

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

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

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17 ABSTRACT

18 Reducing salt levels in processed food is an important
19 target for a growing numbers of food manufacturers. The
20 effects of pulsed delivery (Dynataste) and bouillon base
21 on saltiness and bitterness perception of partially
22 substituted solutions (KCl) were investigated. Pulsed

23 delivery did not enhance salt perception and resulted in
24 greater Overall Bitterness Scores for the same level of
25 substitution with KCl. The presence of the bouillon base
26 masked to a certain extent the loss of saltiness induced
27 by the substitution and resulted in lower Overall
28 Bitterness Scores of the substituted profiles.

29

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

32

33 **1. Introduction**

34 Excessive salt intake contributes to a range of health
35 problems and has been identified as a major cause of
36 cardio vascular diseases. Most food regulatory bodies
37 have set ambitious salt reduction targets for processed
38 foods as these foods can represent up to 80% of the
39 overall salt intake in the Western population (Angus,
40 2007).

41 A number of approaches to salt reduction in processed
42 food exist (Kilcast, 2007a). For example: the use of
43 saltiness enhancers such as MSG or the use of
44 potassium chloride to substitute part of the sodium
45 chloride content. Although potassium chloride imparts a

46 salty taste, it is also reported to have a bitter/metallic off-
47 taste (Frank and Mickelse, 1969, McGregor, 2004,
48 Vanderklaauw and Smith, 1995). This bitter taste has
49 prevented its sole use as a salt replacement, however,
50 sodium chloride has been shown to partially suppress its
51 bitterness (Breslin and Beauchamp, 1995) and potassium
52 chloride is now used in conjunction with sodium chloride
53 in commercial low salt applications. Kemp and
54 Beauchamp (1994) reported that, at supra detection
55 threshold concentrations, MSG suppressed the bitterness
56 elicited by quinine sulfate and it is hypothesized here that
57 MSG could be used, not only as a flavor enhancer, but
58 also to mask potassium chloride bitterness. In general,
59 the presence of a umami eliciting taste such as MSG has
60 been linked to increased palatability and acceptance
61 (Prescott, 2001, Roininen, Lahteenmaki and Tuorila,
62 1996).

63 In parallel to chemical solutions, technological solutions,
64 such as increasing saltiness by different delivery systems,
65 have also been sought to maximize salt perception with
66 the same amount of salt. The relationship between the
67 size and shape of salt crystals (Kilcast, 2007b) or size
68 and location (inside or coating the food) (Shepherd,
69 Wharf and Farleigh, 1989) and saltiness perception have

70 been investigated. However, in liquid and semi-liquid
71 products, salt is not found in its crystal form and one way
72 of optimizing saltiness at reduced sodium level would be
73 through microstructure engineering (such as duplex
74 emulsions or gelled particles). Hence, pulsed delivery of
75 sodium chloride via a Dynataste system to mimic release
76 from microstructures has recently attracted some
77 attention in order to investigate saltiness perception
78 (Morris, Koliandris, Wolf, Hort and Taylor, 2009, Tournier,
79 Busch and Smit, 2009) with mixed successes with
80 respect to saltiness perception enhancement.

81 The aim of this study was to combine these approaches
82 (partial KCl substitution, a pulsed delivery and the use of
83 a “bouillon” base which contains MSG) in an attempt to
84 mask the bitter taste of potassium chloride and/or
85 enhance saltiness perception. In experiment 1, a series of
86 assessments of KCl-NaCl solutions at different
87 substitution levels were performed from cups to select
88 one level of substitution which was deemed less salty and
89 more bitter than a sodium chloride only solution. In
90 experiment 2, the Dynataste system delivered several
91 pulsed and non-pulsed profiles which were designed to
92 deliver identical amounts of KCl and NaCl (corresponding
93 to the selected substitution level) to investigate whether

94 potassium chloride bitter taste could be masked if its
95 delivery was preceded, followed or alternated with, bursts
96 of sodium chloride solutions. These were also delivered
97 in a bouillon base to investigate the effect of umami taste
98 on saltiness and bitterness perception. If pulsed delivery
99 was found to be effective, microstructures could
100 potentially be designed to deliver NaCl and KCl in a
101 specific pattern and increase the overall substitution level
102 while maintaining the same sensory performance.

