

Sweeter together? Assessing the combined influence of product-related and contextual factors on perceived sweetness of fruit beverages

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14

15 **Abstract**

16 It is well-known that multiple sensory cues influence flavour perception and liking. The present
17 study aimed to combine and compare the relative influences of product-related and contextual
18 factors on taste perception and liking, with a focus on the perception of sweetness. Participants
19 tasted samples of the same base fruit beverage with one of three different levels of added aroma,
20 while the contextual cues (either visual or auditory) were displayed simultaneously using iPads. The
21 results revealed that both added aroma and background music significantly influenced participants'
22 sweetness ratings, with a medium level of added aroma enhancing sweetness significantly as
23 compared to no added aroma, and with the sweet-congruent soundtrack enhancing perceived
24 sweetness significantly as compared to the bitter-congruent soundtrack. Moreover, there was a
25 potentially additive effect from the combination of aroma and soundtrack. These results are
26 discussed in terms of potential mechanisms underlying multisensory flavour perception.

27 **Practical Applications**

28 Consumers are nearly always exposed to a multisensory environment whenever they consume food
29 and drink. It is therefore important to acknowledge that, beyond the food itself, what people happen
30 to be exposed to in the environment while eating or drinking can influence their multisensory
31 flavour experiences as well. These results are of relevance for those working on understanding a
32 theoretical model of human sweetness perception, as well as those working on the design of
33 healthier, sugar-reduced food products. Indeed, the knowledge that multiple sensory cues can, at
34 least under the appropriate conditions, work in conjunction to deliver a greater modulation of
35 perceived taste will allow designers to come up with more effective sugar-reduced products without
36 reducing consumer satisfaction. Moreover, the increasing prevalence of sensory and augmented
37 reality applications means that manufacturers can now incorporate external visual and auditory
38 content as part of the total multisensory product experience.

39

40

41 **Keywords:** Crossmodal correspondences, sweetness perception, product intrinsic factors, product
42 extrinsic factors, contextual factors, additive effects,

43 1. Introduction

44 The experience of eating is a multifactorial and dynamic phenomenon, one that often involves all of
45 the senses. A large body of research now supports the notion that food acceptance and perception
46 can be determined by intrinsic product-related factors (e.g., product colour, aroma, flavour, texture,
47 etc.; see Delwiche, 2004; Hewson et al., 2008; Mielby et al., 2016;), extrinsic product-related
48 factors (e.g. visual and tactile properties of packaging; see Ares & Deliza, 2010; Kobayashi & de
49 benassi, 2015; Piqueras-Fiszman & Spence, 2012b), as well as contextual factors (e.g., background
50 music, lighting conditions, etc.; see Crisinel et al., 2012; Oberfeld et al., 2009). What is less clear,
51 however, is how these different factors interact, and the relative importance of product-related and
52 contextual factors to our perception of, and behaviour towards, food and drink. In the present study,
53 we focused on interactions among aroma (as a product-intrinsic factor), colour, and sound (the latter
54 two introduced as contextual factors) on product liking and the perception of basic taste qualities,
55 especially sweetness. Sweetness was the target here because the consumption of sweet foods has
56 been argued to be one of the major contributors to the current obesity epidemic (Johnson et al.,
57 2007; Malik et al., 2006; Meier et al., 2015; Vartanian et al., 2007), and a multisensory,
58 psychological model of sweetness perception is crucial when it comes to the design of healthier
59 sugar-reduced/replaced foods.

60

61 1.1 Influence of aroma on sweetness perception

62 Perception does not work in a unisensory manner. When it comes to food and drink, the myriad of
63 sensory cues provided by the product itself can potentially influence the perception of information
64 presented in any modality, including the taste of sweetness (e.g., Delwiche, 2004; Poinot et al.,
65 2011; Spence, 2015). Additionally, the perception of sweetness has been shown to be affected by
66 different factors depending on the sweetener (Hewson, Hollowood, Chandra, & Hort, 2008). For
67 instance, Hewson et al. found that flavour perception in citrus-flavoured systems increased upon the
68 addition of tastants (citric acid, lactic acid and fructose), but beverages sweetened with either
69 glucose or fructose resulted in different flavour profiles despite being equally sweet.

70 In terms of the effect of aroma on sweetness perception, the body of research supporting the
71 modifying effects of aromas on sweetness perception is certainly not new. Aromas such as those
72 associated with caramel, vanilla, and berries have been found to increase the perception of

73 sweetness, at least in Western participants (e.g., Delwiche, 2004; Frank & Byram, 1988;
74 Schifferstein & Verlegh, 1996; Stevenson & Boakes, 2004; see Auvray & Spence, 2008, for a
75 review). Here, it is important to note that previous experience of co-exposure is key to taste
76 enhancement, which can differ with participants from different cultural backgrounds. For instance,
77 vanilla aroma was found to enhance perceived sweetness in French participants more than in
78 Vietnamese participants, but the reverse was true when lemon aroma was added to a model system
79 (see Nguyen et al., 2001; cf. Spence, 2008). Furthermore, Frank and Byram (1988) studied the
80 perception of sweetness and saltiness in different food matrices: Sucrose-sweetened whipped cream
81 and strawberry aroma, sucrose-sweetened whipped cream and peanut butter aroma, sodium chloride
82 salted whipped cream and strawberry aroma, and finally sucrose-sweetened whipped cream and
83 strawberry aroma evaluated with the nose pinched. These researchers found that strawberry aroma
84 tended to enhance the perception of sweetness; that an aroma's ability to enhance sweetness was
85 aroma-dependent; that an aroma's ability to enhance taste was tastant-dependent; and that the
86 influence of the strawberry aroma on sweetness perception was olfactory rather than gustatory in
87 origin. However, other researchers have found both ortho- and retronasal enhancements effects of
88 certain aromas on tastes such as sweetness (Delwiche & Heffelfinger, 2005; Frank, Ducheny, &
89 Mize, 1989; Spence 2012).

