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Abstract

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

Highlights:

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

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

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

1. Introduction

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

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

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

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

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

2. Materials and methods

2.1 Food samples and preparation

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

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

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

2.2 Quantitative descriptive sensory analysis (QDA)

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

2.3 Consumer screening and recruiting

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

2.4 Consumer acceptability test

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

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

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

2.5 Power calculation

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

2.6 Data collection and statistical analysis

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

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

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

3. Results

3.1 Consumer demographics

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

3.2. Sensory characteristics of regular and reformulated products

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

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

3.3 Consumer acceptability of regular and reformulated products

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

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

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

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

3.4 Agglomerative hierarchal cluster analysis of consumer liking data

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

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

3.5 Relating the sensory characteristics to the consumer liking data

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

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

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

4. Discussion

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

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

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

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

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

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

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

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

5. Conclusion

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

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References

454 Bertino, M., Beauchamp, G. K., & Engelman, K. (1982). Long-term reduction in dietary
455 sodium alters the taste of salt. *American Journal of Clinical Nutrition, 36*(6), 1134-1144.
456 Cardello, H. M., Da Silva, M. A., & Damasio, M. H. (1999). Measurement of the relative
457 sweetness of stevia extract, aspartame and cyclamate/saccharin blend as compared to
458 sucrose at different concentrations. *Plant Foods for Human Nutrition, 54*(2), 119-130.
459 Chollet, M. (2013). Acceptance of sugar reduction in flavored yogurt. *Journal of Dairy*
460 *Science, 96*(9), 5501-5511. doi: 10.3168/jds.2013-6610
461 Cruz, A. G., Cadena, R. S., Walter, E. H. M., Mortazavian, A. M., Granato, D., Faria, J. A.
462 F., & Bolini, H. M. A. (2010). Sensory Analysis: Relevance for Prebiotic, Probiotic, and
463 Synbiotic Product Development. *Comprehensive Reviews in Food Science and Food*
464 *Safety, 9*(4), 358-373. doi: 10.1111/j.1541-4337.2010.00115.x
465 Department of Health. (1991). Dietary Reference Values for Food Energy and Nutrients for
466 the United Kingdom. Vol. 41: Report on Health and Social Subjects. London: HMSO.
467 Drewnowski, A., & Almiron-Roig, E. (2010). Human Perceptions and Preferences for Fat-
468 Rich Foods. In: Fat Detection: Taste, Texture, and Post Ingestive Effects. Boca Raton
469 (FL): CRC Press; 2010. Chapter 11. Available from:
470 http://www.ncbi.nlm.nih.gov/books/NBK53528/ (Accessed 11 June 2014).
471 Drewnowski, A., Mennella, J. A., Johnson, S. L., & Bellisle, F. (2012). Sweetness and food
472 preference. *Journal of Nutrition, 142*(6), 9.
473 Enneking, U., Neumann, C., & Henneberg, S. (2007). How important intrinsic and extrinsic
474 product attributes affect purchase decision. *Food Quality and Preference, 18*(1), 133-138.
475 Foreyt, J., Kleinman, R., Brown, R. J., & Lindstrom, R. (2012). The use of low-calorie
476 sweeteners by children: implications for weight management. *Journal of Nutrition, 142*(6),
477 9.

Fowler, S. P., Williams, K., Resendez, R. G., Hunt, K. J., Hazuda, H. P., & Stern, M. P. (2008). Fueling the obesity epidemic? Artificially sweetened beverage use and long-term weight gain. *Obesity, 16*(8), 1894-1900.

Gardner, C., Wylie-Rosett, J., Gidding, S. S., Steffen, L. M., Johnson, R. K., Reader, D., & Lichtenstein, A. H. (2012). Nonnutritive sweeteners: current use and health perspectives: a scientific statement from the American Heart Association and the American Diabetes Association. *Diabetes Care, 35*(8), 1798-1808.

Ghawi, S. K., Rowland, I., & Methven, L. (2014). Enhancing consumer liking of low salt tomato soup over repeated exposure by herb and spice seasonings. *Appetite, 81*, 20-29.

Glória, M. B. A. (2003). SWEETENERS | Others. In B. Caballero (Ed.), *Encyclopedia of Food Sciences and Nutrition (Second Edition)* (pp. 5695-5702). Oxford: Academic Press.

Grunert, K. G. (2003). Purchase and consumption: the interdisciplinary nature of analysing food choice. *Food Quality and Preference, 14*(1), 39-40.

Hayes, J. E., & Duffy, V. B. (2008). Oral sensory phenotype identifies level of sugar and fat required for maximal liking. *Physiology & Behaviour, 95*(1-2), 77-87.

He, F. J., Brinsden, H. C., & Macgregor, G. A. (2014). Salt reduction in the United Kingdom: a successful experiment in public health. *Journal of Human Hypertension, 28*(6), 345-352.

