



Sensory profiles and consumer acceptability of a range of sugar-reduced products on the UK market

Article

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1 **Sensory profiles and consumer acceptability of a range of sugar-reduced products on**
2 **the UK market**

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21 Abstract

22 Current UK intake of non-milk extrinsic sugars (NMES) is above recommendations.
23 Reducing the sugar content of processed high sugar foods through reformulation is one
24 option for reducing consumption of NMES at a population level. However, reformulation can
25 alter the sensory attributes of food products and influence consumer liking. This study
26 evaluated consumer acceptance of a selection of products that are commercially-available in
27 the UK; these included regular and sugar-reduced baked beans, strawberry jam, milk
28 chocolate, cola and cranberry & raspberry juice. Sweeteners were present in the reformulated
29 chocolate (maltitol), cola (aspartame and acesulfame-K) and juice (sucralose) samples.
30 Healthy, non-smoking consumers ($n = 116$; 55 men, 61 women, age: 33 ± 9 years; BMI: 25.7
31 ± 4.6 kg/m²) rated the products for overall liking and on liking of appearance, flavor and
32 texture using a nine-point hedonic scale. There were significant differences between standard
33 and reduced sugar products in consumers' overall liking and on liking of each modality
34 (appearance, flavor and texture; all $P < 0.0001$). For overall liking, only the regular beans and
35 cola were significantly more liked than their reformulated counterparts ($P < 0.0001$). Cluster
36 analysis identified three consumer clusters that were representative of different patterns of
37 consumer liking. For the largest cluster (cluster 3: 45%), there was a significant difference in
38 mean liking scores across all products, except jam. Differences in liking were predominantly
39 driven by sweet taste in 2 out of 3 clusters. The current research has demonstrated that a high
40 proportion of consumers prefer conventional products over sugar-reduced products across a
41 wide range of product types (45%) or across selected products (27%), when tasted
42 unbranded, and so there is room for further optimization of commercial reduced sugar
43 products that were evaluated in the current study. Future work should evaluate strategies to
44 facilitate compliance to dietary recommendations on NMES and free sugars, such as the
45 impact of sugar-reduced food exposure on their acceptance.

46 **Highlights:**

- 47 • We examine acceptability of commercially-available sugar-reduced products.
- 48 • We compare regular and sugar-reduced beans, jam, chocolate, cola and juice samples.
- 49 • Mean liking scores were significantly lower for sugar-reduced beans and cola.
- 50 • 45% of consumers gave lower liking scores to 4 of 5 sugar-reduced products.

51

52 *Keywords:* Artificial sweeteners, Consumer acceptance, Sensory profile, Sugar, Sugar-
53 reduced products, Sugar reformulation

54

55 *Abbreviations:* Beans, baked beans; Cola, cola drink; Chocolate, milk chocolate; Juice, a
56 mixed juice drink containing cranberry & raspberry juice; EI, energy intake; Jam, strawberry
57 jam; NMES, non-milk extrinsic sugars; REF, reformulated; REG, regular; SEG, socio-
58 economic group; SSB, sugar-sweetened beverages.

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67 **1. Introduction**

68 It is well established that sugar intake has a major contributory role in the progression
69 of dental caries (Moynihan & Kelly, 2013; Sheiham & James, 2014). Conversely, the
70 potential impact of sugar consumption, especially in the form of sugar-sweetened beverages
71 (SSB), on adiposity, cardio-metabolic risk factors is still under debate (Te Morenga, Mallard,
72 & Mann, 2013; van Buul, Tappy, & Brouns, 2014).

73 Currently in the UK, it is advised that intake of non-milk extrinsic sugars (NMES;
74 added sugars, sugars naturally present in unsweetened fruit juice and honey and half of the
75 weight of the sugars in stewed, dried and or preserved fruit) should contribute to no more
76 than 10% of total energy intake (EI) (Department of Health, 1991), with recent draft
77 guidelines by the UK Scientific Advisory Committee on Nutrition advocating a reduction in
78 consumption of free sugars (added sugars and the sugars naturally present in fruit juice,
79 honey and syrups) to a population mean of 5% of total EI (Scientific Advisory Committee on
80 Nutrition, 2014). However the UK population are still not meeting these recommendations;
81 NMES intake is almost 15% and 12% of total EI in children aged 4-18 years and adults aged
82 19-64 years, respectively (NDNS, 2014).

