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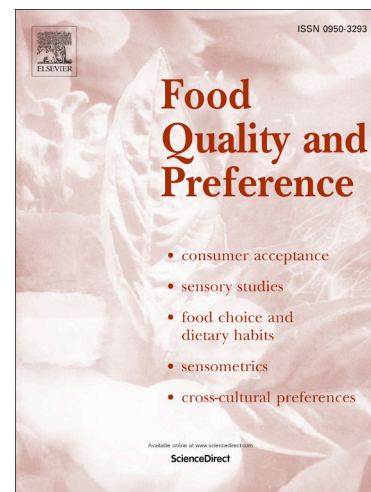
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# Modulation of sweetness perception in confectionary applications

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## Abstract

The development of sugar-reduced food products is a strategy to reduce the high sugar intake, which is a leading cause of global health concerns. Replacement and/or reduction of sucrose often leads to reduced sweetness perception with the consequence of decreased consumer acceptance. The aim of this work is to implement sensory modulation principles in a model confectionery system with the goal of enhancing sweetness perception. By using 3D-printing, confectionary samples were meso-structured by inhomogeneous distribution of sucrose concentrations and assessed, with a trained panel regarding sweetness. All samples were made up of a high and low sucrose phase and compared to a homogeneous reference sample. The overall sugar content was kept constant at 22.8 % in all samples and sweetness perception was compared. A significant increase of sweetness perception by over 30 % could be noted for samples consisting of a sweet outer shell and an inner less sweet core with a high sucrose gradient between the two phases. Whilst textural effects on sweetness perception could not be fully excluded, results can be seen as a strong indication that sweetness modulation by inhomogeneous distribution has a potential to be applied directly in solid food products.

*Keywords:* Sweetness modulation, Pulsatile stimulation, Sugar reduction, Multiphase-food-printing

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## 1. Introduction

The rising consumption of free sugar in the diet is believed to be one of the leading causes for non communicable diseases (NCD) which account for an estimated 68 % of global deaths (Organization et al., 2014). Although often a sugar-reduced reformulation of products is possible, such products are often linked with decreased sensory properties and thus lower consumer acceptance (Markey et al., 2015). To be successful in the combat of sugar consumption, approaches with high consumer acceptance are needed.

By tailoring the spacial and textural properties of products, modulation of sensory perception has been reported in literature. By varying the stimulation intensity of taste receptors over time, an enhancement of tastant perception has been demonstrated for example in liquid systems for the perception of salti-

ness by Yamamoto and Nakabayashi (1999); Metcalf and Vickers (2002). Holm et al. (2009) applied this concept to gelled solid foods and could demonstrate increased sweetness perception in samples with inhomogeneous sugar distributions. In further experiments Mosca et al. (2010); Mosca, van de Velde, Bult, van Boekel and Stieger (2012), sucrose concentrations were reduced successfully by up to 20 % without decreasing the sweetness intensity. Using this layered gelled system with inhomogeneous distribution has also been shown to increase saltiness perception (Emorine et al., 2015), or to reduce perception of bitterness (Hutchings et al., 2015). In systems with emulsified fat, perception of fat related attributes such as creaminess can also be increased by applying this concepts (Mosca, Rocha, Sala, van de Velde and Stieger, 2012). Similar results were achieved in

35 other solid foods, such as bread, where this concept  
 36 has been shown to allow a salt reduction by up to 25  
 37 % without sacrificing product acceptance (Konitzer  
 38 et al., 2013; Noort et al., 2010, 2012).

39 When exposed to a stimulus, taste-receptor cells  
 40 are triggered to release neural signals, the firing rate  
 41 of a receptor cell is governed by intensity of a stim-  
 42 ulus, thus already translated onto timescale. Under  
 43 constant exposure to a stimulus, firing rates of re-  
 44 ceptors decrease causing adaptation leading to a de-  
 45 creased perception over time. Vice versa, a lack of  
 46 stimuli leads to disadaptation and recovery of these  
 47 receptors. By alternating phases of high and low  
 48 stimulation, adaptation is reduced or prevented, ex-  
 49 plaining the higher overall reception under pulsed  
 50 stimulation (Kaissling et al., 1987). Furthermore, the  
 51 intensity of stimulus solutions is judged differently if  
 52 it is preceded by high- or a low-concentration solution  
 53 owing to a stronger sensation of contrast between  
 54 the solutions. (Schifferstein and Oudejans, 1996).  
 55 However, as shown by Burség, Brattinga, de Kok and  
 56 Bult (2010), the sweetness perception does not de-  
 57 pend on conscious perception of contrasts. Pulsatile  
 58 stimulations can lead to enhanced sweetness percep-  
 59 tions even at frequencies below the detection thresh-  
 60 old of individual pulses. The key determining fac-  
 61 tors for the effect of pulsatile stimulation have been  
 62 identified to be the pulsation period, the concentra-  
 63 tion gradient, and the presence of additional aromas  
 64 such as congruent or contrasting flavors. For liquid  
 65 systems, it has been shown that perceived sweetness  
 66 intensity is dependent on the viscosity of a solution.  
 67 Increased solution viscosity leads to a decrease in per-  
 68 ceived sweetness (Walker and Prescott, 2000; Pang-  
 69 born et al., 1978). Generally, this effect is explain-  
 70 able by a kinetically reduced tastant release from the  
 71 matrix, lower diffusion rates, binding of the tastant  
 72 to the thickener polymers or poor mixing of the bulk  
 73 solution. Depending on the thickening agent applied,  
 74 the magnitude of sweetness reduction has been shown  
 75 to vary (Baines and Morris, 1987; Ferry et al., 2006).