90

91 *1.2 Influence of non-product-related colour on sweetness perception*

92 The general (putatively learned) associations between colours and basic tastes have been well-
93 studied (see Spence et al., 2010, 2015, for reviews). What is perhaps more surprising, is the role of
94 contextual colour cues on influencing perceived tastes. For instance, Harrar and colleagues (2011)
95 reported that salty popcorn was perceived as sweeter when served in a red or blue bowl, as
96 compared to a white bowl. In another study, strawberry mousse was rated as roughly 15% sweeter
97 when served on a white plate than on a black plate (Piqueras-Fiszman et al., 2012). Harrar and
98 Spence (2013) replicated these results using black versus white spoons with different coloured
99 yoghurts. Furthermore, they posited that the contrast between the colour of the cutlery and the
100 colour of the food may help to explain differences in consumer liking and thus the perceived value
101 of the food, even if the effect on sweetness was based on the colour of the cutlery alone. When it
102 comes to beverages, a hot chocolate drink was rated as slightly sweeter when served in a dark cream
103 coloured cups as compared to orange, red, or white cups (Piqueras-Fiszman & Spence, 2012).

104 Elsewhere, Van Doorn et al. (2014) have reported that the same café latte tasted less sweet in a
105 transparent glass cup with a white sleeve as compared to cups with a blue sleeve or no sleeve at all
106 (see Spence, 2018, for a review of the literature on background colour’s influence on taste/flavour
107 perception).

108

109 *1.3 Influence of background sound on sweetness perception*

110 “Sonic seasoning”, the idea that certain soundtracks can be used to alter people’s taste perception, is
111 becoming an increasingly popular topic in both the academic literature and the popular press (e.g.,
112 Reinoso Carvalho et al., 2015; Spence 2015; Spence & Wang, 2015; see Spence, Reinoso-Carvalho,
113 Velasco, & Wang, submitted, for a review). Previous research has shown that specific auditory
114 attributes are associated with basic tastes, both when presented as taste words (for instance,
115 “sweet”), and in the form of tasting solutions (Crisinel & Spence, 2009, 2010a, b, 2011; Mesz et al.,
116 2011, 2012; Simner et al., 2010; Wang & Spence, 2016; see Knöferle & Spence, 2012, for a
117 review). For instance, both sweet and sour tastes are mapped to high pitch whereas bitterness is
118 mapped to low pitch (Crisinel & Spence, 2010; Knoeferle et al., 2015; Mesz et al., 2011; Wang et
119 al., 2016). Crisinel and her colleagues (2012) first demonstrated that beyond any crossmodal
120 associations between sounds and taste words, auditory stimuli could also affect people’s taste
121 evaluations. The participants in their study were given samples of bittersweet cinder toffee to
122 evaluate while listening to one of two soundtracks that had been specifically composed to
123 correspond to either sweet or bitter tastes. Crucially, the participants rated the cinder toffee samples
124 higher on the sweet-bitter scale¹ (i.e., more sweet and less bitter) while listening to the sweet
125 soundtrack than while listening to the bitter soundtrack. Similar sonic seasoning effects using
126 independent taste scales² (i.e. separate scales for sweet, bitter, sour, etc) using non-food-sound-
127 related soundtracks have since been found in food and beverage stimuli ranging from beer,
128 chocolate, salsa, and wine (Reinoso Carvalho et al., 2016, 2017; Wang et al., 2017; Wang &
129 Spence, 2015).

130

¹ It should be noted that the practice of putting two tastes on the same scale (i.e. a sweet-bitter scale) is never done in food sensory science because of the potential for confusing panelists/participants. This might account for the failure to replicate Crisinel’s original study by Höchenberger and Ohla, (2018).

131 *1.4 Existing research on reported interaction effects between different factors on sweetness*
132 *perception*

133 In terms of interactions between only food-intrinsic factors, it has been demonstrated that taste-
134 aroma interactions are moderated by the nature of the food matrix in question. Labbe and his
135 colleagues (2016) tested the taste enhancement effects of cocoa and vanilla flavouring in cocoa and
136 caffeinated milk. They found that in the cocoa beverage, cocoa flavouring led to an enhancement of
137 bitterness while vanilla flavouring enhanced sweetness. However, when it came to the relatively
138 less familiar caffeinated milk product, the addition of vanilla flavouring unexpectedly enhanced
139 bitterness instead of sweetness. In another example, Alcaire et al. (2017) found that while an
140 increase in vanilla flavour had a minor effect on the sweetness enhancement effect for a milk
141 dessert, the combination of increasing vanilla concentration together with increasing starch
142 concentration led to an increase in vanilla flavour intensity as well as sweetness perception.

143 Elsewhere, Fairhurst et al. (2015) manipulated both plate shape and the arrangement and shape of
144 the food in a restaurant setting. Participants rated the sweetness, sourness, intensity, and
145 pleasantness of two beetroot salads served on either round or angular plates, with the beetroots cut
146 into either angular or round shapes. One group of participants were served beetroot salads only from
147 round plates, and the other group only from angular plates. Serving the salad in the round plate plus
148 round food shape led to significantly higher ratings of sweetness than the congruent angular plate
149 plus angular food shape condition, with the incongruent conditions (where plate shape did not
150 match food shape) being rated somewhere in-between.

151 In terms of interactions between non-product-related contextual factors, Spence et al. (2014)
152 conducted a study in which the participants tasted the same red wine in an opaque black glass under
153 different lighting and music conditions. In Experiment 1, the wine was liked more in the combined
154 sweet music and red lighting condition (approximately a 5% increase), compared to red lighting
155 alone without music and compared to the control condition (white light, silence). However, there
156 were no changes in rated flavour intensity or freshness (compared to fruitiness). In Experiment 2,
157 the wine was rated as being significantly fresher (an increase of approximately 14%) when tasted
158 under green lighting while listening to sour music, as compared to green lighting alone and to the
159 control condition. What the studies did not assess, however, was the individual effect of music,
160 which leaves the question of whether both visual and auditory cues are required for a joint effect on
161 wine perception.

162 However, there has been no study to date assessing the interaction between food intrinsic factors
163 and contextual factors.

164 *1.5 Hypothesis and aims*

165 The present study was designed to assess whether and how the combined effects of product intrinsic
166 (added aroma) and contextual (non-product-related colour and sound) factors influence consumer
167 perception and liking for fruit beverages. While it may seem strange at the outset to include these
168 extrinsic or contextual factors (such as the colour one happens to be looking at, or background
169 music), it should be kept in mind that for virtually every real food and drink encounter, the
170 consumer is exposed to both intrinsic and extrinsic factors. It is therefore important to acknowledge
171 that, beyond the sensory properties of the food itself, what people are exposed to in the environment
172 while eating or drinking can influence and change the flavour experience as well. Our underlying
173 hypothesis was that all factors - added aroma, background soundtrack, and colour presented on a
174 screen - could influence consumers' sensory and hedonic evaluation of the beverages. However, we
175 would expect product intrinsic factors (aroma) would have a greater effect than contextual cues
176 (background soundtrack, colour seen on a screen), in terms of effect size and significance.
177 Moreover, we predicted that the different factors might have an additive effect - in other words,
178 multiple sensory stimuli might be capable of inducing a greater modulation of taste perception or
179 effect on liking when combined, as compared to when applied singly.