83 Reformulation is one strategy for improving the nutrient profile of sugar-containing
84 commercially-available processed foods and beverages. In the REFORMulated food
85 (REFORM) study, we found that an 8-week sugar-reduced commercially-available product
86 exchange significantly reduced NMES intake, when compared to the consumption of
87 matched regular sugar products (Markey, Le Jeune, & Lovegrove, 2013). Replacing regular
88 sugar products with reformulated options could provide a feasible strategy for reduction of
89 sugar intake at a population level, without the necessity for dramatic alterations to the
90 habitual diet. However, sugar-reduction of foods is challenging with changes in flavor and
91 texture balance, maintenance of food functionality, shelf-life and cost (van Raaij, Hendriksen,

92 & Verhagen, 2009); these are all major determinants of the commercial success of a food in
93 the consumer market (Cruz et al., 2010).

94 This study evaluated consumer acceptance of a selection of commercially-available
95 sugar-reduced products from the UK market which were used in the REFORM study
96 (Markey et al., 2013). These products were compared to regular counterparts and evaluated
97 by a healthy consumer cohort. The objectives of the study were to: (1) investigate consumer
98 acceptability and purchase intent of sugar-reformulated (REF) foods and drinks compared to
99 regular (REG) products and (2) to relate consumer liking to the sensory characteristics of the
100 products, determined by a trained sensory panel.

101 **2. Materials and methods**

102 *2.1 Food samples and preparation*

103 Five matched pairs of commonly consumed foods and drinks were selected to represent
104 a range of REG and REF items that are commercially-available in the UK. The chosen
105 product samples included baked beans (beans), strawberry jam (jam), milk chocolate
106 (chocolate), cola drink (cola), and cranberry & raspberry juice (juice). The nutritional content
107 of the products, manufacturer details and information on sugar substitutes in the reformulated
108 products (i.e. artificial sweeteners (AS) or sugar alcohols), are included in Table 1. The REF
109 beans contained no AS; the NMES content of the REG beans was 5 g/ 0.1 kg which was 32%
110 lower in the REF beans in addition to a 25% reduction in salt. The REF jam similarly
111 contained no alternative sweetener; the NMES reduction from the reference was 28% (from
112 27.6 to 20 g/0.1 kg). The chocolate had a much more substantial reduction in NMES
113 compared to the standard (from 44.0 to 0 g/0.1 kg) which was achieved through the use of
114 maltitol (a sugar alcohol). All of the NMES (10.6 g/0.1 kg) in the REF cola was replaced with

115 high-intensity AS. The REF juice drink achieved an 87% reduction in total sugars through
116 replacing all of the added sugar with sucralose (an AS derived from chlorination of sucrose).

117 All products were de-branded prior to serving, under food-safe conditions. Samples
118 were presented to consumers in white paper cups (100 mL) (beans), on white paper plates (18
119 cm diameter) (chocolate, jam), or clear plastic cups (50 mL) (cola, juice), labelled with three
120 digit randomized codes. Beans were heated to > 75 °C and were served at approximately $67 \pm$
121 2 °C, after being held at this temperature for a maximum of 60 minutes. Jam samples (0.006
122 kg) were presented to consumers on one small piece of crust-less white bread (0.008 kg;
123 Kingsmill Crusts Away, Maidenhead, UK). Jam, chocolate and cola samples were allowed to
124 equilibrate to room temperature and were served at 21 °C. In order to minimize carryover
125 effects, water and low-salt crackers (Carr's Table Water Crackers; United Biscuits Ltd.,
126 Hayes, UK) were provided and consumers were presented with computerized signals
127 prompting them to palate cleanse between samples.

128 *2.2 Quantitative descriptive sensory analysis (QDA)*

129 A trained sensory panel ($n = 10$), with a minimum of 2 years' experience, developed a
130 consensus vocabulary on the sensory attributes (appearance, aroma, taste, flavor,
131 texture/mouth feel and aftertaste/ after effect) of each study product type over five training
132 sessions, using reference standards to assist in defining attributes where required. During
133 duplicate quantification, samples were presented in a balanced order and sample attributes
134 were scored by assessors individually on unstructured 100 mm visual analogue scales using
135 Compusense Software (version 5.5, Ontario, Canada). Assessments were carried out in
136 isolated sensory booths under artificial daylight and with the room temperature controlled at
137 23 °C.

