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IMPACT OF SALT CRYSTAL SIZE ON IN-MOUTH DELIVERY OF SODIUM AND SALTINESS PERCEPTION FROM SNACK FOODS

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KEYWORDS
Salt reduction, sodium chloride, sodium concentration, time–intensity

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ABSTRACT

Fried, sliced potato crisps were flavored with sodium chloride of varying size fractions to investigate the impact of salt crystal size on the delivery rate of sodium to the tongue and resultant saltiness, measured over 65 s with a defined chew protocol (three chews, then holding the bolus in the mouth without swallowing). Salt crystal size impacted upon the delivery rate and perceived saltiness. The smallest crystal size fraction dissolved and diffused throughout the mouth to the tongue saliva faster than the medium and the largest ones; the smallest crystal size fraction also had the highest maximum concentration and greatest total sodium. These results correlated well with the sensory perceived saltiness, where the smallest crystal size fraction resulted in the fastest T_{max}, highest maximum saltiness intensity and maximum total saltiness. The different delivery rates can be explained by differential dissolution kinetics and enhanced mass transfer of sodium across the saliva.

PRACTICAL APPLICATIONS

Sodium reduction is a major challenge for the global food industry. The results of this work illustrate how modification of salt crystal size fraction might impact sensory perceived saltiness, and that a smaller crystal size fraction can achieve a greater maximum saltiness per unit of sodium consumed. There are a number of technical hurdles to be overcome before implementation of this approach, both practical (limitations in processability) and sensorial (changes in the time–intensity profile), but the results do demonstrate that enhanced dissolution and diffusion kinetics can be achieved through modification of salt crystal size, which should be seriously considered by snack food manufacturers when approaching product reformulation.

INTRODUCTION

There is a proven association between excessive sodium intake and the development of hypertension (MacGregor and Sever 1996); the causal link between dietary sodium and hypertension-derived cardiovascular disease has prompted public health bodies and regulatory authorities to recommend reducing dietary salt intake to 5 g/day (WHO 2007). Currently, the average daily salt intake from foods in U.K. adults is 8.1 g (DOH 2011). Further reductions, although being attempted, are technically challenging and new approaches are therefore needed.

Salt has a variety of functions in food including improving the sensory properties of foods by providing saltiness, as the prototypical stimulus for salt taste (Dötsch *et al.* 2009), decreasing bitterness, increasing sweetness, masking processed notes and other congruent flavor effects (Keast and Breslin 2003). It also acts as a preservative, enhances

functionality and controls fermentation (Gelabert *et al.* 2003). In snack foods, salt has a variety of functions: it can act as a process aid generating structure and color in processed snacks and as a topical tastant either on its own or in combination with other flavors (Miller and Barringer 2002). The removal, or reduction, of sodium from snack foods is technically challenging and requires all aspects of the functionality of sodium containing ingredients to be addressed. Recent studies have shown that reductions of the sodium content in some solid foods (2–5%) were not noticeable by consumers (Drake *et al.* 2011); that in crisps, normal eating patterns would not release the majority of the added topical salt (Xian and Fisk 2012); and that the complexity of the food matrix influences the perception of saltiness (Drake *et al.* 2011). In this study, the focus will be on the topical application of sodium chloride to crisps (fried, sliced potato of ca. 1 mm thick) where the sodium chloride not only enhances the flavor of the snack food but also contributes saltiness.

The temporal delivery of flavor has been widely studied in recent years and strongly depicts the overall sensory perception of a food (Busch *et al.* 2009; van Ruth and Roozen 2010). During mastication, the delivery of odorants and tastants is affected by several factors, such as the nature and physicochemical properties of the flavor compounds under study (Boland *et al.* 2006), the structure and breakdown of the food matrix (Wilson and Brown 1997), and oral processing (Buettner *et al.* 2002). If we specifically consider the temporal delivery of sodium from a topically applied crystal on the surface of a crisp, the process of eating crisps can be separated into a number of phases: chewing, hydration, bolus formation and swallowing (Rosenthal 1999). During chewing, the crisp is physically broken down and the topically applied salt is mixed, forming a bolus. Saliva hydrates the salt, which dissolves and becomes locally distributed throughout the mouth by a tongue mixing phenomenon. Finally, the bolus is swallowed and the tongue cleans the palate, removing any residual particles of crisp that remains on the mouth surface.