Hobbs, D., Ashouri, A., George, T., Lovegrove, J., & Methven, L. (2014). The consumer acceptance of novel vegetable-enriched bread products as a potential vehicle to increase vegetable consumption. *Food Research International, 58*, 15-22.

Johansen, S. B., Næs, T., Øyaas, J., & Hersleth, M. (2010). Acceptance of calorie-reduced yoghurt: Effects of sensory characteristics and product information. *Food Quality and Preference, 21*(1), 13-21.

Kroeze, J. H. (1979). Masking and adaptation of sugar sweetness intensity. *Physiology & Behavior, 22*(2), 347-351.

503 Labbe, D., Damevin, L., Vaccher, C., Morgenegg, C., & Martin, N. (2006). Modulation of
504 perceived taste by olfaction in familiar and unfamiliar beverages. *Food Quality and*
505 *Preference, 17*(7–8), 582-589.
506 Levin, G. V., Zehner, L. R., Saunders, J. P., & Beadle, J. R. (1995). Sugar substitutes: their
507 energy values, bulk characteristics, and potential health benefits. *American Journal of*
508 *Clinical Nutrition, 62*(5), 1161S-1168S.
509 Maersk, M., Belza, A., Stodkilde-Jorgensen, H., Ringgaard, S., Chabanova, E., Thomsen, H.,
510 . . . Richelsen, B. (2012). Sucrose-sweetened beverages increase fat storage in the liver,
511 muscle, and visceral fat depot: a 6-mo randomized intervention study. *American Journal*
512 *of Clinical Nutrition, 95*(2), 283-289.
513 Markey, O., Le Jeune, J., & Lovegrove, J. A. (2013). Initial findings of the impact of an 8-
514 week intervention of sugar reformulated product exchange on cardiovascular risk factors.
515 *Proceedings of the Nutrition Society, 72*, E214.
516 Mattes, R. D., & Popkin, B. M. (2009). Nonnutritive sweetener consumption in humans:
517 effects on appetite and food intake and their putative mechanisms. *American Journal of*
518 *Clinical Nutrition, 89*(1), 1-14.
519 Mennella, J. A., Finkbeiner, S., Lipchock, S. V., Hwang, L.-D., & Reed, D. R. (2014).
520 Preferences for Salty and Sweet Tastes Are Elevated and Related to Each Other during
521 Childhood. *PLoS One, 9*(3), e92201. doi: 10.1371/journal.pone.0092201
522 Methven, L., Langreney, E., & Prescott, J. (2012). Changes in liking for a no added salt soup
523 as a function of exposure. *Food Quality and Preference, 26*(2), 135-140. doi:
524 http://dx.doi.org/10.1016/j.foodqual.2012.04.012
525 Monneuse, M. O., Bellisle, F., & Louis-Sylvestre, J. (1991). Impact of sex and age on
526 sensory evaluation of sugar and fat in dairy products. *Physiology & Behaviour, 50*(6),
527 1111-1117.

528 Moynihan, P., & Kelly, S. (2013). Effect on Caries of Restricting Sugars Intake Systematic
529 Review to Inform WHO Guidelines. *Journal of Dental Research*.
530 Mueller, S., & Szolnoki, G. (2010). The relative influence of packaging, labelling, branding
531 and sensory attributes on liking and purchase intent: Consumers differ in their
532 responsiveness. *Food quality and preference, 21*(7), 774-783. doi:
533 http://dx.doi.org/10.1016/j.foodqual.2010.07.011
534 NDNS. (2014). National Diet and Nutrition Survey: results from Years 1 to 4 (combined) of
535 the rolling programme for 2008 and 2009 to 2011 and 2012. 2014. Available from:
536 https://www.gov.uk/government/publications/national-diet-and-nutrition-survey-results-
537 from-years-1-to-4-combined-of-the-rolling-programme-for-2008-and-2009-to-2011-and-
538 2012 (cited 14 May 2014).
539 Ott, D. B., Edwards, C. L., & Palmer, S. J. (1991). Perceived Taste Intensity and Duration of
540 Nutritive and Non-nutritive Sweeteners in Water using Time-intensity (T-I) Evaluations.
541 *Journal of Food Science, 56*(2), 535-542. doi: 10.1111/j.1365-2621.1991.tb05319.x
542 Patterson, N. J., Sadler, M. J., & Cooper, J. M. (2012). Consumer understanding of sugars
543 claims on food and drink products. [Journal article]. *Nutrition Bulletin, 37*(2), 121-130.
544 Pereira, M. A. (2013). Diet beverages and the risk of obesity, diabetes, and cardiovascular
545 disease: a review of the evidence. *Nutrition Reviews, 71*(7), 433-440. doi:
546 10.1111/nure.12038
547 Reed, D. R., & McDaniel, A. H. (2006). The human sweet tooth. *BMC Oral health, 6*(Suppl
548 1), S17.
549 Rose, D., & Pevalin, D. (2010). Volume 3 The National Statistics Socio-economic
550 Classification:(rebased on the SOC2010) User manual (pp. 1–70). Basingstoke: Palgrave
551 Macmillan.