138 *2.3 Consumer screening and recruiting*

139 Untrained, healthy consumers ($n = 116$) were recruited to participate in the study,
140 which was given a favorable ethical opinion to proceed by the School Research Ethics
141 committee (Reference: 05/13). Potential consumers completed a screening questionnaire prior
142 to study participation and were recruited if they were age 20 – 49 years and regular
143 consumers of the study products. Study exclusion criteria included diagnosed CVD or T2D,
144 pregnancy, food allergies and smoking. All consumers gave written informed consent prior to
145 study entry. Consumers represented six demographic categories; (age: 20-34 and 35-49 years;
146 gender: male and female; socio-economic group (SEG): upper and lower. SEG was defined
147 according to the 2010 National Statistics Socio-economic Classification Guidelines (Rose &
148 Pevalin, 2010)). The demographic characteristics of the recruited consumers are outlined in
149 Table 2.

150 *2.4 Consumer acceptability test*

151 Each consumer attended the Sensory Science Centre at the Department of Food and
152 Nutritional Sciences at the University of Reading for one session. Upon arrival, informed
153 consent was taken from all consumers. Measurements of height and weight were collected to
154 the nearest 0.001 m and 0.1 kg, respectively.

155 The sensory acceptability of five sets of products was evaluated (by the sensory
156 panelists and consumers), in individual sensory booths under artificial daylight and
157 temperature-controlled (21 °C) conditions. The two products within each product category set
158 were presented to consumers in a balanced order, as was the presentation order of the two
159 products within the set. Consumers were asked to individually taste each of the five paired
160 coded samples and rate their liking (overall, appearance, flavor and texture) using a nine-
161 point hedonic scale (1: dislike extremely to 9: like extremely). The intensity appropriateness
162 of sweetness and flavor was assessed using a seven-point ‘Just about Right’ (JAR) scale (1:

163 much too little sweetness/texture to 7: much too sweet/texture). Consumers were also asked to
164 rate their purchase/product replacement intent of each of sample using a five-point hedonic
165 scale (1: definitely would not buy/replace, 5: definitely would buy/replace).

166 *2.5 Power calculation*

167 A power calculation was performed based on overall liking, the primary outcome
168 measure. It was estimated that a minimum of 100 consumers was necessary to allow for
169 detection of significant difference in liking of 2 on a 9 point hedonic scale between foods,
170 with $P < 0.05$ and 80% power (Hobbs, Ashouri, George, Lovegrove, & Methven, 2014). With
171 the allowance for a 20% dropout rate, 116 consumers were recruited.

172 *2.6 Data collection and statistical analysis*

173 Sensory analysis data was analyzed using Compusense Five (Compusense Inc.,
174 Ontario, Canada). This software was employed to design questionnaires, present
175 questionnaires to consumers or panelists and for data collection. When a significant product x
176 covariate (gender, age and/or BMI) interaction was identified, hedonic data were analyzed by
177 ANCOVA with product and consumers as fixed effects. Where a significant product x
178 covariate interaction was not present, data were analyzed by ANOVA. Tukey's post hoc tests
179 for multiple comparisons were used to identify where differences existed in the data.
180 Agglomerative hierarchical cluster analysis (AHC) was conducted on consumer liking data and
181 ANOVA for identification of differences in liking between consumer clusters. All analyses of
182 consumer data were carried out in XLStat (AddinSoft, Paris, France).

183 The QDA data were analyzed in SENPAQ (version 3.2; QI Statistics, Reading, UK)
184 using two-way ANOVA, with sample fitted as a fixed effect and assessors as a random effect.
185 Significant differences between samples were assessed by Tukey's post hoc tests.

186 To visualize the liking data across all product types as a multi-dimensional plot, a
187 preference map as a principal component analysis (PCA) was carried out. The only common
188 sensory attribute across all product types was sweet taste, mean values for sweet taste were
189 regressed onto the PCA as supplementary variables along with the liking cluster means from
190 the AHC.