Sodium is only perceived when the saliva concentration of sodium is significantly higher than the resting saliva concentration, or exceeds the residual concentration from a previous stimulus (Delwiche and O'Mahony 1996). Sodium is perceived via receptor cells located close to taste pores on the tongue. Sodium ions pass through sodium specific ion channels on the apical end of the taste cells, leading to cell depolarization, neural transduction via nerve pathways to the nucleus of the solitary tract where neurons synapse at the base of the brain and then further synapse to link to the frontal cortex via the thalamus. Owing to the specificity of the ion channels, alternative "salts" are less effective. Therefore, if sodium reduction is required without modifying perception, one has to address either the availability of sodium (molecular binding) or the delivery of sodium (dissolution, diffusion, mixing kinetics).

It was then hypothesized that sodium delivery is dependent on both effective mixing (oral processing) and effective delivery (dissolution and diffusion), and that if one removes the uncontrollable oral processing factor (artificially by experimental design), the delivery of sodium remains the limiting step. Delivery is dependent on two factors: first, the dissolution of salt from its crystal form, and, second, the diffusion of free sodium through the static saliva barrier layer on the surface of the tongue. As the static diffusion cannot be influenced, the remaining factor is dissolution from crystal to liquid form and one route to control this would be through the reduction of crystal size based on an increase in the surface area.

The objective of this study was therefore to evaluate the impact of various salt crystal size fractions on the delivery of sodium from sliced fried potato crisps to the oral saliva and perception of saltiness over time.

MATERIALS AND METHODS

Salt (98.2%, SAXA, Ashford, U.K.) was ground by hand using a mortar and pestle and mechanically sieved using nickel sieves (Fisher, Loughborough, U.K.) into four different fractions: <106, 106–425, 425–710 and >710 μm. The >710 μm was discarded and the remaining three fractions were loaded onto crisps and labeled as S1, S2 and S3, respectively.

Crisps were purchased from a local supermarket and were within recommended use by date and manufacturer specifications. They contained no added sodium chloride and were individually prescreened by hand to uniform size and shape (weight of 0.9 $\pm$ 0.1 g, diameter of 50 $\pm$ 5 mm).

Sample Preparation

The crisps were pooled, mixed and then divided into three batches of 100 $\pm$ 1 g. The amount of presifted salt needed to achieve a salt/crisp ratio of 1:40 was calculated for each of the three salt crystal size fractions (2.5 g). Each of the crisps batches was placed in a different preweighed polyethylene food-grade 30 $\times$ 49.5 cm transparent bag (Waitrose, Berkshire, U.K.) and heated in a class E 800 W SHARP microwave (Shanghai, China) for 20 s. Salt was gradually sprinkled over the crisps in the bags, while gently shaking to ensure an even distribution throughout the bag. A sample with no salt added was used as well and labeled as blank. All samples containing salt were tested for sodium levels and contained comparable sodium concentrations (analysis of variance [ANOVA], Tukey's post hoc test $P < 0.05$).

Chewing and Swabbing Protocol

Assessors ($n = 8$, aged 42–72 years, 2 male, 6 female) from the University of Nottingham external trained panel volunteered to take part in the study and were trained in the use of a standard chewing protocol during two training sessions. The different crisp samples were offered in identical pots labeled with random three-digit codes and were presented in random balanced order across the panel: false chew, blank, salted with S1, S2 and S3. At time 0, the panelists swabbed their tongue with a preweighed cotton bud (VWR, Vienna, Austria) and placed an individual crisp (1 ± 0.1 g) at the back of the tongue. A clock was started; the crisp was chewed three times with free tongue movement. No more chewing, tongue movement or saliva swallowing was allowed. The bolus was moved to one side of the mouth and the tongue was cleaned by the front teeth and swabbed every 5 s for 65 s using preweighed cotton buds. Subsequently, these were placed in preweighed 15-mL sample tubes (Sarstedt, Nümbrecht, Germany). After 65 s, the panelists were allowed to swallow the samples. All panelists were required to palate cleanse using plain unsalted crackers (99% crackers, Rakusen's, Leeds, U.K.), green apple (Granny Smith variety, U.K.) and bottled water (Evian, Danone, Evian-les-Bains, France) prior to sample tasting with a 5-min break between samples, a 15-min break every 3 samples, doing 6 and 7 samples/day, respectively. In addition, 65 s was chosen as an artificial endpoint as it offered sufficient data points without inducing panel boredom.

