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Effect of pulsed delivery and bouillon base on saltiness and bitterness perceptions of salt delivery profiles partially substituted with KCl.

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ABSTRACT

Reducing salt levels in processed food is an important target for a growing numbers of food manufacturers. The effects of pulsed delivery (Dynataste) and bouillon base on saltiness and bitterness perception of partially substituted solutions (KCl) were investigated. Pulsed delivery did not enhance salt perception and resulted in greater Overall Bitterness Scores for the same level of substitution with KCl. The presence of the bouillon base masked to a certain extent the loss of saltiness induced by the substitution and resulted in lower Overall Bitterness Scores of the substituted profiles.

Keywords: potassium chloride; sodium chloride; salt; Dynataste; MSG; bitterness.

1. Introduction

Excessive salt intake contributes to a range of health problems and has been identified as a major cause of cardio vascular diseases. Most food regulatory bodies have set ambitious salt reduction targets for processed foods as these foods can represent up to 80% of the overall salt intake in the Western population (Angus, 2007).

A number of approaches to salt reduction in processed food exist (Kilcast, 2007a). For example: the use of saltiness enhancers such as MSG or the use of potassium chloride to substitute part of the sodium chloride content. Although potassium chloride imparts a salty taste, it is also reported to have a bitter/metallic off-taste (Frank and Mickelse, 1969, McGregor, 2004, Vanderklaauw and Smith, 1995). This bitter taste has prevented its sole use as a salt replacement, however, sodium chloride has been shown to partially suppress its bitterness (Breslin and Beauchamp, 1995) and potassium chloride is now used in conjunction with sodium chloride in commercial low salt applications. Kemp and Beauchamp (1994) reported that, at supra detection threshold concentrations, MSG suppressed the bitterness elicited by quinine sulfate and it is hypothesized here that MSG could be used, not only as a flavor enhancer, but also to mask potassium chloride bitterness. In general, the presence of a umami eliciting taste such as MSG has been linked to increased palatability and acceptance (Prescott, 2001, Roininen, Lahteenmaki and Tuorila, 1996).

In parallel to chemical solutions, technological solutions, such as increasing saltiness by different delivery systems, have also been sought to maximize salt perception with the same amount of salt. The relationship between the size and shape of salt crystals (Kilcast, 2007b) or size and location (inside or coating the food) (Shepherd, Wharf and Farleigh, 1989) and saltiness perception have been investigated. However, in liquid and semi-liquid products, salt is not found in its crystal form and one way of optimizing saltiness at reduced sodium level would be through microstructure engineering (such as duplex emulsions or gelled particles). Hence, pulsed delivery of sodium chloride via a Dynataste system to mimic release from microstructures has recently attracted some attention in order to investigate saltiness perception (Morris, Koliandris, Wolf, Hort and Taylor, 2009, Tournier, Busch and Smit, 2009) with mixed successes with respect to saltiness perception enhancement.

The aim of this study was to combine these approaches (partial KCl substitution, a pulsed delivery and the use of a “bouillon” base which contains MSG) in an attempt to mask the bitter taste of potassium chloride and/or enhance saltiness perception. In experiment 1, a series of assessments of KCl-NaCl solutions at different substitution levels were performed from cups to select one level of substitution which was deemed less salty and more bitter than a sodium chloride only solution. In experiment 2, the Dynataste system delivered several pulsed and non-pulsed profiles which were designed to deliver identical amounts of KCl and NaCl (corresponding to the selected substitution level) to investigate whether potassium chloride bitter taste could be masked if its delivery was preceded, followed or alternated with, bursts of sodium chloride solutions. These were also delivered in a bouillon base to investigate the effect of umami taste on saltiness and bitterness perception. If pulsed delivery was found to be effective, microstructures could potentially be designed to deliver NaCl and KCl in a specific pattern and increase the overall substitution level while maintaining the same sensory performance.

2. Materials and Methods

2.1. Dynataste

Dynataste is a multichannel delivery system for solutions, based on a series of pumps which can be programmed to deliver different profiles while maintaining a constant flow rate (Hort and Hollowood, 2004). The flow rate used for all experiments was 10 $mL.min^{-1}$ and solutions were delivered at ambient temperature (18-21 ^{o}C). A 1.75 m long piece of Teflon tubing (internal diameter: 0.18 mm) brought the delivered solution from the Dynataste to the sensory booth where the panelist was located so that the panelists were unaware of Dynataste operation.