191

192 **3. Results**

193 *3.1 Consumer demographics*

194 A total of 116 healthy consumers participated in the study. The consumer
195 characteristics are highlighted in Table 2. The study population was split relatively equally
196 for age; 55% of consumers were aged 20 – 34 years (26.1 ± 4.4 years) and 45% fell into the
197 35 – 49 years age category (41.5 ± 4.1 years). The population was well split between males
198 (47%) and females (53%) and SEG (46 and 44% for groups 1-4 and groups 5-8, respectively
199 (Rose & Pevalin, 2010). There was no significant difference between age, gender and SEG
200 categories ($P > 0.05$).

201 *3.2. Sensory characteristics of regular and reformulated products*

202 The trained sensory panel used a mean of thirty-five different sensory attributes to
203 describe each study product type. The attributes that were significantly different between
204 REG and REF products are characterized in Supplementary Table 1. A total of 39 attributes
205 were used to describe the bean samples, of which 14 significantly differed between the REG
206 and REF samples. The REF beans were significantly less sweet in taste and aftertaste, with
207 the ratings in the latter two modalities being almost halved. The REF beans were also
208 significantly lower in salty, tomato, spice and pepper flavor, and higher in earthy flavor, than
209 the REG beans. These differences were explained by the reduction in sugar and salt in the

210 REF formulation without the addition of sweeteners. The REF jam, which also contained no
211 sweetener addition, was significantly different from the REG jam in 11 out of 35 attributes.
212 Although the REF jam was less sweet than the REG jam, the difference was far less and did
213 not reach significance. However, the REF jam was perceived to be significantly ($P < 0.05$)
214 less cooked, as well as having less body, less mouth coating and dissolving faster in the
215 mouth as might be expected with a lower sugar content. The REF chocolate differed from the
216 REG chocolate in 7 out of 41 attributes; it was lower in sweet taste and aftertaste and had a
217 cooling effect, an attribute characteristic to sugar alcohols, such as the maltitol used in this
218 product (Levin, Zehner, Saunders, & Beadle, 1995). The lower sugar content also resulted in
219 a product perceived to be easier to chew and less substantial in the mouth. The REF cola,
220 where all sugar had been replaced by AS, only differed from REG cola in 3 out of 29
221 attributes; it was significantly less sweet, less citrus in flavor and was found to have a more
222 bitter taste. High-intensity AS, including Acesulfame-K, are known to have bitter taste
223 characteristics (Ott, Edwards, & Palmer, 1991). In addition, high-intensity AS give a different
224 dynamic flavor profile (Zorn, Alcaire, Vidal, Giménez, & Ares, 2014), yet this was not
225 assessed in our QDA sensory profile. The REF juice drink only differed from the REG juice
226 drink in 3 out of 31 attributes; however in this case the use of the sweetener, sucralose,
227 resulted in a significantly sweeter product than the REG juice.

228 *3.3 Consumer acceptability of regular and reformulated products*

229 There were significant effects of product type and consumer on overall liking (both $P <$
230 0.0001) and on liking of each modality (appearance, flavor and texture) (all $P < 0.0001$).
231 Mean overall liking scores for the REG and REF beans and cola differed significantly (Table
232 3), with the REG versions being significantly more liked for these two product categories.
233 The mean consumer liking scored for the appearance of the REG cola and chocolate were
234 significantly higher, compared to the REF samples ($P < 0.0001$ and $P = 0.008$, respectively;