103 **2. Materials and Methods**

104 **2.1. Dynataste**

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

115 **2.2. Panelists: recruitment, training and selection**

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

120 The training consisted of three 1 hour sessions.

121 During the first session, all panelists were familiarized
122 with the “bitter” or “metallic” taste of potassium chloride.
123 Although, potassium chloride’s off-taste did not
124 correspond exactly to what they generally perceived as
125 bitter (such as caffeine), it was agreed to use the terms
126 “bitter” and “bitterness” to qualify it. Sensitivities to
127 saltiness and bitterness were assessed using 5 solutions
128 of varying NaCl and caffeine concentrations (NaCl: 0; 3.0;
129 4.5; 6.0 and 7.5 g.L⁻¹ caffeine: 0; 0.25; 0.50; 1.00; 1.50
130 g.L⁻¹). The solutions were presented in cups. Panelists
131 were asked to rank and rate those solutions and the
132 results were discussed.

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

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

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

145 **2.3. Samples**

146 **2.3.1. Experiment 1: substitution levels** 147 **assessed in cups**

148 In order to define the substitution level to be used in
149 experiment 2 and gain an insight into each panelist’s
150 ability to taste potassium chloride, all original panelists
151 were asked to rank five solutions for saltiness and
152 bitterness. Samples were swallowed and presented in a
153 balanced order, coded with random 3 digits numbers and
154 panelists were instructed to cleanse their palates with
155 water (Evian, Danone, France) and unsalted crackers (99%
156 Fat Free, Rakusen’s, UK) between samples. The
157 solutions were served in 45 mL plastic cups and were
158 prepared such that the overall salt (KCl + NaCl)
159 concentration was constant (68.4 mmol.L⁻¹) but with
160 varying degrees of KCl substitution
161 (KCl %mol:NaCl %mol): 0:100; 10:90; 20:80; 30:70 and
162 40:60. The panelists were unaware that they were

163 assessing the same solutions twice for two different
164 attributes: saltiness and bitterness.

165 **2.3.2. Experiment 2: effects of pulsed delivery**
166 **and bouillon base (Dynataste)**

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

170 Figure 1 hereabouts

171 Two profiles acted as controls (profile 1: NaCl only and 2:
172 KCl and NaCl delivered in a continuous fashion) while
173 profiles 3 to 5 were the experimental pulsed profiles
174 delivering the same overall level of substitution as profile
175 2 and having the same overall amount of salt (NaCl + KCl)
176 as profiles 1 and 2. Table 1 presents the amount of NaCl
177 and KCl delivered over 17 seconds for each profile.

178 Table 1 hereabouts

179 The substitution level was determined from the results of
180 experiment 1 and chosen to appear both less salty and
181 more bitter than the NaCl control. However, the
182 respective delivery timing of KCl to NaCl was varied.
183 While profile 1 was a NaCl only control, profile 2 acted as
184 a 2nd control by delivering the mixture of KCl and NaCl
185 continuously. In that respect, profile 1 and profile 2

186 corresponded respectively to an unsubstituted product
187 and a substituted product with no engineered
188 microstructures to control the timing of the delivery of KCl
189 and NaCl. Profiles 3 to 5 were pulsed to mimic
190 engineered microstructures able to provide dynamic
191 delivery of KCl and NaCl. Profile 3 was designed to
192 assess whether a 1st pleasant, salty sensation would
193 prevail and mask the subsequent bitter taste of KCl
194 through a lingering effect while profile 4 was designed to
195 assess whether reintroducing an unmixed pleasant salty
196 taste at the end of the profile would supersede the
197 unpleasant bitter taste of KCl delivered in the 1st part of
198 the profile. Profile 5 was designed to investigate the effect
199 of faster alternations between the solutions if profiles 3
200 and 4 failed to achieve similar saltiness and bitterness
201 ratings as the controls.