2.2. Panelists: recruitment, training and selection

Twenty students and staff members of the University (11 women and 9 men, aged between 22 and 48) were recruited by advertisement to take part in the training and selection process.

The training consisted of three 1 hour sessions.

During the first session, all panelists were familiarized with the “bitter” or “metallic” taste of potassium chloride. Although, potassium chloride’s off-taste did not correspond exactly to what they generally perceived as bitter (such as caffeine), it was agreed to use the terms “bitter” and “bitterness” to qualify it. Sensitivities to saltiness and bitterness were assessed using 5 solutions of varying NaCl and caffeine concentrations (NaCl: 0; 3.0; 4.5; 6.0 and 7.5 $g.L^{-1}$ caffeine: 0; 0.25; 0.50; 1.00; 1.50 $g.L^{-1}$). The solutions were presented in cups. Panelists were asked to rank and rate those solutions and the results were discussed.

During the second and third sessions, panelists were familiarized with sample delivery via Dynataste and Time-Intensity techniques.

Fifteen panelists were selected for the saltiness perception part of the study based on their ability to a) rank the NaCl solutions from the 1st training session and

b) from their ability to rate saltiness using Time-Intensity in a reproducible manner. Fifteen panelists were selected for the bitterness part of the study based on their ability to give reproducible Overall Bitterness Scores (OBS) for profiles delivered via the Dynataste system. Two panelists withdrew from the “bouillon” part of study.

2.3. Samples

2.3.1. Experiment 1: substitution levels assessed in cups

In order to define the substitution level to be used in experiment 2 and gain an insight into each panelist’s ability to taste potassium chloride, all original panelists were asked to rank five solutions for saltiness and bitterness. Samples were swallowed and presented in a balanced order, coded with random 3 digits numbers and panelists were instructed to cleanse their palates with water (Evian, Danone, France) and unsalted crackers (99% Fat Free, Rakusen’s, UK) between samples. The solutions were served in 45 mL plastic cups and were prepared such that the overall salt (KCl + NaCl) concentration was constant (68.4 mmol.L^{-1}) but with varying degrees of KCl substitution (KCl %mol:NaCl %mol): 0:100; 10:90; 20:80; 30:70 and 40:60. The panelists were unaware that they were assessing the same solutions twice for two different attributes: saltiness and bitterness.

2.3.2. Experiment 2: effects of pulsed delivery and bouillon base (Dynataste)

Five different profiles (Figure 1) of 17 seconds each were delivered in triplicate in water (W1 to W5) and in bouillon (B1 to B5).

Figure 1 hereabouts

Two profiles acted as controls (profile 1: NaCl only and 2: KCl and NaCl delivered in a continuous fashion) while profiles 3 to 5 were the experimental pulsed profiles delivering the same overall level of substitution as profile 2 and having the same overall amount of salt (NaCl + KCl) as profiles 1 and 2. Table 1 presents the amount of NaCl and KCl delivered over 17 seconds for each profile.

Table 1 hereabouts

The substitution level was determined from the results of experiment 1 and chosen to appear both less salty and more bitter than the NaCl control. However, the respective delivery timing of KCl to NaCl was varied. While profile 1 was a NaCl only control, profile 2 acted as a 2nd control by delivering the mixture of KCl and NaCl continuously. In that respect, profile 1 and profile 2 corresponded respectively to an unsubstituted product and a substituted product with no engineered microstructures to control the timing of the delivery of KCl and NaCl. Profiles 3 to 5 were pulsed to mimic engineered microstructures able to provide dynamic delivery of KCl and NaCl. Profile 3 was designed to assess whether a 1st pleasant, salty sensation would prevail and mask the subsequent bitter taste of KCl through a lingering effect while profile 4 was designed to assess whether reintroducing an unmixed pleasant salty taste at the end of the profile would supersede the unpleasant bitter taste of KCl delivered in the 1st part of the profile. Profile 5 was designed to investigate the effect of faster alternations between the solutions if profiles 3 and 4 failed to achieve similar saltiness and bitterness ratings as the controls.

