 2%	0^{e}	1.867^{d}
Microsized salt, 1.5%	0^{e}	2.156^{ab}
Microsized salt, 1%	0^{e}	2.175^{ab}
Nano spray-dried salt,[2] 2%	0^{e}	1.835^{d}
Nano spray-dried salt, 1.5%	0^{e}	2.052^{bc}
Nano spray-dried salt, 1%	0^{e}	1.960^{cd}

[a–e]Means not containing a common letter are significantly different ($P < 0.05$).

[1]Cargill Salt (Minneapolis, MN).

[2]Salt produced in our laboratory by nano spray drying.

are subject to osmotic pressure—the effect of water moving in and out of the cell (Wassenaar, 2013). If the cell did not have a cell wall, this could cause the cell to burst. Salt works as a preservative because when the outside environment around a cell is salty and the concentration of water in the solution is less than that inside the cell, water tends to leave the cell, causing cell dehydration (Wassenaar, 2013). In our study, surface salting using nano spray-dried salt may have increased cell dehydration and hence significant reduction in yeast growth at 4 mo because of increases in surface area compared with regular and Microsized salts.

Mold Counts

We did not detect mold growth in any of the treatments at 1 wk or 4 mo. Saddozai and Khalil (2009) analyzed molds in snack foods (crackers and potato chips) at different schools and colleges and reported absence of molds in each of the places. Moreover, Hozova et al. (1997) evaluated mold in amaranth crackers every month for 4 mo and they reported absence of mold until the end of 4 mo.

Sensory Evaluation

Because the main question was whether the sensory saltiness of 1% and 1.5% nano spray-dried salt was similar to that of regular 2% (control) salt, as currently used by industry, all sensory comparisons were made to regular 2% salt.

Color. The sensory analysis of color of surface-salted cheese crackers as influenced by different salt particle sizes and concentrations is reported in Table 2. We detected a significant ($P < 0.0125$) effect for treatment ×

Table 2. Least squares means for sensory color, aroma, saltiness, just about right (JAR) saltiness, crunchiness, overall liking, and acceptability of surface-salted cheese cracker at 1 wk and 4 mo[1]

Salt type and concentration (wt/wt)	Color 1 wk	Color 4 mo	Aroma 1 wk	Aroma 4 mo	Saltiness 1 wk	Saltiness 4 mo	JAR Saltiness 1 wk	JAR Saltiness 4 mo	Crunchiness 1 wk	Crunchiness 4 mo	Overall liking 1 wk	Overall liking 4 mo	Acceptability 1 wk	Acceptability 4 mo
Regular, 2%	5.73^{b}	6.12^{ab}	5.83^{c}	6.19^{bc}	5.08^{cd}	4.86^{d}	1.41^{gh}	1.29^{h}	6.54^{cde}	6.43^{cde}	5.30^{d}	5.52^{cd}	0.65^{d}	0.69^{cd}
Microsized,[2] 2%	6.28^{ab}	6.39^{a}	6.78^{ab}	6.47^{ab}	6.08^{ab}	6.27^{ab}	1.94^{bcde}	2.16^{ab}	6.35^{de}	6.75^{abcd}	6.11^{abc}	6.45^{ab}	0.83^{abc}	0.87^{ab}
Microsized, 1.5%	6.41^{a}	6.43^{a}	6.51^{ab}	6.81^{a}	6.67^{a}	6.47^{ab}	1.93^{bcde}	1.86^{cde}	7.23^{ab}	6.44^{cde}	6.65^{a}	6.22^{ab}	0.93^{a}	0.88^{ab}
Microsized, 1%	6.41^{a}	6.36^{ab}	6.76^{ab}	6.40^{ab}	6.19^{ab}	6.35^{ab}	1.68^{ef}	1.67^{efg}	7.33^{a}	6.68^{abcd}	6.44^{ab}	6.38^{ab}	0.88^{ab}	0.83^{abc}
Nano spray-dried salt,[3] 2%	6.12^{ab}	6.57^{a}	6.38^{ab}	6.71^{ab}	6.55^{ab}	6.19^{ab}	2.24^{a}	2.21^{ab}	7.07^{abc}	6.62^{bcd}	6.53^{a}	6.14^{abc}	0.94^{a}	0.80^{abcd}
Nano spray-dried salt, 1.5%	6.27^{ab}	6.19^{ab}	6.65^{ab}	6.46^{ab}	6.73^{a}	6.23^{ab}	2.09^{abc}	2.02^{abcd}	7.27^{ab}	6.29^{de}	6.82^{a}	6.17^{abc}	0.96^{a}	0.85^{abc}
Nano spray-dried salt, 1%	6.48^{a}	6.13^{a}	6.69^{ab}	6.59^{ab}	6.69^{a}	5.79^{bc}	1.79^{def}	1.55^{fgh}	7.22^{ab}	5.89^{e}	6.57^{a}	5.84^{bcd}	0.88^{ab}	0.75^{bcd}