235 Table 4). This difference in liking may have been due to carbonation or color. It was noted
236 that there was a more substantial foam head on the REF cola. Secondly, when tested by
237 Hunterlab colourquest spectrophotometer the cola samples were found to differ significantly
238 in color as defined by L*a*b* values. The REF cola was significantly higher in red (a*) and
239 yellow (b*) hue (data not shown). The mean liking of flavor scores were significantly higher
240 for REG beans ($P < 0.0001$), chocolate ($P = 0.017$) and cola ($P < 0.0001$) compared to the
241 REF versions. The liking of texture of the REG beans ($P = 0.000$), chocolate ($P = 0.028$) and
242 cola ($P < 0.0001$) were significantly higher. The consumer opinion of the flavor intensity
243 (JAR ratings) differed between products, where the REG beans ($P < 0.0001$), milk chocolate
244 ($P = 0.000$), cola ($P = 0.007$) and jam ($P = 0.013$) were closer to JAR than the REF versions
245 of the products. Consumer JARs for sweetness intensity were significantly different for beans
246 ($P = 0.012$), chocolate ($P < 0.0001$) and cola ($P = 0.000$) (Fig.1); for beans and cola the REG
247 versions of the products were closer to JAR and their REF counterparts were lower than JAR
248 in sweetness, however for chocolate the mean rating for the REG version was higher than
249 just-about-right.

250 There were significant effects of both product type and consumer on product replacement
251 ratings, when an adjustment was made for gender (gender used as a covariate in the ANOVA)
252 ($P = 0.063$ and $P = 0.002$, respectively) (Table 5). When asked, consumers were significantly
253 more likely to replace their habitually consumed products with the REG beans ($P < 0.0001$),
254 cola ($P = 0.000$) and juice ($P = 0.003$), when compared to their reformulated counterparts.
255 There were significant effects of both product type ($P = 0.019$) and consumer ($P < 0.0001$) on
256 purchase intent ratings. Consumers were more likely to buy the REG beans and cola products
257 (both $P < 0.0001$). However, although the purchase intent scores were significantly greater
258 for the majority of regular study products, there was still a low purchase intention for both

259 product types; the mean purchase intent scores ranged from almost 2: ‘probably would not
260 buy’ to almost 4: ‘probably would buy.’

261 *3.4 Agglomerative hierarchal cluster analysis of consumer liking data*

262 Cluster analysis of the consumer liking data revealed three consumer clusters that were
263 representative of different patterns of consumer liking (Table 3). Cluster 2 (28%) were non-
264 discriminators where there were no significant differences in their liking scores between any
265 of the products types. Cluster 1 (27%) differentiated only two product types, beans and jam,
266 where they gave significantly higher liking scores to the regular products. However, for the
267 largest cluster (cluster 3: 45%) there was a significant and substantial difference in mean
268 liking scores across 4 of the 5 products where the REG product scored higher for beans,
269 chocolate, cola and juice.

270 The demographic characteristics of each consumer cluster are highlighted in Table 2.
271 Cluster one was characterized by a relatively homogenous split of consumers with regards to
272 age and SEG but contained a higher proportion of males (66%). Cluster two, the non-
273 discriminating cluster were mostly younger (61%), contained a higher proportion of females
274 (64%) and those from a lower SEG (64% from SEG group 5 – 8). There were no substantial
275 age, gender or SEG differences between consumers who fell into cluster three.

276 *3.5 Relating the sensory characteristics to the consumer liking data*

277 The REG beans were liked more, overall and in flavor, than the REF beans; this is
278 perhaps not surprising as the latter were not only less sweet, but they were also lower in salty
279 taste, tomato, pepper and spice flavor. The texture of the REG beans was also more liked, and
280 again the sensory panel scored the REF beans to be more broken. The differences in sensory
281 attributes between the REG and REF jams had little effect on liking with only consumers in
282 cluster 1 liking the REG jam significantly more. The REF chocolate was less sweet and had a