Isolated cotton buds were weighed to calculate saliva weight, diluted with 6 mL of diluent (ultrapure water and diluent; Sherwood Scientific Ltd., Cambridge, U.K.) and 2 mL of methanol (ACROS, Geel, Belgium) and mixed using a D-91126 vortex (Heidolph Instruments, Schwabach, Germany) for 1 min. Furthermore, 2 mL of solution was extracted using a 2-mL plastic syringe (BD Plastipak, NJ, USA), and passed through a 0.45-μm filter (Sartorius Stedim Biotech Minisart, Göttingen, Germany) into a polystyrene $10 \times 10 \times 45$ mm cuvette (Sarstedt).

Sodium Concentration

Sodium concentration of diluted isolate of saliva collected was analyzed using a model 410 Sherwood flame photometer (Sherwood Scientific Ltd.). The concentration of sodium in the samples was evaluated at a wavelength of 589 nm against control standards at 0, 2, 4, 6 and 10 ppm. The calibrating curve showed repeatability with an $R^2 > 0.99$ and linearity in the region of 0–10 ppm.

Sensory Evaluation

An experienced panel, same as in previous experiment, was trained (two sessions of 2 h each) on time–intensity evaluation of saltiness and using time–intensity scales using the computerized data acquisition system FIZZ 2.46 (Biosystems, Couternon, France) at an acquisition rate of one data point per second. The perceived intensity was recorded on an unstructured category scale anchored at the extremes by the numbers "0" and "10." Panelists were presented with four different crisp samples labeled with random three-digit codes: unsalted, salted with S1, S2 and S3 salt crystals, respectively. Each sample weighed 1 ± 0.1 g and was presented in quintuplicate for evaluation of saltiness by time–intensity. At time 0, preweighed individual crisps were placed by the panelist at the back of their tongue. The crisp was chewed three times with free tongue movement and the panelist was able to use the mouse to start the rating. No more chewing, tongue movement or saliva swallowing was allowed. After 65 s, the panelists were allowed to swallow the sample, but no more rating was recorded. The order of presentation of samples was randomized within a session and across the panel. All assessors were required to palate cleanse using plain unsalted crackers (99% crackers; Rakusen's), green apple (Granny Smith variety) and bottled water (Evian) prior to sample tasting with a 5-min break between samples.

Judges differed significantly ($P < 0.001$) in their responses to all samples but were consistent among replications. A large variation between panelists was expected on time–intensity data as reported in previous studies (Heymann and Lawless 1998). In this study, each judge demonstrated a distinctive curve shape, which was reproducible across replicates.

Scanning Electron Microscope

For the study of the surface of the crisps, the samples were attached to the specimen holder by double-coated adhesive tape. The specimens were examined by a JEOL T-200 (Akishima, Japan) scanning electron microscope (SEM) at 8 kV for isolated S1, S2 and S3 salt particle sizes, and at 20–25 kV for the individual salted crisps.

Statistical Analysis

The FIZZ 2.46 software (Biosystems) normalization and computation algorithm was used for the formulation of extracted parameters from the time–intensity curves: T_{max} = time to maximum intensity and I_{max} = maximum intensity (Fig. 2). *T–I* curve profiles for saltiness of each sample were determined by calculating the mean of intensity values of all the replicates over the entire panel's response. Mean values were plotted versus time to give a visual representation of the *T–I* curve properties of each sample for saltiness. In addition, the total area under the

curve (TA) measuring the total perceived intensity and the total sodium concentration in saliva was determined.