202 All the profiles started by delivering a few drops of pure
203 NaCl solution (identical to the one used in profile 1) in
204 order to anchor the initial saltiness sensation. The
205 panelists had been familiarized with this level of saltiness
206 during the training sessions and they were instructed to
207 start saltiness rating at 50 (on a vertical continuous line
208 scale labeled 0, 10, 20, 30, 40, 50, 60, 70, 80, 90 and 100)
209 as soon as the solution flowed into their mouth, then

210 move the cursor up or down as they perceived changes
211 in saltiness intensity. Panelists were instructed to hold the
212 tubing tip between their teeth and lips so as to have the
213 tip of the tubing resting on the front of the tongue. This
214 prevented jaw movements and limited tongue movements.
215 Panelists were free to swallow as they wished. Between
216 profiles, panelists were provided with water (Evian,
217 Danone, France) and unsalted crackers (99% Fat Free,
218 Rakusen's, UK) to cleanse their palates. The order of
219 presentation was randomized for each test for each
220 assessor. The bouillon formulation was provided by Dr J
221 Busch (Unilever, Vlaardingen, The Netherlands) and was
222 prepared by dissolving the following compounds in
223 mineral water (Evian, Danone, France): monosodium
224 glutamate (2 g.L^{-1} ; Daesang-Miwon Seoul, Korea),
225 Sucrose (1.2 g.L^{-1} ; local supermarket), succinic acid (0.15
226 g.L^{-1} ; Aldrich. Gillingham, UK), disodium 5'-inosinate
227 (0.0275 g.L^{-1}) and disodium 5'-guanylate (0.027 g.L^{-1} ;
228 both Daesang-Miwon). To achieve the same overall
229 amount of sodium delivered for the same profile in water
230 and bouillon, the amount of salt added to the bouillon
231 base was corrected by the amount of sodium present in
232 MSG, IMP and GMP.
233

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

248 **2.4. Time – Intensity and data analysis**

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

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

260 **3. Results**

261 **3.1. Experiment 1: effect of substitution level on** 262 **saltiness and bitterness perception (in cups)**

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

268 Figure 2 hereabouts

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

275 **3.2. Experiment 2: effect of pulsed delivery and** 276 **bouillon base on saltiness and bitterness** 277 **perception**

278 **3.2.1. Time-Intensity Curves**

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

284 Figure 3 hereabouts

285 In both water and bouillon, the average Time-Intensity
286 curves for profile 1 (NaCl only) increased slightly with
287 time and systematically lay above the others indicating
288 that profile 1 was perceived as being saltier than the
289 others. The three pulsed profiles (3 to 5) also lay below
290 the substituted non-pulsed profile (profile 2) except in
291 water where the pulsed profile starting with a sodium
292 chloride only delivery (profile W3) lay above it for as long
293 as only NaCl was delivered. For the first 10 seconds, the
294 average Time-Intensity curve for profile 3 was identical to
295 that of profile 1. Introducing a high concentration of
296 potassium chloride always resulted in a drastic reduction
297 of saltiness perceived. The time at which this occurred
298 was related to the time at which the potassium chloride
299 was introduced. A delay of 3 seconds (1.2 seconds of
300 which can be attributed to the solution travelling in the
301 tubing) was observed between a change in solution
302 composition and the panelists' response as recorded

303 using Time-Intensity for W4 whereas the panelists
304 reacted faster to the change from NaCl only to a mixture
305 of KCl/NaCl in profile 3. These reaction times were
306 increased in bouillon. In both water and bouillon, the
307 saltiness intensity picked up towards the end of profile 4
308 indicating that reintroducing a NaCl only solution towards
309 the end increased saltiness perception. Delivering the
310 profiles in bouillon resulted in narrowing the differences
311 between the five profiles but the trend remained the same.

312 **3.2.2. Saltiness**

313 The average Area Under the Curve for the five profiles
314 delivered in water (W1 to W5) and bouillon (B1 to B5) are
315 presented in Figure 4 A). An ANOVA on the AUC
316 revealed that the significant factors were the profiles
317 ($F(4,278)=5.32$; $p<0.001$), the assessors
318 ($F(14,278)=16.634$; $p<0.001$) and the matrix
319 ($F(1,278)=11.332$; $p=0.001$). The interactions
320 profile*matrix and assessor*matrix were also found to be
321 significant (respectively $F(4,278)=1.720$; $p=0.006$ and
322 $F(12,278)=2.045$; $p=0.021$). The former was due to the
323 fact that profiles 1 and 3 obtained similar AUC in water
324 and bouillon while profiles 2, 4 and 5 had higher AUC in
325 bouillon. The assessor*matrix interaction was due to only
326 one panelist. The grouping for significantly different

327 profiles obtained performing a Tukey's HSD test is
328 depicted in Figure 4 B).