283 cooling sensation, which seem to be responsible for the reduction in the liking of flavor for
284 the REF chocolate; however this only significantly reduced overall liking for cluster 3. The
285 textural differences in the REF product had no significant effect on liking. The reduced
286 sweetness and bitter taste of the REF cola reduced the overall consumer mean liking;
287 however this was largely driven by the substantial differences in liking in the consumers
288 within cluster 3. The consumers in cluster 1 and 2 were not affected by this; with cluster 1
289 disliking both cola samples and cluster 2 liking both. The cola products were both from the
290 global Coca-Cola brand and many consumers will have been familiar with these products.
291 Although the diet version of Coca-Cola is disliked by some consumers (cluster 3), it is a large
292 brand that has a strong consumer allegiance which may explain the equal liking ratings in
293 clusters 1 and 2. Findings from a recent review suggest that consumption of AS is more
294 prevalent in women than men (Pereira, 2013) and this could help to explain why cluster 2 had
295 the highest mean rating for the REF cola drink. The differences in sensory attributes between
296 the REG and REF juice drinks had little effect on liking with only consumers in cluster 3
297 liking the REG juice significantly more. In the juice, this difference cannot have been driven
298 by overall sweetness as the REF drink was sweeter; however the sucralose content may have
299 led to a different sweetness profile (length of impact of sweet taste) compared to the REG
300 product. Such a difference in profile was not characterised by our sensory panel as they were
301 not undertaking a time intensity profile. However, it has previously been reported that
302 sucralose may have a slow onset of sweetness and a longer sweetness perception, when
303 compared to sucrose (Glória, 2003). A PCA map of the liking scores across all products is
304 represented in Fig. 2. The first three principal components were representative of 50.8% of
305 the variation in the data. The first dimension (PC1) represented 23.5% of the variance in the
306 liking scores, the REG and REF products were separated along PC1 with the regular products
307 to the right hand side.

308 Where the sensory panel scores for sweetness were related to the consumers mean
309 liking scores we can see that across product types, sweetness appears to be driving the liking
310 for the consumers in clusters 1 and 3.

311 **4. Discussion**

312 The main focus of the present study was to examine impact of NMES content on
313 acceptability and purchase probability of a selection of commonly consumed commercially-
314 available foods and drinks that were previously used in the REFORM human dietary
315 intervention study (Markey et al., 2013). Consumers, broadly representative of the current
316 UK demographics with regards to age, gender, BMI and SEG, generally accepted the sugar-
317 reduced jam, chocolate and juice samples that were presented to them. As nutritional
318 information about sugar content may affect product liking and purchase intent (Johansen,
319 Næs, Øyaas, & Hersleth, 2010; Shepherd, Sparks, Bellier, & Raats, 1992), consumers in the
320 present study were blinded to the purpose of the sensory evaluation. We found that
321 consumer's liking of the products was primarily driven by sweet taste.

322 Overall, the largest difference in mean overall liking was observed between the paired
323 samples of beans and cola. There was only a 2.4 g/0.1 kg difference in NMES content
324 between the two presented bean samples, although this did lead to a substantially lower sweet
325 taste. It is possible that the dissimilarity in liking between the samples was confounded by the
326 salt taste of the product (Kroeze, 1979). A 44 g/0.1 kg disparity in NMES content was
327 evident for the study chocolate samples. The replacement of sucrose by sugar alcohols can
328 affect the rheological properties and the quality of chocolate but maltitol, the sugar alcohol
329 present in our reformulated chocolate, has been recommended as a sucrose replacement in
330 chocolate formulations (Sokmen & Gunes, 2006). Consumers significantly liked the flavor,
331 texture and appearance of the REG chocolate more than the REF sample and thought that the
332 intensity of flavour of the REG chocolate sample was closer to JAR. However, the sweetness

333 intensity of the REF chocolate was too high for some consumers (mean JAR value 4.4
334 compared to 3.4 for the REG chocolate; where just-about-right was 4 on the 7 point
335 scale)which could partly explain why there was no difference in overall liking between the
336 two chocolate samples.

337 Three distinct cluster patterns of overall product liking were identified. Factors,
338 including age and gender, can control liking for sweetness (A. Drewnowski, Mennella,
339 Johnson, & Bellisle, 2012). In agreement with literature which suggests that adiposity is not
340 related to liking of sweet stimuli (Salbe, DelParigi, Pratley, Drewnowski, & Tataranni, 2004),
341 we found a similar mean BMI across our clusters. Cluster two did not discriminate between
342 product types; this is not surprising as the cluster was predominantly female and it has been
343 shown that females have higher acceptance of AS as discussed previously ~~men prefer higher~~
344 ~~sweetness intensities more than women~~ (Hayes & Duffy, 2008; Monneuse, Bellisle, & Louis-
345 Sylvestre, 1991; Pereira, 2013). Sweetness was the dominant factor driving overall liking in
346 cluster one and three. This supports research that suggests individuals tend to have an
347 increased preference of foods and liquids containing higher sucrose concentrations until a
348 sensory optimum is reached (A. Drewnowski & Almiron-Roig, 2010; Mennella, Finkbeiner,
349 Lipchock, Hwang, & Reed, 2014; Thompson, Lopetcharat, & Drake, 2007). Interestingly, the
350 first consumer cluster only differentiated between beans and jam; these were the paired
351 samples that had the smallest difference in sugar content and were the only reformulated
352 samples where sugar was not replaced with sweeteners. Although our research was conducted
353 in a blinded manner, this finding is in agreement with some qualitative research where it was
354 found that consumers generally expected that sucrose would be replaced by AS (Patterson,
355 Sadler, & Cooper, 2012). Cluster three gave significantly greater liking ratings to the regular
356 beans, chocolate, cola and juice and it is speculated that this consumer cluster would find it
357 most difficult to reduce NMES consumption to $\leq 10\%$ of total EI (Department of Health,