All the parameters were subjected to an ANOVA (with Duncan post hoc, repeated measures, 2012), performed using R 2.15.0 (R Development Core Team) to determine whether significant differences could be found between the different salt crystal fractions ($P < 0.05$). Data are expressed as means ± standard deviation.

RESULTS AND DISCUSSION

Crisps were chewed with a defined chew protocol, and saliva sodium concentration and sensory perceived saltiness were measured over 65 s. Salivary sodium concentrations are presented in Table 1 and Fig. 1, and those of sensory perceived saltiness are presented in Table 2 and Fig. 2.

Temporal Delivery of Sodium to the Saliva

Sodium was steadily released into the saliva in the oral cavity over the experimental time course (Fig. 1). Initially, sodium concentration was low, and over the first 20–50 s, the concentration increased in a sigmoidal fashion, as sodium dissolved from the crisp bolus into the saliva. Saliva sodium concentration then peaked (2,713–4,847 mg/kg) and reduced; there was a significant impact of salt crystal size on the sodium concentration over time, the maximum sodium concentration found in the saliva and the time required to achieve the maximum sodium concentration.

TABLE 1. FLAME PHOTOMETER CURVE ANALYSIS FOR SODIUM CONCENTRATION IN SALIVA AFTER CHEWING CRISPS SALTED WITH THE THREE DIFFERENT SALT CRYSTAL FACTIONS, S1, S2 AND S3

Sample	I_{max} mg/kg (±SD)	T_{max} s (±SD)	TA mg s/kg (±SD)
S1	4847 (±346)^{c}	20 (±5)^{a}	15×10^4 ($\pm 2.1 \times 10^4$)^{b}
S2	3481 (±779)^{b}	40 (±5)^{b}	10×10^4 ($\pm 2.3 \times 10^4$)^{a}
S3	2713 (±529)^{a}	50 (±5)^{c}	9×10^4 ($\pm 2.1 \times 10^4$)^{a}

Different letters indicate significant differences within the data set. Data collected from eight assessors for 65 s in triplicate.
I_{max}, maximum sodium concentration; T_{max}, time to I_{max}; TA, overall sodium concentration.

To ensure a stable background was maintained throughout the experiment, a false chew (no crisps) data set was generated, which was relatively stable about the baseline (Fig. 1). Samples were then generated with no sodium and these again generated no major changes in the saliva sodium concentration. Statistically, there was no significant difference in the sodium concentration over time or the maximum sodium concentration for either the false chew sample or the blank sample.

Crisp samples containing different crystal size fractions of salt produced different temporal delivery curves. Figure 1