[a–h]Means within an attribute not containing a common letter are significantly different ($P < 0.05$).

[1]Color, aroma, saltiness, crunchiness, and overall liking were evaluated using a 9-point rating scale (1 = dislike extremely to 9 = like extremely); JAR-saltiness was evaluated as 1 = not enough, 2 = just about right, and 3 = too much; acceptability was evaluated as yes = 1 and no = 0.

[2]Cargill Salt (Minneapolis, MN).

[3]Salt produced in our laboratory by nano spray drying.

time interaction. At 1 wk, nano spray-dried salt 1% had significantly ($P < 0.05$) higher sensory scores compared with control (Table 2). However, at 4 mo, we found no significant ($P > 0.05$) differences in sensory color scores between the treatments (Table 2).

Aroma. The aroma data are shown in Table 2. We detected a significant ($P < 0.0003$) effect for treatment × time interaction. At 1 wk, Microsized salt and nano spray-dried salt treatments had significantly ($P < 0.05$) higher aroma scores compared with controls (Table 2). At 4 mo, there were no significant ($P = 0.5560$) differences between nano spray-dried salt treatments (1, 1.5, and 2%) and the control (Table 2).

Saltiness. Saltiness data are presented in Table 2. We detected a significant ($P < 0.0173$) effect for treatment × time interaction. At 1 wk and 4 mo, nano spray-dried salt treatments resulted in significantly ($P < 0.05$) higher preferred saltiness scores compared with controls (Table 2). These results are encouraging because the cheese cracker industry uses regular 2% salt. Consumers preferred the saltiness of surface-salted cheese cracker with nano spray-dried salt 1% (50% less salt) instead of control (regular 2%).

JAR Saltiness. To further understand the consumers' saltiness scores, the consumers attending the sensory study were asked to select the saltiness of the surface-salted cheese cracker in 3 categories: too weak (1), just about right (2), and too strong (3). The JAR saltiness data of surface-salted cheese cracker as influenced by different salt particle sizes and concentrations are shown in Table 2. The treatment × time interaction effect was significant ($P < 0.0131$). At 1 wk, nano spray-dried salt and Microsized salt treatments had significantly ($P < 0.05$) more JAR saltiness ratings than the regular 2% salt (Table 2). At 4 mo, nano spray-dried salt (1.5 and 2%) and Microsized salt (1, 1.5, and 2%) showed significantly ($P < 0.05$) more JAR saltiness ratings compared with controls (Table 2). These results obtained for JAR saltiness are encouraging because cheese cracker industries use regular 2% salt. Consumers had more JAR saltiness ratings of surface-salted cheese cracker with nano spray-dried salt 1.5% (25% less salt) than control.

Crunchiness. The crunchiness data are shown in Table 2. The treatment × time interaction effect was significant ($P < 0.0001$). At 1 wk, nano spray-dried salt 1% and 1.5% and Microsized salt 1 and 1.5% had significantly ($P < 0.05$) higher crunchiness scores compared with the control (regular 2%; Table 2). At 4 mo, there were no significant ($P > 0.05$) differences in crunchiness scores between control, Microsized salt, and nano spray-dried salt treatments (Table 2).

Overall Liking. The overall liking of surface-salted cheese crackers as influenced by different salt particle sizes and concentrations is shown in Table 2. The treatment × time interaction effect was significant ($P < 0.0002$). At 1 wk, nano spray-dried salt 1, 1.5, and 2% and Microsized salt 1, 1.5, and 2% had significantly ($P < 0.05$) higher scores for overall liking compared with control (regular 2%; Table 2). At 4 mo, Microsized salt 1, 1.5, and 2% had significantly ($P < 0.05$) higher scores for overall liking than regular 2% and we detected no differences in nano spray-dried salt 1 and 1.5% compared with the control. Thus, overall liking for cheese crackers with 25 and 50% less salt, through smaller particle size, was comparable to that of cheese crackers with regular salt (2%).