180

181 **2. Materials and methods**

182 *2.1 Experimental setup*

183 There were six individual designs in the experiment (T1-6, see Figure 1 for a schematic). Each
184 study (design) consisted of 5 conditions - a control condition with no audio or visual stimuli, and
185 four conditions with either auditory or visual stimuli (T1, T2, and T3) or with both auditory and
186 visual stimuli (T4, T5, and T6). The level of added aroma differed between each test. The product
187 with no added aroma (P1) was used in T1 and T4, the product with a moderate amount of added
188 aroma (P2) was used in T2 and T5, and the product with a higher amount of added aroma (P3) was
189 used in T3 and T6. The added aroma is described below in Section 2.3.1.

190

< INSERT FIGURE 1 ABOUT HERE >

2.2 Participants

A total of 331 adult participants (111 males, total mean age of 32 years \pm 13.2 years) were recruited to take part in the experiment at Aarhus University's stand at a large food festival over a two-day period in September 2017 in Aarhus, Denmark. All of those who took part were recruited at the actual test site. After agreeing to participate, the participants were asked to take a seat at a table in front of an available iPad. Participants were randomly assigned to one of six individual designs.

2.3 Stimuli

2.3.1 Beverages

Three different beverages, P1-3 varying in the concentration of added pomegranate aroma (Bolchehuset, Albertslund, Denmark) were used in the experiment. The base product used for all beverage products was an apple elderflower fruit beverage (Rynkeby Foods A/S, Ringe, Denmark) currently available to only one Danish retail chain (COOP) and otherwise not commercially available (see ingredient details of the apple elder flower fruit beverage in Table 1). The pomegranate aroma used was a natural food grade aroma suited for food and beverages such as hard candies (see Table 1 For the content of the experimental beverage products). The apple elderflower fruit beverage was chosen as a base beverage since it was relatively sour and somewhat unfamiliar as compared to other fruit beverages available on the Danish market. The choice of base product, the aroma, as well as concentration of added aroma was determined through several pilot-tasting sessions conducted between the experimenters. Pomegranate aroma was chosen since it complemented the base beverage well while adding an unfamiliar aroma to the product. Note that the intention behind using an unfamiliar aroma was to prevent participants from guessing the nature of the juice sample and hence perhaps feeling overconfident, especially given the within-participants nature of the experimental design (see Mielby et al., 2016, and Wang & Spence, 2015, for similar approaches in previous research). Pomegranate aroma has previously been described as being both sweet and sour (Koppel & Chambers, 2010). However, in combination with the relatively sour base beverage, the particular pomegranate aroma resulted in a “sweet fruity aroma”, as reported from the pilot tasting sessions. The aroma concentrations were determined in the pilot-

tasting sessions in order to reflect product ranges one could expect on the market. The goal was to use aroma concentrations that created perceivably different levels of aromas (according to the pilot session participants) while keeping the highest concentration from being overpowering. A similar approach was used for design of products in previous study (Mielby et al., 2016).

To make beverages P1-3, the aroma was added under hygienic conditions and mixed thoroughly, then the beverage was immediately poured into transparent cylindrical containers (height = 7 cm, diameter = 3 cm, volume = 40 mL) with red sealable lids (Gosselin, Hazebrouck, France). Each container was filled with 20 mL of the product the day before the study, and stored at 5 °C until usage to ensure optimal storage conditions with regards to shelf life. Each container was then labelled with a 3-digit identifier (see Figure 2A). The products were served to participants in the same containers at 5°C.

< INSERT TABLE 1 ABOUT HERE >

2.3.2 Visual stimuli

The visual stimuli consisted of coloured rectangles (748 x 470 px) presented on an iPad. The control colour was a pale yellow (R=255, G=255, B=128, hue=40, saturation=240 and luminance=180), designed to match the colour of the beverage. The other colour, a pale pink (R=255, G=174, B=201, hue=227, saturation=240 and luminance=202) was chosen, based on research (Saluja & Stevenson, 2018; Woods and Spence, 2016), as the one best at communicating sweetness. We chose to assess the impact of colour displayed on a screen as the contextual visual cue because it is increasingly common for people to look at devices while eating (Spence et al., 2016). Furthermore, research has shown that people's perceived sweetness can be influenced by looking at shapes and words displayed on a computer screen (Liang et al., 2013) or by the angularity of typeface (Velasco et al., 2018).

2.3.3. Auditory stimuli

Two 60-second soundtracks, one corresponding to sweetness and the other to bitterness, were chosen based on Wang et al.'s (2015) study comparing how well people associated basic tastes (sweet, bitter, sour, salty) to soundtracks which had been designed to correspond to specific tastes.

250 The soundtracks were both composed by Jialing Deng and Harlin Sun, as part of Deng's MA thesis
251 project *Synaesthetic Appetiser* (June, 2015). Both the sweet soundtrack (assigned as sweet by
252 89/100 people, $p < .0005$) and bitter soundtrack (assigned as bitter by 39/100 people, $p = .004$) were
253 significantly matched with their intended tastes, compared to chance.

254

255 2.4 Questionnaires and procedure

256 The experimenters provided the participants, who were seated in front of an iPad with connected
257 headphones, with the five beverages and water (Figure 2B). Given the public nature of the food
258 festival, the participants were seated inside a tent away from foot traffic to minimise distractions. In
259 addition, we used noise-cancelling over-ear headphones to reduce any background noise. The
260 participants were instructed to put the headphones on after a short introduction to the test was given.
261 The questionnaires which were presented on iPads first contained questions regarding the
262 participant's gender and age. Then, for each stimulus, questions regarding the participant's
263 beverage liking on a nine point hedonic scale, and perception of sourness-, sweetness-, and
264 bitterness intensities were given using nine point scales with endpoint categories ranging from not
265 at all (1) to extremely (9). Participants were provided with all 5 beverage samples in the beginning,
266 and were asked to match the 3-digit identifier given in each trial with the 3-digit identifier labelled
267 on each sample. To control for presentation bias, the order of presentation of the stimuli was
268 randomised as were the questions related to the perception of sweetness, bitterness, and sourness of
269 the stimuli. All of the participants were offered sweet treats and apples after having taken part in the
270 study. The questionnaires presented on iPads, were collected using Compusense online data
271 collection software (Compusense, Guelph, Canada). The study lasted for around 10 minutes.