329 Figure 4 hereabouts

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

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

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

346 **3.2.3. Bitterness**

347 The average OBS for the five profiles delivered in water
348 (W1 to W5) and bouillon (B1 to B5) are presented in
349 Figure 5 A). An ANOVA on the OBS revealed that the

350 significant factors were the profiles ($F(4,287)=14.105$;
351 $p<0.001$), the assessors ($F(14,287)=8.775$; $p<0.001$) and
352 the matrix ($F(1,287)=20.894$; $p<0.001$). The interaction
353 assessor*matrix was also found to be significant
354 ($F(13,287)=3.663$; $p<0.001$). The grouping for
355 significantly different profiles obtained performing a
356 Tukey's HSD test is depicted in Figure 5 B).

357 Figure 5 hereabouts

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

365 **4. Discussion**

366 **4.1. Experiment 1: saltiness and bitterness at** 367 **different substitution levels**

368 There are a number of studies investigating the maximum
369 substitution level attainable using KCl in "real" food
370 products. The amount of salt which can be substituted
371 without adverse effects on consumers' acceptance
372 depends greatly on the product itself and the attributes

373 investigated. Al-Otaibi and Wilbey (2006) reported no
374 significant difference in feta cheeses for “bitterness” of
375 highly substituted samples (NaCl (w):KCl (w) / 1:3.4)
376 which was in agreement with the study by Katsiari,
377 Voutsinas, Alichanidis and Roussis (1997) who did not
378 measure any significant differences in “flavour” for
379 substitution levels up to 50% KCl. This is in contrast with
380 the findings of Aly (1995) and Lindsay, Hargett and Bush
381 (1982) who reported that cheeses were less salty and
382 more bitter when substitution levels (expressed in %
383 weight) of respectively 75% KCl and 50% KCl were
384 reached. For fermented sausages, substitution levels of
385 40% KCl (Gelabert, Gou, Guerrero and Arnau, 2003) and
386 30% (Gou, Guerrero, Gelabert and Arnau, 1996) were
387 shown to yield a significant increase in bitterness. Indeed,
388 Desmond (2006) reviewed the acceptable substitution
389 levels in the meat industry and found that, in general,
390 levels of 25%-40% were not noticeable. In fish sauce, a
391 40% substitution level yielded an unacceptable taste
392 (Sanceda, Suzuki and Kurata, 2003). These findings are
393 in agreement with this study’s results in solution which
394 indicated that, in water solutions, bitterness noticeably
395 increased from 20% (mol/mol) substitution onwards and a
396 loss of perceived saltiness occurred almost

397 simultaneously (from 30% (mol/mol) onwards). Table
398 provides equivalences between % (w/w) and % (mol/mol).

399 Table 2 hereabouts

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

407 **4.2. T-I curves**

408 Although for clarity, the errors bars are not presented in
409 the Time-Intensity raw data (Figure 3), they are shown in
410 Figure 4. A large variation among panelists is a well
411 known feature of Time-Intensity (Lawless and Heymann,
412 1998) and in this case can be very striking due to the
413 shortness of the profiles and the purposely designed
414 small difference among them. The swallowing was
415 neither controlled nor measured in this study and
416 reproducibility may be improved by giving the panelists
417 swallowing instructions. Different swallowing patterns
418 among panelists could explain the differences observed
419 (Morris et al., 2009) between panelists who integrated

420 several pulses under a large Time-Intensity peak and
421 those who followed the peaks. On the other hand, adding
422 a swallowing constraint may distract the panelists from
423 their already difficult task and could result in worse
424 reproducibility. The effects of swallowing patterns on the
425 quality of Time-Intensity data are currently being
426 investigated. Minor swallowing movements could result in
427 a mixing of the solution delivered by the Dynataste thus
428 introducing a discrepancy between what is delivered and
429 what reaches the panelists' taste receptors (Bakalis,
430 2009).