Acceptability. The acceptability data are reported in Table 2. We detected a significant ($P < 0.023$) effect for the treatment × time interaction. At 1 wk, nano spray-dried salt (1, 1.5, and 2%) and Microsized salt (1, 1.5, and 2%) treatments had significantly ($P < 0.05$) higher acceptability scores than controls (Table 2). At 4 mo, use of Microsized salt 1.5 and 2% had significantly higher scores compared with regular 2% but there was no significant ($P > 0.05$) difference between control and the nano spray-dried salt treatments (Table 2). This means that for 25 and 50% lower salt content, through smaller particle size, acceptability was comparable to control (regular salt at 100% usage level).

Table 3. Probability > F of purchase intent (PI) changes of Microsized salt (1 and 1.5% wt/wt) and nano spray-dried salt (1 and 1.5% wt/wt) obtained from the sensory study before and after information about 25 and 50% reduction in salt content of surface-salted cheese cracker at 1 wk and 4 mo

Salt type and concentration (wt/wt)	1 wk McNemar's test	1 wk Pr > F	4 mo McNemar's test	4 mo Pr > F
Microsized[1] salt, 1.5%	6.05	0.0139	11.21	0.0011
Microsized salt, 1%	10.89	0.001	5.41	0.0265
Nano spray-dried salt,[2] 1.5%	18.75	<0.0001	10.24	0.0014
Nano spray-dried salt, 1%	5.22	0.0321	1	0.3173

[1]Cargill Salt (Minneapolis, MN).

[2]Salt produced in our laboratory by nano spray drying.

Purchase Intent. The PI of surface-salted cheese crackers as influenced by different salt particle sizes and concentrations was measured using McNemar's test (McNemar 1947). The PI probabilities were estimated before and after consumers were informed that the surface-salted cheese crackers were either 25 or 50% lower in salt content and told about the proven health benefits of less sodium. All 25 and 50% lower salt treatments had significant PI probabilities except nano spray-dried salt 1% at 4 mo (Table 3). At 1 wk, PI of surface-salted cheese crackers using Microsized salt 1.5 and 1% and nano spray-dried salt 1.5 and 1% increased from 49, 51, 44, and 54.9% to 70.5, 78.4, 80.4, and 73.5%, respectively (Figure 3). At 4 mo, PI of surface-salted cheese crackers using Microsized salt 1.5 and 1% increased from 48 and 51.96 to 77 and 71.6%, respectively, and PI of surface-salted cheese crackers using nano spray-dried salt 1.5% increased from 50.98