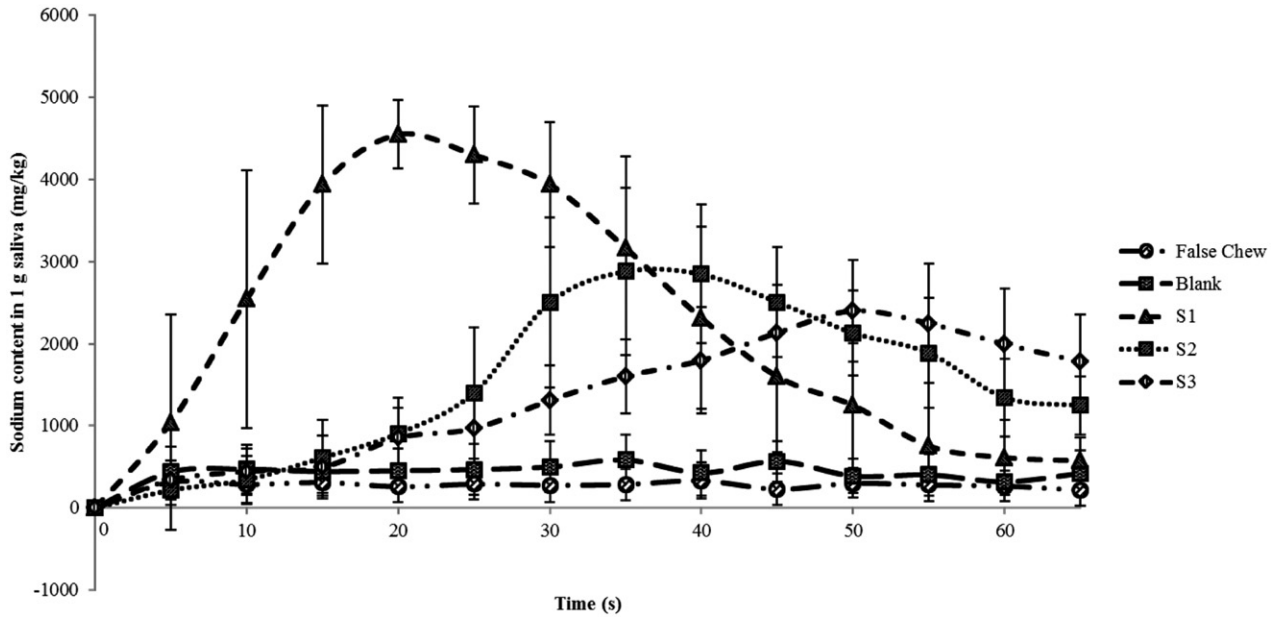

FIG. 1. SALIVA SODIUM CONCENTRATION AFTER CHEWING CRISPS SALTED WITH THREE DIFFERENT SALT CRYSTAL FRACTIONS, S1, S2 AND S3, BLANK (NO SALT) AND FALSE CHEW ($n = 8$)
Error bars indicate ± standard deviation.

TABLE 2. TIME–INTENSITY CURVE ANALYSIS FOR SALTINESS PERCEPTION FOR THE THREE DIFFERENT SALT CRYSTAL FRACTIONS AFTER CHEWING CRISPS SALTED WITH THE THREE DIFFERENT SALT CRYSTAL FACTIONS, S1, S2 AND S3

Sample	I_{max} (±)	T_{max} s (±SD)	TA s (±SD)
S1	9.48 (±0.63)[c]	17 (±8)[a]	476 (±81)[c]
S2	8.10 (±1.24)[b]	22 (±9)[b]	358 (±85)[b]
S3	6.01 (±1.41)[a]	20 (±8)[b]	257 (±79)[a]

Data collected from eight assessors for 65 s in quintuplicate.
I_{max}, maximum perceived sensory saltiness; T_{max}, time to I_{max}; TA, overall perceived saltiness sensation.

shows the concentration of sodium over time for each sample; it can be clearly seen that there is a trend between crystal size and I_{max} with the highest measured sodium concentration in saliva (4,847 ± 346 mg/kg) achieved in the fastest rate (20 s) for the smallest salt crystal size (<106 μm); the middle size crystal size fraction (106–425 μm) had an intermediate I_{max} and T_{max} and the largest (425–710 μm) crystal size fraction had the lowest maximum sodium concentration (2,713 ± 529 mg/kg) and longest time to maximum concentration (50 s).

In Table 1, $I_{max,}$ T_{max} and TA are summarized for all the samples considered in this study. Salt particle size negatively correlates with the maximum sodium concentration and total area, and salt particle size positively correlates with T_{max}. For a fixed mass of sodium chloride, a reduced particle size will result in an increase in surface area; this increase in surface area could explain the shape of the curves observed as a higher surface area will facilitate a more rapid dissolution of sodium into the saliva, which would explain the more rapid increase in oral sodium concentration observed in the samples with the smallest crystal size.

Temporal Perception of Sodium

The maximum intensity of saltiness, as recorded for all assessors, is shown in Table 2 with the time to maximum intensity and total area under the saltiness–time curve also calculated for the three different crystal size fractions.

The maximum perceived intensity of sodium was significantly enhanced in the samples containing the smallest salt crystal size fraction when compared with the largest and the intermediate crystal size fraction ($P < 0.05$). The time to maximum intensity (T_{max}) was also dependent on the crystal size fraction and the smallest salt crystal size fraction had the fastest T_{max}. These results are in agreement with a previous study where the intensity of saltiness was measured on pâté samples coated with different salt particle sizes (Shepherd *et al.* 1989), which showed that small crystals on the surface of the sample gave a maximum perceived intensity of sodium when compared with both larger particle sizes and the salt incorporated into the food.