431 **4.3. Time-Intensity saltiness**

432 **4.3.1. Effect of the profiles on saltiness** 433 **perception**

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

443 **4.3.2. Effect of the bouillon base on saltiness**
444 **perception**

445 It has been shown, in several instances, that although
446 MSG on its own or combined with GMP and IMP alone is
447 not enough to improve the palatability of food products
448 (Halpern, 2000), it can be used in synergy with NaCl to
449 achieve higher hedonic ratings even at constant sodium
450 concentrations (Okiyama and Beauchamp, 1998).
451 However, a limited number of studies are available, which
452 study the effect of MSG on saltiness perception. Tuorila,
453 Helleman and Matuszewska (1990) showed in an Ad Lib
454 experiment (where panelists freely added salt to their
455 liking), that adding MSG increased pleasantness but did
456 not significantly decrease the optimum amount of salt.
457 Yamaguchi and Takahashi (1984) found that one way to
458 achieve identical saltiness perception using less NaCl
459 was to compensate using MSG; however, the amount of
460 added MSG, needed to compensate for a small decrease
461 In NaCl, was quite large and resulted in the same overall
462 amount of sodium intake, producing thus an equi-salty
463 perception. This was confirmed by Morris et al. (2009),
464 where the presence of the bouillon base (at constant
465 sodium content) did not significantly impact on the Overall
466 Saltiness Scores. The results in the present study appear

467 to contradict those findings, here the matrix was found to
468 be a significant factor, with the presence of the bouillon
469 base generally yielding higher AUCs. However, looking
470 closely at the average AUC for each profile in water and
471 bouillon, it appeared that profiles 2, 4 and 5 had greater
472 AUCs in bouillon than water whereas the AUCs for
473 profiles 1 (NaCl only) and 3 (NaCl only for the first 10
474 seconds) were identical in water and bouillon (although
475 lower for profile 3 than 1). This explains the significant
476 profile*matrix interaction observed. Thus, the apparent
477 discrepancy between these results and those of previous
478 studies can be resolved with the following explanation:
479 although the bouillon base did not enhance the perceived
480 saltiness of NaCl, it succeeded in masking the loss of
481 saltiness produced by the KCl substitution.

482 **4.4. Overall Bitterness Scores**

483 **4.4.1. Effect of the profiles on the Overall** 484 **Bitterness Scores**

485 The large inter-individual difference observed in OBS can
486 be explained by the panel selection criterion which was
487 reproducibility in rating OBS. However, a large range of
488 sensitivity to KCl bitterness was observed among
489 panelists. The pulsed profiles appeared more bitter than
490 both control profiles, including the substituted one. This

491 could be explained by the fact that during the pulsed
492 delivery, higher concentrations of KCl were delivered for
493 short period of times compared to the non-pulsed
494 substituted profile which delivered lower and continuous
495 KCl concentrations. Panelists were very sensitive to the
496 high bursts of bitterness delivered which greatly
497 influenced the OBS. This indicates a clear disadvantage
498 of using a pulsed delivery to deliver the same amount and
499 ratio of potassium chloride.

500 **4.4.2. Effect of the bouillon base on Overall** 501 **Bitterness Scores**

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

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

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

529 **5. Conclusion**

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

534 Pulsed delivery of potassium chloride with respect to
535 sodium chloride resulted in similar or less desirable
536 performances in terms of both saltiness and bitterness
537 compared to the pure sodium chloride control. Only the

538 non-pulsed, substituted profile achieved performances
539 which were not significantly different from that of the
540 control. There does not seem to be any advantages in
541 terms of sensory properties in using microstructures to
542 deliver potassium chloride in a dynamic manner, however,
543 microstructures such as double emulsions could be
544 engineered with potassium chloride rather than sodium
545 chloride used to “fill” the duplex structure and balance the
546 osmotic pressure. An important constraint of those double
547 emulsions would be that they would not break in the
548 mouth to release potassium chloride as the bursts of
549 highly concentrated potassium chloride would be
550 perceived as more bitter than systems prepared with the
551 same ratio of potassium to sodium chloride in both
552 aqueous phases.

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

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685 Figure captions

686 **Figure 1 Profiles delivered in water and bouillon.**

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

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

694 **Figure 4 A) Area Under the Curve for the 5 profiles**
695 **delivered in water and bouillon. Error bars represent**
696 **+/- 1 SD (3 replicates per assessor). B) Tukey's HSD**
697 **test grouping results: different letters (a, b) refer to**
698 **significantly different samples.**

699 **Figure 5 A) Overall Bitterness Score for the 5 profiles**
700 **delivered in water and bouillon. Error bars represent**
701 **+/- 1 SD (3 replicates per assessor). B) Tukey's HSD**
702 **test grouping results: different letters (a, b) refer to**
703 **significantly different samples.**

704

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

707

708 **Table 2 Conversion of substitution levels from %**
709 **weight to % moles**