All the profiles started by delivering a few drops of pure NaCl solution (identical to the one used in profile 1) in order to anchor the initial saltiness sensation. The panelists had been familiarized with this level of saltiness during the training sessions and they were instructed to start saltiness rating at 50 (on a vertical continuous line scale labeled 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100) as soon as the solution flowed into their mouth, then move the cursor up or down as they perceived changes in saltiness intensity. Panelists were instructed to hold the tubing tip between their teeth and lips so as to have the tip of the tubing resting on the front of the tongue. This prevented jaw movements and limited tongue movements. Panelists were free to swallow as they wished. Between profiles, panelists were provided with water (Evian, Danone, France) and unsalted crackers (99% Fat Free, Rakusen's, UK) to cleanse their palates. The order of presentation was randomized for each test for each assessor. The bouillon formulation was provided by Dr J Busch (Unilever, Vlaardingen, The Netherlands) and was prepared by dissolving the following compounds in mineral water (Evian, Danone, France): monosodium glutamate (2 $g.L^{-1}$; Daesang-Miwon Seoul, Korea), Sucrose (1.2 $g.L^{-1}$; local supermarket), succinic acid (0.15 $g.L^{-1}$; Aldrich. Gillingham, UK), disodium 5'-inosinate (0.0275 $g.L^{-1}$) and disodium 5'-guanylate (0.027 $g.L^{-1}$; both Daesang-Miwon). To achieve the same overall amount of sodium delivered for the same profile in water and bouillon, the amount of salt added to the bouillon base was corrected by the amount of sodium present in MSG, IMP and GMP.

Saltiness was evaluated using Time-Intensity analysis. Both the Area Under the Curve (AUC) and the maximum intensity (Imax) have been shown to correlate well with saltiness scores given by panelists even when the delivery profile was pulsed (Morris et al., 2009). Therefore both parameters were extracted and used to estimate saltiness perception. At the end of each profile, the panelists were asked to give an OBS for the profile. 0 represented no bitterness perceived and a solution of 48 $mmol.L^{-1}$ KCl + 20 $mmol.L^{-1}$ NaCl was used as the bitterness reference 100. A solution of 8 $g.L^{-1}$ (136.8 $mmol.L^{-1}$) of NaCl was used as a saltiness reference (100). Both these solutions were available in cups before and in between Dynataste runs.

2.4. Time – Intensity and data analysis

Time-Intensity data were acquired using the Fizz software system (Biosystèmes, France) at an acquisition rate of 1 point/s. The AUC and OBS were subjected to an analysis of variance with three fixed factors (profile / matrix: water *vs.* bouillon / panelist) and potential interaction between the factors analyzed (SPSS Inc, Chicago, USA). Post hoc, where appropriate, a Tukey's HSD test was used to identify which samples were significantly different to the others (α = 0.05). Friedman tests followed by Least

Significant Ranked Difference tests were performed on the ranking results obtained in experiment 1.

3. Results

3.1. Experiment 1: effect of substitution level on saltiness and bitterness perception (in cups)

Panelists were asked to rank the five solutions with different substitution levels from least salty or least bitter (rank 1) to most salty or most bitter (rank 5). The rank sum for saltiness and bitterness of the five solutions with different substitution levels are presented in Figure 2.

Figure 2 hereabouts

The two most heavily substituted solutions (30% and 40% KCl) appeared significantly less salty than the three other solutions. The solutions containing 20% and 40% KCl appeared significantly more bitter than the sodium chloride only control and the least substituted solution (10% KCl).

3.2. Experiment 2: effect of pulsed delivery and bouillon base on saltiness and bitterness perception

3.2.1. Time-Intensity Curves

The averages of the all Time-Intensity curves (3 replicates per panelist; 15 panelists for the saltiness perception in water and 13 panelists for the saltiness perception in bouillon) are presented in Figure 3 A) and B) for water and bouillon respectively.