552 Salbe, A. D., DelParigi, A., Pratley, R. E., Drewnowski, A., & Tataranni, P. A. (2004). Taste
553 preferences and body weight changes in an obesity-prone population. *Am J Clin Nutr, 79*(3), 372-378.
555 Scientific Advisory Committee on Nutrition. (2007). Update on trans fatty acids and health.
556 Position statement. 2007. Available from:
557 http://www.sacn.gov.uk/pdfs/sacn_trans_fatty_acids_report.pdf (cited 2 March 2014).
558 Scientific Advisory Committee on Nutrition. (2014). Draft Carbohydrates and Health report.
559 Scientific consultation: 26 June to 1 September 2014. Available from:
560 http://www.sacn.gov.uk/reports_position_statements/reports/scientific_consultation_draft_
561 sacn_carbohydrates_and_health_report_-_june_2014.html (cited 30 June 2014).
562 Sheiham, A., & James, W. P. T. (2014). A new understanding of the relationship between
563 sugars, dental caries and fluoride use: implications for limits on sugars consumption.
564 *Public Health Nutrition, FirstView*, 1-9. doi: doi:10.1017/S136898001400113X
565 Shepherd, R., Sparks, P., Bellier, S., & Raats, M. (1992). The effects of information on
566 sensory ratings and preferences: the importance of attitudes. *Food Quality and Preference, 3*(3), 147-155.
568 Sokmen, A., & Gunes, G. (2006). Influence of some bulk sweeteners on rheological
569 properties of chocolate. *LWT - Food Science and Technology, 39*(10), 1053-1058. doi:
570 http://dx.doi.org/10.1016/j.lwt.2006.03.002
571 Stubbs, R. J., Hughes, D. A., Johnstone, A. M., Whybrow, S., Horgan, G. W., King, N., &
572 Blundell, J. (2004). Rate and extent of compensatory changes in energy intake and
573 expenditure in response to altered exercise and diet composition in humans. *American*
574 *Journal of Physiology - Regulatory, Integrative and Comparative Physiology, 286*(2), 350-
575 358.

576 Stuckey, B. (2013). *Taste: Surprising Stories and Science about Why Food Tastes Good*.
577 London: Atria Books.
578 Te Morenga, L., Mallard, S., & Mann, J. (2013). Dietary sugars and body weight: systematic
579 review and meta-analyses of randomised controlled trials and cohort studies. *British*
580 *Medical Journal, 346*.
581 Thompson, J. L., Lopetcharat, K., & Drake, M. A. (2007). Preferences for commercial
582 strawberry drinkable yogurts among African American, Caucasian, and Hispanic
583 consumers in the United States. [Research Support, Non-U S Gov't]. *J Dairy Sci*, *90*(11),
584 4974-4987.
585 Tournier, C., Sulmont-Rossé, C., Sémon, E., Vignon, A., Issanchou, S., & Guichard, E.
586 (2009). A study on texture–taste–aroma interactions: Physico-chemical and cognitive
587 mechanisms. *International dairy journal*, *19*(8), 450-458.
588 van Buul, V. J., Tappy, L., & Brouns, F. J. P. H. (2014). Misconceptions about fructose-
589 containing sugars and their role in the obesity epidemic. *Nutrition Research*, 1-12.
590 van Raaij, J., Hendriksen, M., & Verhagen, H. (2009). Potential for improvement of
591 population diet through reformulation of commonly eaten foods. [Research Support, Non-
592 U S Gov't]. *Public Health Nutr*, *12*(3), 325-330.
593 WHO. (2003). *Diet, nutrition and the prevention of chronic diseases*: World Health Organ
594 Tech Rep Ser. 2003;916:i-viii, 1-149, backcover.
595 WHO. (2014). Draft Guideline: Sugars intake for adults and children. 2014. Available from:
596 http://www.who.int/nutrition/sugars_public_consultation/en/ (cited 22 April 2014).
597 Yang, Q. (2010). Gain weight by "going diet?" Artificial sweeteners and the neurobiology of
598 sugar cravings: Neuroscience 2010. *Yale J Biol Med.*, *83*(2), 101.

599 Zorn, S., Alcaire, F., Vidal, L., Giménez, A., & Ares, G. (2014). Application of multiple-sip
600 temporal dominance of sensations to the evaluation of sweeteners. *Food quality and*
601 *preference, 36*(0), 135-143. doi: http://dx.doi.org/10.1016/j.foodqual.2014.04.003

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