272

273 < INSERT FIGURE 2 ABOUT HERE >

274

275 2.5 Data analysis

276 First, a multivariate analysis of variance (MANOVA) was conducted on all the data (T1-6) with
277 levels of aroma, visual cue, and soundtrack type as the between-participants factors, with reported
278 liking, reported intensities of sweetness, sourness, and bitterness as measures (SPSS, version 23.0,

279 IBM Corp., Armonk, NY). To test whether separate sensory stimuli have an additive effect on
280 sweetness perception, we compared the sweetness enhancement effect of the conditions in which
281 the soundtrack and colour were combined with the effect of soundtrack alone and colour alone.
282 Similarly, we compared the sweetness enhancement effects of combined soundtrack and aroma
283 factors with the effects of soundtrack alone and aroma alone.

284

285 3. Results

286 3.1 Overall results over T1-6 - influence of aroma, colour, and sound on product evaluation

287 A MANOVA was conducted with levels of aroma (P1-P3), visual cue (none, yellow, pink), and
288 soundtrack type (none, sweet, bitter) as the between-participant factors. Liking, intensities of
289 sweetness, sourness, and bitterness were used as measures. The analysis revealed significant main
290 effects of aroma level ($F(8, 3252) = 3.19, p = .001$, Wilks' Lambda = .98) and music ($F(8,$
291 $3252)=2.67, p = .006$, Wilks' Lambda = .99), but no significant effect of colour ($F(8,3252)=0.54, p$
292 $= .83$), and no interaction effects between any of the factors. Follow-up univariate tests revealed
293 significant effects of aroma on intensities of perceived sweetness, sourness, and bitterness; and a
294 significant effect of music on sweetness (see Table 2). Analysis of the data revealed that the effect
295 size of the soundtrack ($\eta_p^2 = 0.011$) was nearly double than that of aroma on perceived sweetness
296 ($\eta_p^2 = 0.006$). Nevertheless, both effect sizes are classified as small (Cohen, 1988). However, there
297 were no observed effects on liking. Post-hoc tests with Bonferroni correction (see Table 3) revealed
298 that, for aroma, P2 was significantly sweeter ($p = 0.011, d = 0.17$) and less bitter ($p = 0.001, d =$
299 0.22) than P1, and significantly less sour than P3 ($p = 0.007, d = 0.18$); and for music, perceived
300 sweetness was lower when the participants listened to the bitter soundtrack, as compared to the
301 sweet soundtrack ($p < 0.0005, d = 0.27$) or the control condition ($p = 0.034, d = 0.16$).

302 Figure 3 illustrates the influence of each sensory modality (visual, auditory, olfactory) on sweetness
303 enhancement.

304 < INSERT FIGURE 3 ABOUT HERE >

305 < INSERT TABLES 2 AND 3 ABOUT HERE >

306

307

308

309 3.2 Comparison of single vs. combined multisensory factors - are they additive?

310 It should be noted that our experimental design allows for the testing of single versus combined
311 multisensory factors in two different ways. First, by comparing extrinsic factors of colour and
312 soundtrack, and second, by comparing the extrinsic factor of soundtrack with the intrinsic factor of
313 added aroma. The discussion here is limited to sweetness ratings since we are interested in
314 modelling sweetness perception. In addition, sweetness was the only rating influenced by both
315 intrinsic and extrinsic cues in the present study.

316 3.2.1 The role of colour vs. soundtrack

317 First, we compared the extent of sweetness enhancement from single extrinsic stimulus conditions
318 (T1-3), where the audio/visual stimuli were presented one-at-a-time, against the extent of sweetness
319 enhancement from two-stimuli conditions (T4-6), where the audio/visual stimuli were presented in
320 pairs (see Figure 4A for an illustration of the method). From T1-3, we calculated D_{music} , the
321 difference between the sweetness soundtrack condition and the control condition ($M = 0.26$, $SE =$
322 0.12), and D_{colour} , the difference between the pink soundtrack condition and the control condition
323 ($M = 0.04$, $SE = 0.13$). From T4-6, we calculated $D_{music+colour}$, the difference between the sweet
324 soundtrack + pink colour condition and the control condition ($M = 0.35$, $SE = 0.12$). An
325 independent samples t-test to determine whether $D_{music+colour}$ differs from $D_{music} + D_{colour}$ revealed
326 that they are not significantly different, $t(329) = -0.21$, $p = .83$. That said, one-sample t-tests
327 comparing D values against zero revealed that both D_{music} and $D_{music+colour}$ have significant effects on
328 sweetness enhancement ($t(165) = 2.26$, $p = 0.025$, for music; $t(165) = 2.84$, $p = 0.005$, for
329 music+colour), but D_{colour} does not ($t(165) = 0.33$, $p = 0.74$). In other words, since colour does not
330 have a sweet enhancement effect, it is likely that the sweet enhancement effect we observed in the
331 combined music+colour condition comes only from the influence of the soundtrack.

332 <INSERT FIGURE 4 ABOUT HERE>

333 3.2.2 Aroma vs. Soundtrack

334 In addition to the extrinsic factors of colour and music, we also observed an overall sweetness
335 enhancement effect attributable to the presence of aroma. Specifically, Table 3 revealed that the
336 medium level of aroma was perceived to be the sweetest compared to the no aroma condition and
337 high concentration conditions. The fact that medium concentration of added aroma was perceived to

be sweeter than both no aroma and high concentration of aroma might be due to the fact that there is an inverted U-shaped function between perceived sweetness and aroma concentration. This is the case, for instance, in terms of visual preference and perceived complexity in foods (Mielby et al., 2012). Therefore, we decided to assess the relative influence of aroma and soundtrack, since both factors have been shown to elicit sweet enhancement effects (see Figure 4B for a schematic).