Figure 3 hereabouts

In both water and bouillon, the average Time-Intensity curves for profile 1 (NaCl only) increased slightly with time and systematically lay above the others indicating that profile 1 was perceived as being saltier than the others. The three pulsed profiles (3 to 5) also lay below the substituted non-pulsed profile (profile 2) except in water where the pulsed profile starting with a sodium chloride only delivery (profile W3) lay above it for as long as only NaCl was delivered. For the first 10 seconds, the average Time-Intensity curve for profile 3 was identical to that of profile 1. Introducing a high concentration of potassium chloride always resulted in a drastic reduction of saltiness perceived. The time at which this occurred was related to the time at which the potassium chloride was introduced. A delay of 3 seconds (1.2 seconds of which can be attributed to the solution travelling in the tubing) was observed between a change in solution composition and the panelists' response as recorded using Time-Intensity for W4 whereas the panelists reacted faster to the change from NaCl only to a mixture of KCl/NaCl in profile 3. These reaction times were increased in bouillon. In both water and bouillon, the saltiness intensity picked up towards the end of profile 4 indicating that reintroducing a NaCl only solution towards the end increased saltiness perception. Delivering the profiles in bouillon resulted in narrowing the differences between the five profiles but the trend remained the same.

3.2.2. Saltiness

The average Area Under the Curve for the five profiles delivered in water (W1 to W5) and bouillon (B1 to B5) are presented in Figure 4 A). An ANOVA on the AUC revealed that the significant factors were the profiles ($F(4,278)=5.32$; $p<0.001$), the assessors ($F(14,278)=16.634$; $p<0.001$) and the matrix ($F(1,278)=11.332$; $p=0.001$). The interactions profile*matrix and assessor*matrix were also found to be significant (respectively $F(4,278)=1.720$; $p=0.006$ and $F(12,278)=2.045$; $p=0.021$). The former was due to the fact that profiles 1 and 3 obtained similar AUC in water and bouillon while profiles 2, 4 and 5 had higher AUC in bouillon. The assessor*matrix interaction was due to only one panelist. The grouping for significantly different profiles obtained performing a Tukey's HSD test is depicted in Figure 4 B).

Figure 4 hereabouts

None of the substituted profiles (same level of substitution) appeared to be significantly different from one another in terms of saltiness. However, all three pulsed profiles appeared significantly less salty than the NaCl control (Profile 1) while the substituted non pulsed profile (Profile 2) was not significantly less salty than the NaCl control.

Tukey's HSD test revealed slightly different groupings for maximum intensity values yielding two distinctive subgroups: Profile 1 (NaCl only) being the only profile for which Imax was significantly greater than those of all the other substituted profiles, profile 2 included. The maximum intensities of the four substituted profiles were not found to differ significantly.

Overall, the presence of a bouillon base increased the Area Under the Curve.

3.2.3. Bitterness

The average OBS for the five profiles delivered in water (W1 to W5) and bouillon (B1 to B5) are presented in Figure 5 A). An ANOVA on the OBS revealed that the significant factors were the profiles ($F(4,287)=14.105$; $p<0.001$), the assessors ($F(14,287)=8.775$; $p<0.001$) and the matrix ($F(1,287)=20.894$; $p<0.001$). The interaction assessor*matrix was also found to be significant ($F(13,287)=3.663$; $p<0.001$). The grouping for significantly different profiles obtained performing a Tukey's HSD test is depicted in Figure 5 B).

Figure 5 hereabouts

The three pulsed profiles appeared significantly more bitter than control profile 1 delivering sodium chloride only but they also appeared more bitter than profile 2 which had the same overall substitution level (and amounts of KCl and NaCl delivered). The OBS for profile 2 (non pulsed substituted profile) was not found to be significantly different from profile 1.

4. Discussion

4.1. Experiment 1: saltiness and bitterness at different substitution levels

There are a number of studies investigating the maximum substitution level attainable using KCl in “real” food products. The amount of salt which can be substituted without adverse effects on consumers’ acceptance depends greatly on the product itself and the attributes investigated. Al-Otaibi and Wilbey (2006) reported no significant difference in feta cheeses for “bitterness” of highly substituted samples (NaCl (w):KCl (w) / 1:3.4) which was in agreement with the study by Katsiari, Voutsinas, Alichanidis and Roussis (1997) who did not measure any significant differences in “flavour” for substitution levels up to 50% KCl. This is in contrast with the findings of Aly (1995) and Lindsay, Hargett and Bush (1982) who reported that cheeses were less salty and more bitter when substitution levels (expressed in % weight) of respectively 75% KCl and 50% KCl were reached. For fermented sausages, substitution levels of 40% KCl (Gelabert, Gou, Guerrero and Arnau, 2003) and 30% (Gou, Guerrero, Gelabert and Arnau, 1996) were shown to yield a significant increase in bitterness. Indeed, Desmond (2006) reviewed the acceptable substitution levels in the meat industry and found that, in general, levels of 25%-40% were not noticeable. In fish sauce, a 40% substitution level yielded an unacceptable taste (Sanceda, Suzuki and Kurata, 2003). These findings are in agreement with this study’s results in solution which indicated that, in water solutions, bitterness noticeably increased from 20% (mol/mol) substitution onwards and a loss of perceived saltiness occurred almost simultaneously (from 30% (mol/mol) onwards). Table provides equivalences between % (w/w) and % (mol/mol).