Each batch of crisp samples was prepared with an equal loading of sodium; this is important to consider when reviewing the total area under the saltiness–time intensity curve (TA), which was strongly dependent on the crystal size fraction (Table 2), with the smallest crystal size fraction having the highest total saltiness. Over the experimental time course of 65 s, the larger salt crystal size fractions did not fully equilibrate and the sodium level did not return to its baseline by the end of the experiment (Fig. 1). This can be compared with the smallest salt crystal size fraction, which reached equilibrium at 65 s. This suggests that the particle size is limiting the process of diffusion and that residual sodium is still interacting with the bolus for the larger crystal sizes, as previously demonstrated (Xian and Fisk 2012). The total saltiness values therefore cannot be

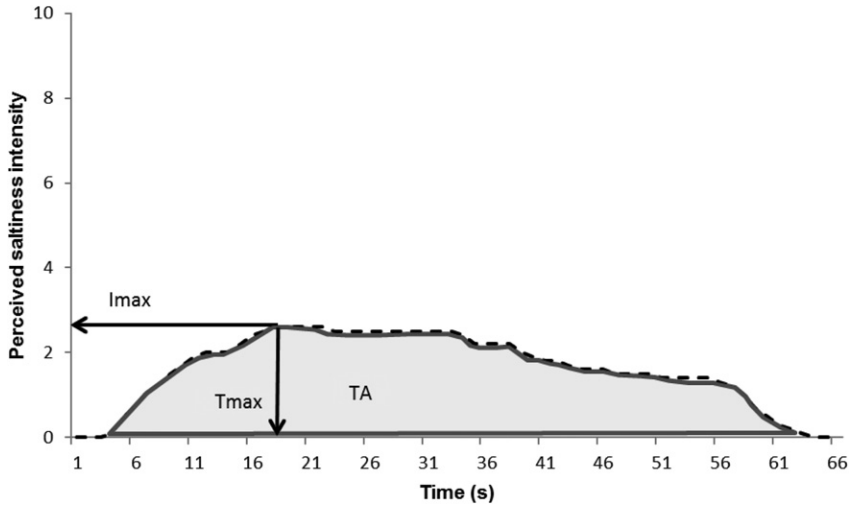

FIG. 2. A TYPICAL RESPONSE FROM PANELIST 3 RECORDING TIME–INTENSITY FOR PERCEIVED SALTINESS FOR S3 CRYSTAL SALT FRACTIONS, AND EXAMPLE OF PARAMETERS EXTRACTED

compared directly, but do indicate that in a realistic eating event (<65 s), the smaller salt crystals do deliver a greater total saltiness and a greater proportion of saltiness is available for perception.

Link between Temporal Delivery of Sodium to the Saliva and Temporal Perception of Sodium

The maximum sodium concentration measured in saliva followed a similar trend as maximum perceived saltiness by the panelists. The time to reach the perceived maximum intensity was considerably shorter than the time it took for the maximum sodium concentration to peak, for all crystal sizes. This is probably due to a number of reasons, primarily driven by the resolution limit of the sensory *T–I* protocol; in addition, it has been suggested previously that saltiness perception may not be only linked to the concentration of sodium ions in saliva, but also with difference in peak concentration to baseline concentration (Bartoshuk *et al.* 1964) and the speed of the delivery (the rate of change of concentration of sodium per unit time), or the sum of the sodium delivered over time (TA) (Morris *et al.* 2009) may contribute to enhanced perception of saltiness.

If salt crystals are considered as independent three-dimensional spheres, and that the dissolution of sodium starts as soon as they are in contact with oral saliva, it can be hypothesized that there would be a causal link between surface area and dissolution. As the salt crystals dissolve, solid mass is converted into solubilized ions, which subsequently can diffuse into the bulk saliva. The rate of change of conversion to solubilized ions will be dependent on the surface area and the differential concentration gradient, i.e., if sodium is present at a higher concentration in the saliva, the rate of dissolution will be retarded. The process of dissolution will decrease the mass and number of salt particles, and increase the surface area to volume ratio. This will continue to a point where there will be a balance between saliva being generated (Heinzerling *et al.* 2011), saliva being lost though drainage and sodium equilibrating between the bolus and the saliva in the oral cavity; as this balance is reached, the concentration in the saliva will peak and then reduce, as demonstrated in Fig. 1.