We focused on the P2 and P1 conditions in terms of aroma, since P2 (medium concentration of aroma) was shown to be the sweetest and P1 (no added aroma) the least sweet. Likewise, we focused on auditory conditions of M1 and M2, since M1 (sweet soundtrack) was shown to be the sweetest and M2 (bitter soundtrack) the least sweet. First, the joint sweetness enhancement effect by both aroma and soundtrack was confirmed via an independent samples t-test comparing sweetness rating conditions in P2M1 and P1M2 ($M_{P2M1} = 6.43$, $SE = 9.18$; $M_{P1M2} = 5.44$, $SE = 0.21$; $t(109) = 3.56$, $p = 0.001$). Next, we tested the influence of aroma alone, by comparing P2M1 and P1M1 ($M_{P1M1} = 5.80$, $SE = 0.21$; $t(109) = 2.28$, $p = .025$). This result implies that aroma played a significant role in sweetness enhancement, on top of any effects of soundtrack. Similarly, we tested for the influence of the soundtrack by itself, by comparing P2M1 and P2M2 ($M_{P2M2} = 5.80$, $SE = 0.24$; $t(55) = 2.82$, $p = .007$). This result implies that the soundtrack played a significant role in sweetness enhancement, on top of any effects of aroma. In terms of the degree of sweetness enhancement, the % enhancement of combined added aroma and sweet soundtrack is roughly twice that of aroma alone or soundtrack alone (see Figure 5). This result suggests, although by no means confirms for certain, that there seems to be a linearly additive sweetness enhancement effect by extrinsic (aroma) and intrinsic (soundtrack) factors.

< INSERT FIGURE 5 ABOUT HERE >

4. Discussion

The results of the present study revealed that overall, aroma and soundtrack both exerted a significant influence over the perceived sweetness intensity of a fruit drink, and the combined effect of aroma and soundtrack was greater than either aroma or soundtrack alone. Specifically, the same fruit drink was rated as significantly sweeter with the medium concentration of added aroma (compared to no added aroma), and while listening to a sweet soundtrack (as compared to the bitter soundtrack). These results support the growing body of literature on aroma sweetness enhancement

368 (e.g. Delwiche, 2004, Frank & Byram, 1988) as well on sonic seasoning effects (e.g., Crisinel et al.,
369 2012; see Spence et al., submitted, for a review). Furthermore, added aroma also had a significant
370 effect on reducing the perceived bitterness and sourness of the beverage. While there appears to be
371 a linearly additive relationship between the sweetness enhancement effects of aroma and
372 soundtrack, more comprehensive studies (for instance, studies where both aroma and sound are
373 varied on a within-participant basis) will be needed in order to draw any definitive conclusions
374 concerning such a possible additive relationship.

375 It should be noted that, in the present study, we did not observe any main effect of colour on the
376 participants' evaluation of the beverage. While there was no influence of colour, this was likely due
377 to the fact that the colour cue was presented on the iPad screen, which was removed from the actual
378 product itself. In addition, participants were not told about any possible relationships between the
379 coloured rectangle on the iPad screen and the drink samples. Most of the studies that have been
380 conducted so far on the influence of colour has either dealt with the colour of the product itself or
381 the colour of servingware (which is close to the food being served). Therefore, it is plausible that
382 we did not see a taste enhancement effect because the pink colour cue was simply too far removed
383 from the food itself. In a study that showed visual cues on iPad screens, Becker et al. (2011)
384 observed that images of different packaging shapes influenced taste ratings of yogurt samples, but
385 the effect was mediated by the participants' sensitivity to design aesthetics. And unlike in the
386 Becker study, participants in the present study were also able to see the colour of the samples
387 through the clear containers. This arguably gave participants less reason to be influenced by the
388 colour cue displayed on screen. Furthermore, while we observed differences in perceived tastes
389 between the sweet and bitter soundtrack, it is possible we did not observe any differences in colour
390 because pink and yellow are not associated with similarly opposing tastes. While pink strongly
391 communicates sweetness, yellow is not associated with bitterness (Saluja & Stevenson, 2018;
392 Woods & Spence, 2016). It would be interesting to conduct a further study with colour cues of pink
393 and black (a colour strongly associated with bitterness, see Ares & Deliza, 2010; Woods & Spence,
394 2016; see Spence et al., 2015, for a review), in order to test the relative effects of visual cues.

395 There is a subtle point to be made here concerning the distinction between product-extrinsic (but
396 still somehow product-related) cues and contextual cues. In the framework of the present study,
397 sound and colour cues were used as contextual factors. Moreover, the participants were not
398 explicitly told about the connection between sound/colour and the product they were tasting.
399 However, if the same soundtracks or colours were used as part of a sensory marketing app (e.g., if

400 the consumers were told something along the lines of “the soundtrack was specifically designed to
401 enhance the consumption experience”), then they would be considered product-related extrinsic
402 factors.

403 Interestingly, we did not observe any overall effects of extrinsic or intrinsic effects on consumer
404 liking. Analysis of singly presented audiovisual factors (T1-3) revealed that the beverage consumed
405 in the bitter soundtrack condition was liked less than the beverage consumed in the sweet
406 soundtrack condition or the pink colour condition, but this effect did not reveal itself when the
407 combined audiovisual factors (T4-6) were taken into consideration. This was possibly because the
408 combinations of colour and soundtrack conditions did not have clear emotional associations,
409 whereas it was easier to associate positive or negative feelings with a single audiovisual factor.
410 Wang and Spence (2017) performed a comparative analysis of sweetness vs. liking enhancement by
411 soundtracks across six studies, and hypothesised that only soundtracks with clear emotional
412 associations influenced both participants’ hedonic evaluations and sweetness ratings.

413 Intriguingly, our findings revealed that the sweet soundtrack enhanced perceived sweetness when
414 compared to the bitter soundtrack condition, but not when compared to the control no music
415 condition. It would seem to imply that the bitter soundtrack *lowers* sweetness rather than the sweet
416 soundtrack necessarily *enhancing* sweetness. This brings up the possibility of a distraction model,
417 where an incongruent soundtrack can distract the taster from perceiving a specific taste as intensely,
418 rather than a congruent soundtrack focusing one’s attention on a particular taste (Yan & Dando,
419 2015). Moreover, the suggestion that sound-taste crossmodal influences require explicit contrast in
420 stimuli (for instance, between the sweet and bitter soundtrack) has already been raised in literature
421 (e.g. Reinoso Carvalho et al., 2016; Wang & Spence, 2016).

422 The present study has several limitations stemming from the fact that we used a convenience
423 sample of consumers recruited from a large food festival. For instance, rather than having
424 approximately equal numbers of males and females, only about one-third of our participants were
425 male. This was due to the fact that the attendees at the festival were skewed towards females. We
426 could have artificially created gender balance, but we did not want to turn away female participants
427 in favour of male participants. In the future, we can consider setting separate gender quotas for
428 males and females. Another drawback was that while we were interested in contextual factors (i.e.
429 background sound), we could not control the exact environment inside the testing area (e.g., time of
430 day, humidity, lighting, the number of people who happened to be in the testing area, etc). The use

431 of closed ear headphones did help towards isolating excessive background noise, but it was not the
432 ideal distraction-free environment. Further studies in carefully controlled laboratory conditions will
433 be needed, for instance, to validate the linear additive effects of aroma and sound, but we believe
434 the present study makes an valuable contribution to literature as an ecologically valid study with
435 real Danish consumers.