1991). This cluster might be composed of consumers that have a ‘sweet tooth’ phenotype and a preference for foods with a high-intensity of sweetness, rather than savory alternatives (Reed & McDaniel, 2006).

The use of AS, in replacement for sucrose, can cause alterations in the perception of sweet and bitter tastes (Cardello, Da Silva, & Damasio, 1999) and this could have contributed to the low mean liking rating of the REF cola. The REF beans and jam samples were the only products in our sample set that did not contain AS or sugar alcohols. Our REF jam received the highest mean rating for overall liking. Although it could be argued that the difference in NMES content between the two jam samples is quite low (7.6 g/ 0.1 kg), this finding agrees favorably with the opinion that systematic reduction of sugar in processed foods, without the use of AS substitution, may be a more realistic strategy for lowering NMES intake (Yang, 2010). Furthermore, there is concern that AS use may hinder readjustment of consumers’ palates to a lower sweetness intensity (Stuckey, 2013). As an alternative to AS, it has been shown that the addition of flavor compounds to sweet matrices enhances consumer perception of sweetness (Labbe, Damevin, Vaccher, Morgenegg, & Martin, 2006; Tournier et al., 2009), with others emphasizing the importance of finding a balance between flavoring and sugar reduction as a means of improving the sweetness intensity of a specific product (Chollet, 2013). In the context of salt reformulation, it has been illustrated that the preferred level of sodium in food can be altered after reduced intake of that nutrient (Bertino, Beauchamp, & Engelman, 1982) and simple exposure to a no added salt soup can increase consumers’ liking ratings for that product (Methven, Langrenney, & Prescott, 2012). Moreover, a recent study suggested that repeated exposure a salt-reduced soup with additional herbs and spices increased overall liking, in comparison to standard and low-salt soup treatments (Ghawi, Rowland, & Methven, 2014). Future research is needed to evaluate whether repeated exposure is applicable to sugar-reduced products.

383 Food reformulation strategies have been successfully utilized to improve the salt and
384 *trans* fatty acid profile of commonly consumed processed foods (He, Brinsden, & Macgregor,
385 2014; Scientific Advisory Committee on Nutrition, 2007). Although the success of using
386 sugar-reformulation as a strategy for reducing sugar intake has yet to be determined, the
387 replacement of sugar with AS is seen as a means for achieving reductions in sugar intake,
388 whilst maintaining the sweetness. While some studies have shown the benefit of AS beverage
389 consumption on weight loss promotion (Foreyt, Kleinman, Brown, & Lindstrom, 2012),
390 others have shown a positive association between consumption of these beverages and weight
391 gain (Fowler et al., 2008; Mattes & Popkin, 2009). Indeed, the potential benefits incurred by
392 using AS will be overridden, if the reduction in sugar intake is hindered by energy
393 compensatory responses, through increased EI at subsequent meals or reduced physical
394 activity-related energy expenditure (Gardner et al., 2012; Stubbs et al., 2004). Individuals
395 may overcompensate for perceived caloric savings by AS usage (Mattes & Popkin, 2009).
396 Previously, we found that consumption of sugar-reduced products for an 8-week period led to
397 energy compensation and no significant weight gain or change in cardio-metabolic risk
398 markers (Markey et al., 2013). Similarly, no significant changes in body weight were
399 observed in overweight individuals following random assignment to 1000 mL/d of diet cola
400 when compared to sugar-sweetened cola, semi-skimmed milk or water for a 6-month period
401 but the authors did find that daily intake of the regular cola led to a significantly increased
402 accumulation of ectopic fat (Maersk et al., 2012).