Windisch *et al.* (2013) previously looked at the solubilization of sugar into saliva and assumed that if the particle maintains its spherical shape and that the mass transfer rate is constant throughout dissolution, the following equation can be applied:

$$\frac{dm}{dt} = c \cdot s(m)$$

where $s(m)$ is the total surface area for a fixed mass (m) over time (t) with a fixed mass transfer rate (c). In this idealized model, the rate of loss of mass from the candy, or in our case, the salt crystal, will be directly dependent on the surface area, implying that smaller crystals will dissolve more quickly, resulting in a faster delivery to the oral saliva. This is a very idealized model as the salt crystals will not be ideal spheres, mass transfer rates will not be fixed, there will be a dependence on the diffusivity of the saliva and the saliva sodium concentration and the bolus will interact physically with the salt crystals, e.g., by physical entrapment.

Once solubilized in the saliva, the local region around the salt crystal will have a higher sodium ion concentration, mass transfer will then occur through diffusion through the saliva to the regions of the tongue containing sodium ion channels; the diffusion of sodium ions through saliva could therefore be predicted to follow Fickian diffusion, where the rate of transfer (F_x) of sodium through the saliva along direction x is directly proportional to the concentration (c) gradient per unit length (x), as shown below (where D is the diffusion coefficient):

$$F_x = -D\frac{\delta c}{\delta x}$$

At any point in time, during early dissolution, the local concentration around the smaller salt crystals will be higher than that around those that are larger due to the enhanced dissolution kinetics; therefore, the concentration gradient will be greater and the mass transfer rate F_x will be greater, as observed in Fig. 1. Again, this model is idealized and may not truly represent reality, but it does serve to facilitate an explanation for the greater sodium delivery rate, higher peak sodium concentration and lower onset time for the samples containing smaller salt crystals.

It should be noted that within this controlled study, the kinetics of oral processing are slowed so that oral mixing is minimized, and dissolution and diffusion can start to be explained; as a result, there is a strong relationship between reduced crystal size fraction, reduced onset time, maximum saliva sodium concentration and maximum perceived saltiness. In addition, other studies carried out at the University of Nottingham have further indicated that intelligent control of salt crystal size does offer an overall consumer benefit (unpublished data).

Physical Morphology of Salt Crystals and Attachment to the Sample Matrix

When viewed under an SEM, S3 salt crystals have a diamond or cubic shape, whereas S1 and S2 have a more irregular shape (Fig. 3); this is a direct result of the physical damage during the grinding process. In addition to the overall shape of the crystals, it can be noticed that the crystals are free flowing and do not agglomerate.