436 **5. Conclusions**

437 The results of the present study suggest that varying the intensity of product aroma, as well as the
438 background sound, changes the consumer's perception of sweetness in a non-carbonated apple-
439 elderflower beverage. Specifically, the beverage with a medium level of added pomegranate aroma
440 was perceived to be sweeter and less bitter than a beverage with no added aroma. Additionally,
441 tasting the beverage while listening to a putatively bitter soundtrack resulted in lower perceived
442 sweetness as compared to listening to a sweet soundtrack or in silence. Furthermore, in our
443 assessment of various sensory cues, we found aroma and sound to be additive attributes when it
444 comes to the perception of sweetness intensity. In other words, the combination of a medium
445 concentration of a aroma (which was perceived to be sweet) plus exposure to a putatively sweet
446 background soundtrack enhanced perceived sweetness more than just aroma alone or soundtrack
447 alone.f

448 While we also altered the colour of the visual cue that participants were exposed to on an iPad
449 screen while they tasted the beverages, we did not find any significant effects of colour. This was
450 possibly because the colour cues were too far removed from the beverage itself to have any
451 meaningful effect. Similarly, we did not observe any overall influences of any factors (colour,
452 sound, or aroma) on consumer liking, potentially due to the fact that the groupings of multiple
453 sensory factors did not have clear affective associations.

454 These results are of relevance for those working on understanding a theoretical model of human
455 sweetness perception, as well as those working to design healthier, sugar-reduced food products.
456 While it may seem strange at the outset for those working in food research and development to
457 consider contextual factors (such as background sound), it should be kept in mind that real world
458 eating/drinking scenarios do not take place in isolated tasting booths. On the contrary, food-
459 extrinsic and contextual factors are always present and should be taken into account as part of the
460 (designable) flavour experience (e.g. Biswas et al., 2018; see Spence, 2017, for a review). The
461 prevalence of sensory and augmented reality applications (see Spence, 2019 for a review) makes

462 clear that what people happen to be seeing or hearing while consuming a product can be
463 incorporated by the food manufacturer as a part of the total purchasing or eating experience. The
464 knowledge that multiple sensory cues can, at least under the appropriate conditions, work in
465 conjunction for a greater taste modulation effect will allow product manufacturers to come up with
466 more effective sugar-reduced products without taking away consumer satisfaction. It also presents a
467 convincing argument for food researchers, packaging designers, and marketing agencies to work
468 together, in order to optimally balance product-intrinsic and extrinsic cues for maximal sweetness
469 enhancement (or, at the very least, avoid sending conflicting messages between what's
470 communicated by product packaging, advertising, and the content itself).

471 The results of the present study represent a starting point for a multisensory approach when it comes
472 to psychological enhancement of sweetness perception. Granted, the results so far have been limited
473 to a single population, namely Danish adults attending a food festival. Further research
474 development will focus on collecting data from different populations, such as adolescents (who are,
475 some might argue, especially susceptible to advertisement for sugary foods), to study the role of
476 gender, age, and culture in crossmodal perceptual effects. This will pave the way for the
477 development of custom healthy interventions (in terms of product colour/flavour, packaging design,
478 and advertisement) for specific populations.

479

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486

487

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650

651 **Figure Legends**

652 **Figure 1.** Schematic demonstrating the different test conditions used in Tests 1-6. For each test (T1-
653 6), the 5 columns refer to the different conditions. P refers to product, where P1 = original product,
654 P2 = moderate concentration of added aroma, P3 = high concentration of added aroma. V refers to
655 visual condition: V1 = pink cue, V2 = yellow cue. M refers to auditory condition: M1 = sweet
656 soundtrack, M2 = bitter soundtrack.

657 **Figure 2.** A) Experimental stimuli presented to the participants. Each sample was labelled with a 3-
658 digit blinding code. B) Experimental setup: Each participant sat at a chair facing an iPad and
659 wearing a pair of headphones. A carafe of water for rinsing in between trials was shared between all
660 of the participants sitting at the table.

661 **Figure 3.** Participants' average ratings of sweetness for each sensory condition. Error bars indicate
662 standard errors. Asterisks denote statistical significance (* $p < .05$).