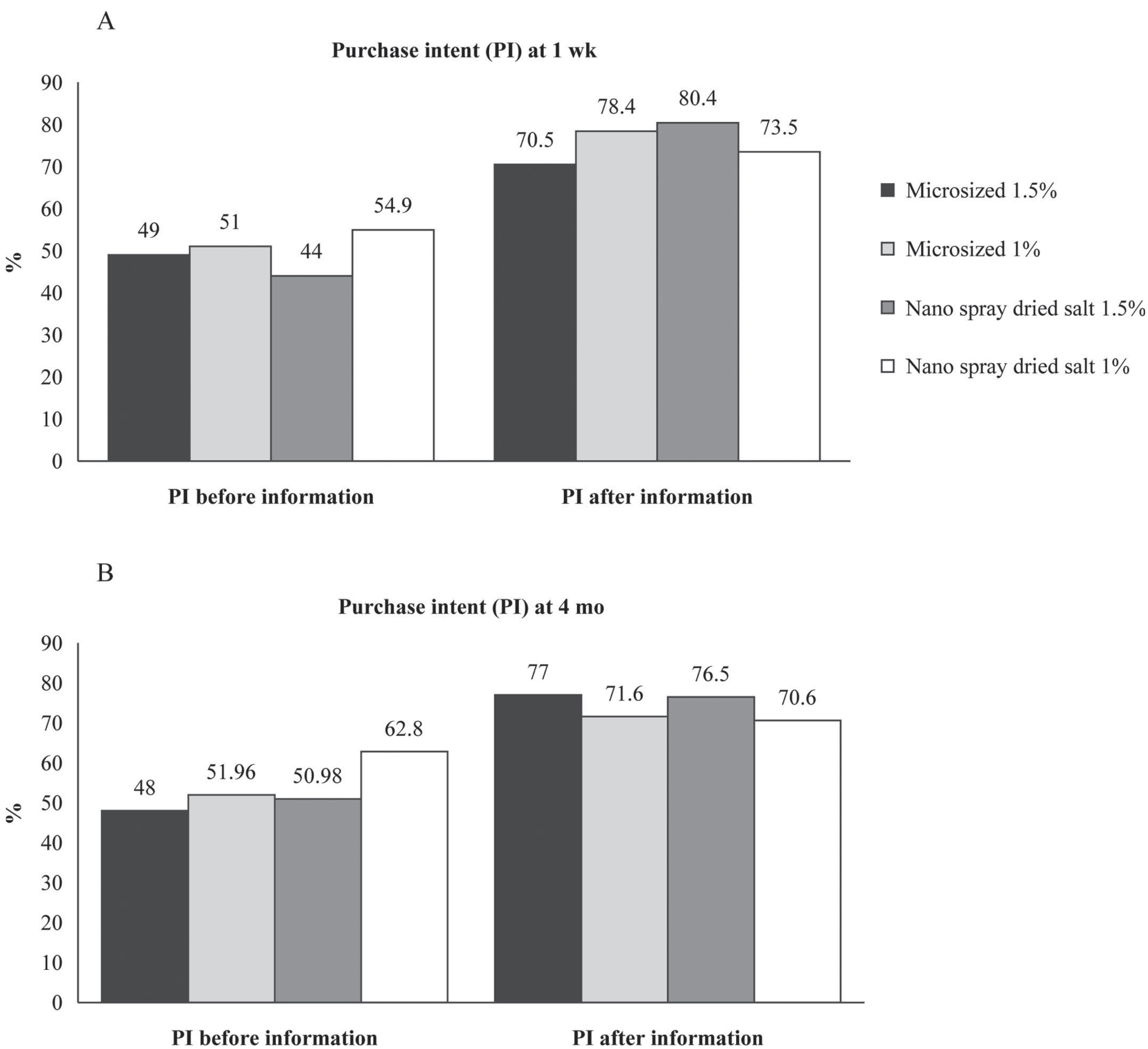

Figure 3. Purchase intent (PI) changes obtained from the sensory study before and after information about 25 and 50% reduction in table salt use on surface-salted cheese crackers at (A) 1 wk, and (B) 4 mo. The microsized 1% and 1.5% salts were Microsized 95 extra fine salt obtained from Cargill Salt (Minneapolis, MN) and had an average particle size of 15 μm. The nano spray-dried 1% and 1.5% salts were manufactured in our laboratory and had an average particle size of 1.5 μm.

to 76.5% after consumers were informed about the 25% salt reduction (Figure 3).

CONCLUSIONS

Nano spray-dried salt treatments had a positive effect on yeast reduction at 4 mo compared with regular salt. At 4 mo, nano spray-dried salt treatments (1.5 and 1% wt/wt) resulted in significantly higher saltiness scores compared with controls (regular 2% salt), and nano spray-dried salt (1.5 and 2%) treatments showed significantly more JAR saltiness scores compared with controls. Sodium chloride nano spray-dried particles enhanced saltiness in cheese crackers and maintained low counts of yeasts and absence of molds, and did not adversely influence sensory quality attributes. Purchase intent increased by 25% for use of nano spray-dried salt 1.5% after consumers were informed about the 25% reduction in salt content of the cheese cracker. At 4 mo, consumers detected no significant differences in sensory color, aroma, crunchiness, overall liking, and acceptability scores in crackers with 1.5% and 1% nano spray-dried salt compared with 2% regular salt. This indicated that 25 to 50% less salt would be appropriate if particle sizes were reduced 3 log from regular salt to nano spray-dried salt. Reduction in sodium chloride particle size of 3 log from regular salt to nano spray-dried salt increased saltiness but reduction in particle size of 1 log from Microsized salt to nano spray-dried salt did not increase the saltiness of surface-salted cheese crackers. Salt with reduced particle sized prepared by nano spray drying can be recommended for use in surface-salted cheese crackers to reduce sodium intake.

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