403 Regardless of the impact of sugar consumption on cardio-metabolic risk factors, sugar
404 intake is the most significant dietary factor in the progression of dental caries (Moynihan &
405 Kelly, 2013; WHO, 2003). The introduction of a gradual step reduction in the sugar content
406 of commercially-available foods could be a realistic approach for minimizing risk of caries

407 throughout the lifecycle and maximizing the ability of the population to reach the target
408 intake for NMES (WHO, 2014).

409 The provision of health information related to the nutritional quality of sugar-
410 reformulated foods is beneficial to the acceptance and understanding of these products
411 (Patterson et al., 2012; van Raaij et al., 2009). Previous research has illustrated that providing
412 consumers with sugar or energy-reduced labeling increases consumer acceptance or product
413 choice of yoghurts and soft drinks (Enneking, Neumann, & Henneberg, 2007; Johansen et al.,
414 2010) but the effect of information may be dependent on the product category type as well as
415 the type of information that is relayed to consumers (Johansen et al., 2010). In addition to
416 this, although health information on calorie-reduced products may play an influential role on
417 food choice during a first time purchase, evidence suggests that the sensory attributes and the
418 product experience are key drivers for product re-purchase (Grunert, 2003). Commercial
419 products generally require a mean liking score of seven before they are launched (Hobbs et
420 al., 2014). Interestingly, none of our commercially-available products reached this liking cut-
421 off for market acceptance. Furthermore, the highest purchase intent rating observed was 3.5
422 (almost 'probably would buy') for one of the most commonly consumed brand regular baked
423 beans in the UK. It seems likely that tasting in an uninformed condition, and not being aware
424 of the brand, packaging and labeling, could have impacted negatively on the sensory
425 perception of all our study products (Mueller & Szolnoki, 2010). Additionally, an
426 acknowledged limitation of the study is that the chocolate and jam samples were not
427 produced by the same company and different manufacturing processes and raw materials
428 could have impacted on product liking, independent of differences in sugar content.

429

430 **5. Conclusion**

431 Consumer acceptability is key to the success of sugar reformulation as a strategy for
432 reducing intake of NMES or free sugars at a UK population level. Although product
433 reformulation may be an acceptable means of reducing intake of sugars by some consumers,
434 the current study indicates that significant improvements in the sensory qualities of some
435 sugar-reduced products are required before their acceptance as a means of reducing sugar
436 intake; however our findings cannot be generalised beyond the selection of sugar-reduced
437 foods that were employed in the current study. This was particularly true for 45% of
438 consumers in this study, a cluster of consumers that were representative of the UK population
439 with regards to age, gender, BMI and SEG. Future research into the impact of repeated
440 exposure or the use of sweet odors as flavorings on liking of sugar reformulated products is
441 required. Furthermore, the effects of branding, labeling and health information on the
442 acceptability of reformulated sugar-reduced products should be considered.

443

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452

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602

LIST OF FIGURES

Fig. 1. Just about right (JAR) sweetness ratings. Baked beans (beans), strawberry jam (jam), milk chocolate (chocolate), cola drink (cola) and cranberry & raspberry juice (juice). Values are means \pm SD. Significance is shown as: ANOVA with comparisons between matched regular (REG) and reformulated (REF) product pairs, followed by Tukey's post hoc tests, * $P < 0.05$, ** $P < 0.01$, *** $P < 0.0001$.

Fig. 2. Internal preference map showing the consumer mean liking scores (represented by diamond shapes) for the five product types of regular (A) and reformulated (B) products with the trained sensory panel ratings for sweet taste regressed onto the map. Beans_A, regular baked beans, Beans_B, reformulated baked beans, Jam_A, regular strawberry jam and Jam_B, reformulated strawberry jam, Choc_A, regular milk chocolate, Choc_B, reformulated milk chocolate, Cola_A, regular cola drink, Cola_B, reformulated cola drink, Juice_A, regular cranberry & raspberry juice, Juice_B, reformulated cranberry & raspberry juice.