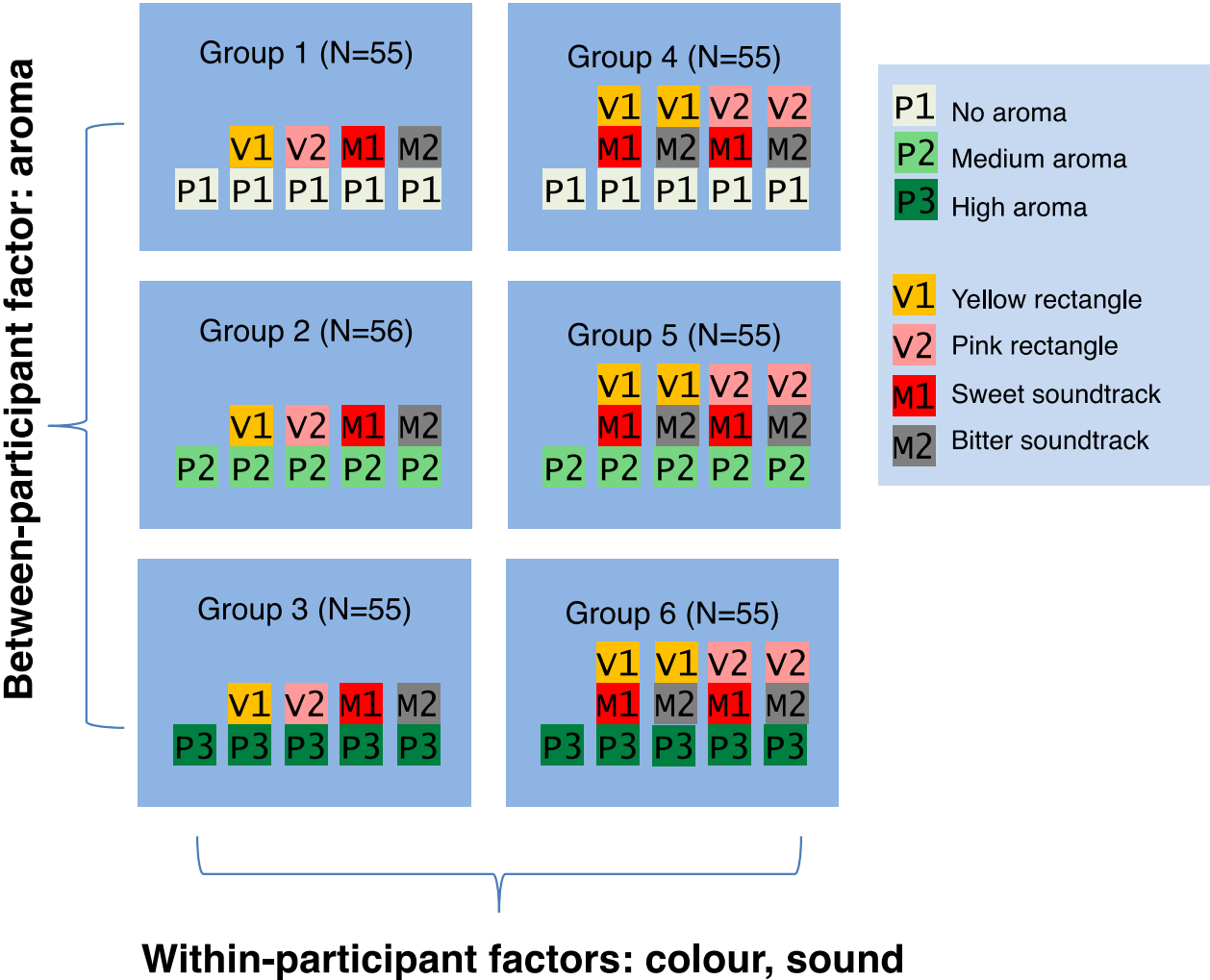
663 **Figure 4.** A) Methods for comparing the effect of: A) combined versus individual auditory and
664 visual stimuli; and B) combined versus individual aroma and auditory stimuli. Blocks of the same
665 colour indicate that they are conditions that were experienced by the same participant. P* stands for
666 products at all aroma levels (P1-P3). P1 = product with no added aroma; P2 = product with medium
667 concentration of added aroma. M1 = sweet soundtrack condition, M2 = bitter soundtrack condition.
668 V1 = pink condition.

669 **Figure 5.** Sweetness enhancement effects (in terms of %) due to soundtrack only, aroma only, or
670 combined soundtrack and aroma conditions. The baseline condition reflects no added aroma and
671 bitter soundtrack. The comparison condition reflects medium level of added aroma and sweet
672 soundtrack.

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675 **Figure 1**



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678 **Figure 2**

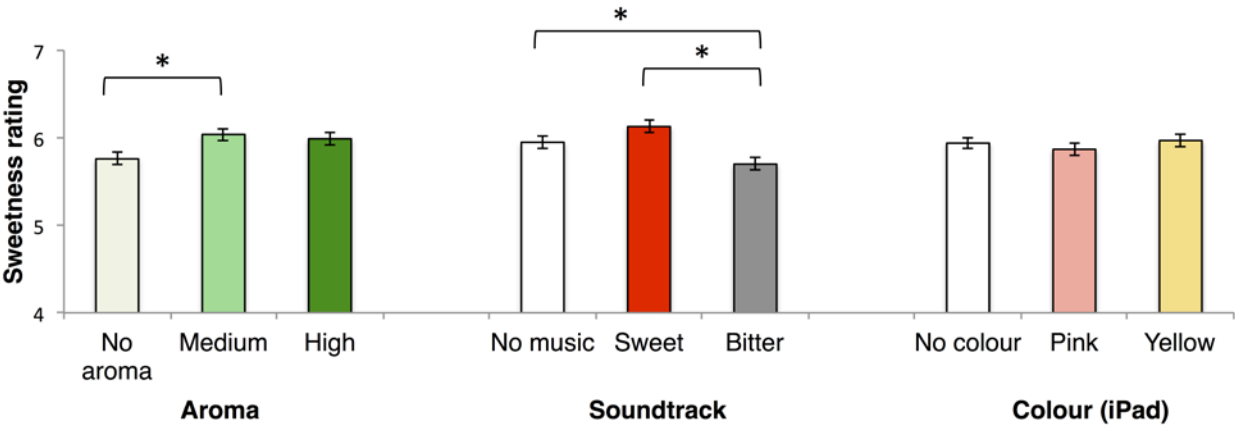
679 A)