Table 2 hereabouts

These results indicated that there are two dimensions to the problem of salt substitution with potassium chloride, which are the loss of perceived saltiness on the one hand, and increased bitterness on the other. Based on those results, a level of substitution of 35.2% KCl (mol/mol) was selected to investigate the effect of pulsed delivery and use of bouillon on perceived saltiness and bitterness.

4.2. T-I curves

Although for clarity, the errors bars are not presented in the Time-Intensity raw data (Figure 3), they are shown in Figure 4. A large variation among panelists is a well known feature of Time-Intensity (Lawless and Heymann, 1998) and in this case can be very striking due to the shortness of the profiles and the purposely designed small difference among them. The swallowing was neither controlled nor measured in this study and reproducibility may be improved by giving the panelists swallowing instructions. Different swallowing patterns among panelists could explain the differences observed (Morris et al., 2009) between panelists who integrated several pulses under a large Time-Intensity peak and those who followed the peaks. On the other hand, adding a swallowing constraint may distract the panelists from their already difficult task and could result in worse reproducibility. The effects of swallowing patterns on the quality of Time-Intensity data are currently being investigated. Minor swallowing movements could result in a mixing of the solution delivered by the Dynataste thus introducing a discrepancy between what is delivered and what reaches the panelists' taste receptors (Bakalis, 2009).

4.3. Time-Intensity saltiness

4.3.1. Effect of the profiles on saltiness perception

There was no significant difference in saltiness between either of the substituted profiles. The pulsed profiles all appeared less salty than the NaCl control. In this respect a pulsed delivery does not seem to bring any advantage or disadvantage in terms of salt perception. This is consistent with the findings of Morris et al. (2009) where the overall amount of sodium delivered was found to be the overriding factor in short pulsed profiles rather than the delivery profile itself.

4.3.2. Effect of the bouillon base on saltiness perception

It has been shown, in several instances, that although MSG on its own or combined with GMP and IMP alone is not enough to improve the palatability of food products (Halpern, 2000), it can be used in synergy with NaCl to achieve higher hedonic ratings even at constant sodium concentrations (Okiyama and Beauchamp, 1998). However, a limited number of studies are available, which study the effect of MSG on saltiness perception. Tuorila, Hellemann and Matuszewska (1990) showed in an Ad Lib experiment (where panelists freely added salt to their liking), that adding MSG increased pleasantness but did not significantly decrease the optimum amount of salt. Yamaguchi and Takahashi (1984) found that one way to achieve identical saltiness perception using less NaCl was to compensate using MSG; however, the amount of added MSG, needed to compensate for a small decrease In NaCl, was quite large and resulted in the same overall amount of sodium intake, producing thus an equi-salty perception. This was confirmed by Morris et al. (2009), where the presence of the bouillon base (at constant sodium content) did not significantly impact on the Overall Saltiness Scores. The results in the present study appear to contradict those findings, here the matrix was found to be a significant factor, with the presence of the bouillon base generally yielding higher AUCs. However, looking closely at the average AUC for each profile in water and bouillon, it appeared that profiles 2, 4 and 5 had greater AUCs in bouillon than water whereas the AUCs for profiles 1 (NaCl only) and 3 (NaCl only for the first 10 seconds) were identical in water and bouillon (although lower for profile 3 than 1). This explains the significant profile*matrix interaction observed. Thus, the apparent discrepancy between these results and those of previous studies can be resolved with the following explanation: although the bouillon base did not enhance the perceived saltiness of NaCl, it succeeded in masking the loss of saltiness produced by the KCl substitution.