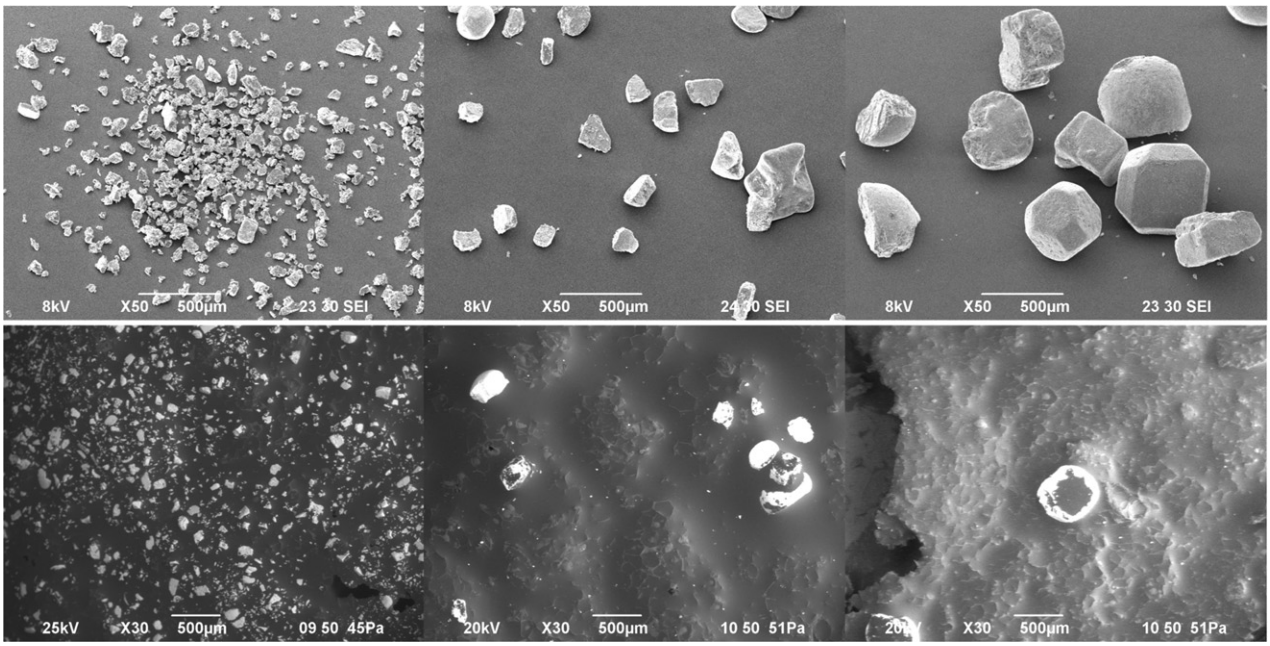

FIG. 3. SCANNING ELECTRON MICROSCOPY IMAGES OF S1 (A, D), S2 (B, E), S3 (C, F) SALT CRYSTAL FRACTIONS, AS FREE CRYSTALS (A–C) AND AFTER ADDITION TO THE SURFACE OF THE CRISPS (D–F)
Samples are labeled from upper left to upper right (a–c) and from lower left to lower right (d–f).

The images illustrating the crisp surface loaded with salt crystals clearly show the adhesion of the salt crystals to the fat coating of the crisp and the distribution of the crystals across the crisp surface (Fig. 3). Salt was applied to each batch of crisps at an identical loading rate, and as the smaller crystals were ground to a lower particle size, the ground fractions gave a broader distribution across the crisp surface, whereas the larger crystals had a more inhomogeneous distribution. This was verified in a number of SEM images, of which six were chosen to be characteristic of the samples and are shown in Fig. 3. It is interesting to note that although the samples were loaded with, and contained, equal levels of sodium, different salt particle sizes have previously been shown to have different loading abilities. The adhesion of salt to the surface of fried potato crisps has been shown to significantly increase with reduced salt size for crisps containing surface oil (Buck and Barringer 2007). Oil after frying and cooling is viscous and can hold salt particles through the formation of liquid bridges. The adhesion of smaller crystals on the surface is primarily due to van der Waals forces, and as the surface area : mass increases, van der Waals forces and capillary forces per unit mass become stronger. Larger particles have higher particle contact area than smaller particles; however, van der Waals force per unit mass decreases (Niman 2000). This maybe of relevance if the results presented are taken to an industrial setting and this may result in a beneficial reduction in process/packing salt loss. Additionally, shape may also play a role in adhesion, with flaked salts having a greater surface area and enhanced adhesion. In another example, the impact of salt particle size and shape on salt loading on popcorn was studied and it was concluded that the coating efficiency of salt was higher for smaller particles (Miller and Barringer 2002).

CONCLUSION

The particle size of salt crystals applied to fried potato crisps has a significant impact on the delivery rate of sodium into the saliva, the maximum concentration of sodium in the saliva, the maximum perceived saltiness and the saltiness onset time. In summary, in a controlled chewing environment with controlled mixing, smaller crystals of salt (sodium chloride) gave a faster, more salty delivery of sodium per unit sodium, and therefore, modification of salt crystal size is proposed to be a viable approach to reduce sodium in crisp snacks.

Consumer insight studies are recommended prior to adoption of this approach by the food industry, as the use of smaller crystals will not only increase the onset time and peak intensity of saltiness, but also have a much more rapid loss of saltiness after chewing, which may be of relevance in some products.

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