680 B)

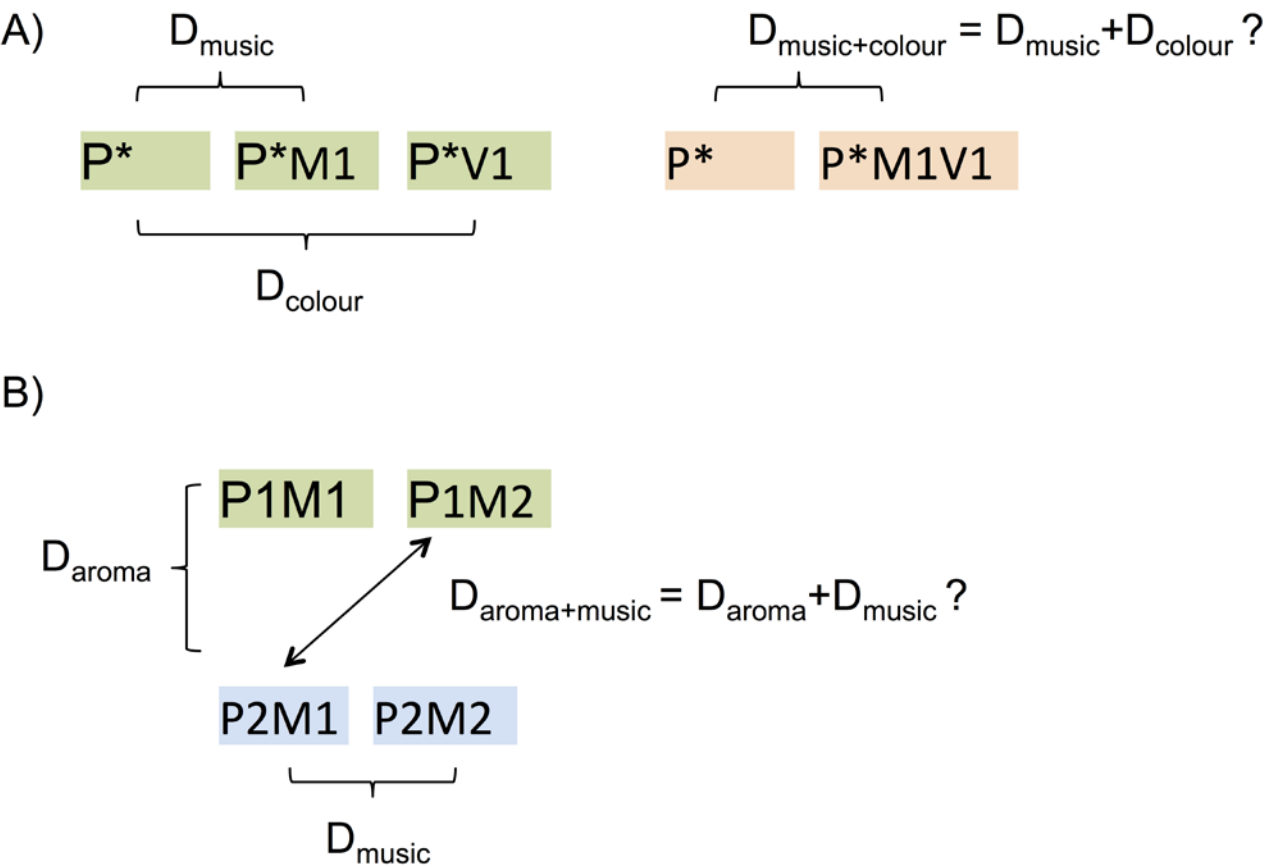


681 **Figure 3**



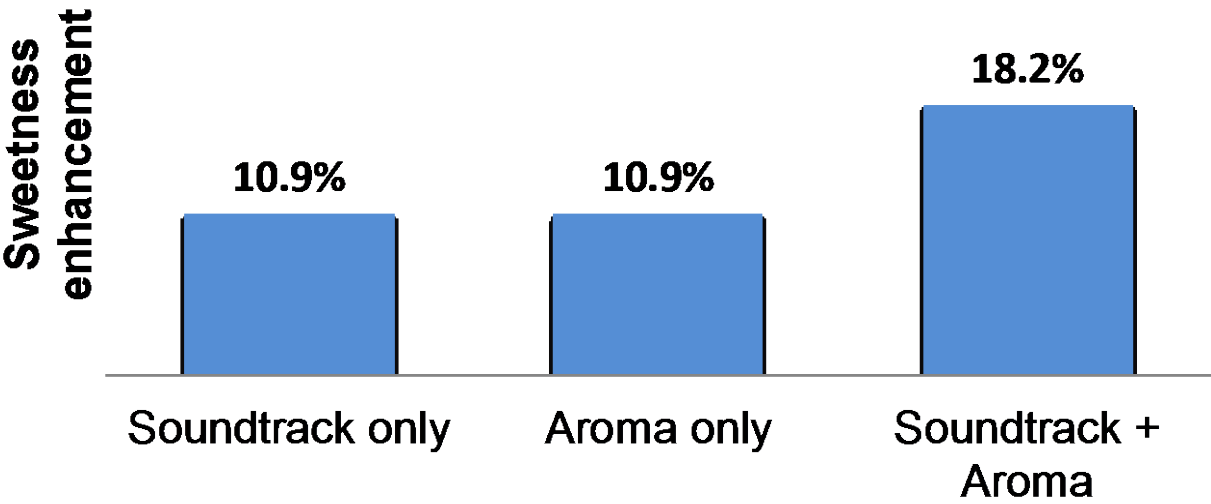
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684 **Figure 4**



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688 **Figure 5**



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Tables

691 **Table 1.** List of the contents of the beverages used in the experiment.

Content of base product	Nutritional content of base product (per 100 g)	Beverage stimuli	Aroma (µL/L)
Water, unfiltered apple juice (20%), sugar, unfiltered lemon juice (5%) from concentrate and elderflower extract (5%)	Energy 41 kcal, Fat 0.5 g, Carbohydrates 10 g (9.8 g sugars), protein 0.5 g	P1 P2 P3	0 (none) 250 (medium concentration) 500 (high concentration)

692

693

694 **Table 2.** Effects of aroma concentration and music for each rated attribute, in terms of degrees of freedom, error
695 degrees of freedom, F value, p value, and effect size (partial eta squared). Significant effects ($p < .05$) are shown
696 in bold.

	Effect	<i>Df</i>	<i>Error df</i>	<i>F</i>	<i>p</i>	η_p^2
Sweetness	Aroma	2	1628	4.55	.011	.006
	Music	2	1628	9.38	< .0005	.011
Bitterness	Aroma	2	1628	6.33	.002	.008
	Music	2	1628	1.53	.22	.002
Sourness	Aroma	2	1628	5.00	.007	.006
	Music	2	1628	1.99	.14	.002
Liking	Aroma	2	1628	0.18	.84	< .0005
	Music	2	1628	2.13	.12	.003

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698

699 **Table 3.** Average ratings and standard deviation of samples per aroma condition (left side of table) and per
700 sound condition (right side of table). Within each rated attribute (sweetness, bitterness, sourness, and liking),
701 samples that do not share a letter are significantly different from each other ($p < .05$) in Bonferroni-corrected
702 post-hoc tests.

Aroma				Music		
	Aroma concentration	Mean (SD)	Comparison	Sound condition	Mean (SD)	Comparison
Sweetness	None	5.76 (1.60)	A	No music	5.95(1.56)	b
	Medium	6.04 (1.62)	B	Sweet	6.13 (1.59)	b
	High	5.99 (1.53)	AB	Bitter	5.70 (1.60)	a
Bitterness	None	3.56 (2.00)	B	No music	3.41 (2.06)	a
	Medium	3.13 (1.96)	A	Sweet	3.24 (1.94)	a
	High	3.42 (2.05)	AB	Bitter	3.46 (2.00)	a
Sourness	None	4.46 (1.87)	AB	No music	4.38 (1.98)	a
	Medium	4.20 (2.04)	A	Sweet	4.30 (1.93)	a
	High	4.57 (1.99)	B	Bitter	4.55 (1.99)	a
Liking	None	6.74 (1.49)	A	No music	6.82 (1.46)	a
	Medium	6.79 (1.50)	A	Sweet	6.83 (1.44)	a
	High	6.77 (1.40)	A	Bitter	6.66 (1.49)	a