4.4. Overall Bitterness Scores

4.4.1. Effect of the profiles on the Overall Bitterness Scores

The large inter-individual difference observed in OBS can be explained by the panel selection criterion which was reproducibility in rating OBS. However, a large range of sensitivity to KCl bitterness was observed among panelists. The pulsed profiles appeared more bitter than both control profiles, including the substituted one. This could be explained by the fact that during the pulsed delivery, higher concentrations of KCl were delivered for short period of times compared to the non-pulsed substituted profile which delivered lower and continuous KCl concentrations. Panelists were very sensitive to the high bursts of bitterness delivered which greatly influenced the OBS. This indicates a clear disadvantage of using a pulsed delivery to deliver the same amount and ratio of potassium chloride.

4.4.2. Effect of the bouillon base on Overall Bitterness Scores

The OBS of profile 1 was identical in water and bouillon, which lent credibility to the data set as profile 1 did not contain any KCl, and could thus be regarded as an OBS baseline measurement. The OBS for all the substituted profiles were higher in water than in bouillon. This is in line with the findings of Kemp et al. (1994) who noticed that the addition of MSG, at levels normally found in food, suppressed quinine sulfate bitterness. Pasin et al. (1989) working on fresh pork sausages found that adding MSG to KCl substituted samples decreased the degree of liking at all levels although the reasons why this was observed were not commented on. It is likely that there is an interaction between matrix or system investigated and

MSG level on the degree of liking as observed by Barylko-Pikielna and Kostyra (2007), this could be extended to KCl containing systems and the synergy between KCl and MSG may be different for different food systems. Indeed, Kuramitsu, Segawa, Nakamura, Muramatsu and Okai (1997) observed that partially substituting NaCl with KCl resulted in an increase in umami taste at all concentrations.

The observed decreased bitterness could also be attributed to the sucrose present in the bouillon base, as a sweet stimulus has been shown to suppress bitterness (Keast and Breslin, 2003) or, more generally, the decreased bitterness could be due to an increased system complexity.

5. Conclusion

The results of this study demonstrate that salt reduction remains a complex challenge when the most effective salt replacer fails to elicit similar saltiness to sodium chloride and actually elicits bitterness.

Pulsed delivery of potassium chloride with respect to sodium chloride resulted in similar or less desirable performances in terms of both saltiness and bitterness compared to the pure sodium chloride control. Only the non-pulsed, substituted profile achieved performances which were not significantly different from that of the control. There does not seem to be any advantages in terms of sensory properties in using microstructures to deliver potassium chloride in a dynamic manner, however, microstructures such as double emulsions could be engineered with potassium chloride rather than sodium chloride used to “fill” the duplex structure and balance the osmotic pressure. An important constraint of those double emulsions would be that they would not break in the mouth to release potassium chloride as the bursts of highly concentrated potassium chloride would be perceived as more bitter than systems prepared with the same ratio of potassium to sodium chloride in both aqueous phases.

The presence of a bouillon base (including MSG, IMP and GMP) did not enhance sodium chloride salty taste but masked the perceived saltiness loss due to the partial substitution of sodium chloride by potassium chloride. Moreover, although results from other studies show that caution should be applied in generalising results to other systems, in these systems, the presence of the bouillon base decreased the perceived bitterness resulting from potassium chloride.

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Figure captions

Figure 1 Profiles delivered in water and bouillon.

Figure 2 Sum ranks for A) saltiness and B) Bitterness of solutions of varying levels of KCl substitution (%mol/%mol). Different letters (a, b) indicate significantly different samples.

Figure 3 Time-Intensity Curves for the 5 profiles in A) water (average of 15 assessors in triplicate) and B) bouillon (average of 13 assessors in triplicate).

Figure 4 A) Area Under the Curve for the 5 profiles delivered in water and bouillon. Error bars represent +/- 1 SD (3 replicates per assessor). B) Tukey's HSD test grouping results: different letters (a, b) refer to significantly different samples.

Figure 5 A) Overall Bitterness Score for the 5 profiles delivered in water and bouillon. Error bars represent +/- 1 SD (3 replicates per assessor). B) Tukey's HSD test grouping results: different letters (a, b) refer to significantly different samples.

Table 1 Amounts of NaCl and KCl delivered over 17 seconds for each profile

Table 2 Conversion of substitution levels from % weight to % moles