76 3D printing techniques allows to arrange food in a  
 77 3D space in a targeted manner. Tailored deposition  
 78 of differently composed masses (e.g. masses with dif-  
 79 ferent functional ingredients such as sugar) is suitable  
 80 for establishing concentration gradients, which may

81 allow product properties such as sensory perception  
 82 to be adjusted. The resolution of the internal product  
 83 structure is merely limited by the nozzle diameter(s),  
 84 the layer height as well as the material properties.  
 85 Therefore, 3D printing is seen here as an enabling  
 86 method that allows the investigation of more sophis-  
 87 ticated internal gradient structures and their effects  
 88 on sensory perception further than it has been possi-  
 89 ble so far. This may lead to new insights into struc-  
 90 ture design rules with the aim of reducing nutrition-  
 91 ally critical or expensive components or to enhance  
 92 desired perceptions.

93 In this work, the goal was to investigate (a) how  
 94 different spacial anisotropic distributions of sucrose  
 95 as well as the gradient impact sweetness perception  
 96 and (b) if pulsatile stimulation is the concept to be  
 97 favored to enhance sweetness perception in solid food  
 98 items. Model chocolate confectionery products were  
 99 manufactured with inhomogeneously distributed su-  
 100 crose quantities to create sucrose gradients in the  
 101 product with spatially different arrangements. Upon  
 102 melting in the mouth, sucrose was expected to be  
 103 released at different concentrations and varying time-  
 104 points, leading to increasing, decreasing or "pulsed"  
 105 sucrose perception over consumption time and thus  
 106 altered sweetness perceptions.

## 2. Materials and Methods 107

### 2.1. Materials 108

109 For all samples, gelatin from pig skin with a Bloom  
 110 nr. of 100, manufactured by Gelita AG (Eberbach,  
 111 Germany), was used. Cocoa butter was obtained  
 112 from Max Felchlin AG (Schwyz, Switzerland), mono-  
 113 & diglycerides of fatty acid as emulsifiers were pur-  
 114 chased from Danisco (Grindsted, Denmark). Sucrose  
 115 and cocoa powder were purchased in local grocery  
 116 stores and used directly. All samples were prepared  
 117 with tap water.

### 2.2. Sample preparation 118

119 Two different types of phase arrangements were  
 120 tested in this study, illustrations are shown in Fig.  
 121 1. Cube in cube samples were arranged with an in-  
 122 ner cube consisting of one phase surrounded by an

outer cubic shell consisting of the second phase, these samples were named  $In_{XX}Out_{YY}$  with XX and YY indicating the sugar concentrations of the inner and outer phase, respectively. The layered structure was named  $L_{XX/YY}$ . For all samples the overall sugar content was the same as the reference with 22.8 % sugar. All sugar concentrations in this manuscript are indicated as w/w percentages.

The preparation of the basic masses (BM) ( $BM_{9.8}$ ,  $BM_{19.5}$ ,  $BM_{22.8}$ ,  $BM_{26.0}$ ,  $BM_{35.8}$ ) was as follows where all data refer to 100g of the final product: Gelatin (4 g, 3.3 g, 3.0 g, 2.5 g, 1.0 g, respectively) was weighted and mixed into the corresponding amount of tap water (41.5 g, 32.5 g, 29.54 g, 26.7 g, 18.5 g, respectively) and left to swell for a minimum of 5 minutes. The mixture was heated to 55 °C for the gelatin to dissolve. After the addition of sugar (9.8 g, 19.5 g, 22.8 g, 26.0 g, 35.8 g, respectively) and cocoa powder (9.8 g), the mixture was homogenized at 10'000 rpm using a Polytron PT 3100 D (Kinematica AG, Switzerland). Simultaneously cocoa butter (34.3 g) and the mono- & diglycerides of fatty acid (0.7 g) were melted at 75 °C and stirred to dissolve. To produce an o/w emulsion, the oil mixture was slowly added to the aqueous phase under constant mixing. Once the entire oil phase had been added, the sample was left to homogenize for further 10 minutes at 55 °C. To prevent phase separation, the samples were stirred with a Kenwood Major Titanium KMT056 (Kenwood Swiss AG, Switzerland) while cooling to reach an optimal printing temperature of  $25 \pm 2$  °C. Once this target temperature was reached, the mass was transferred into a piping bag and vacuum sealed to 40 mbar in order to remove any air inclusions, followed by its transfer into stainless-steel printing cartridges.

### 2.3. Printing

Samples with a size of  $16 \times 16 \times 16$  mm<sup>3</sup> were printed in two distinct structures, a layered and a cube-in-cube, as illustrated in Fig. 1. All masses were printed with a stainless-steel syringe type extrusion setup with 1.7 mm nozzles, the cartridge temperature was kept constant at  $25 \pm 2$  °C by an aluminum heating jacket. The printing stage consisted of a custom built three-axis Cartesian printer shown in Fig. 2 designed

by the Institute of Printing-Technology (IDT) of the Bern University of Applied Sciences. To achieve multi-phase printing, the printer was equipped with three separate extruders, of which two were used in this work. To ensure rapid solidification of the masses after exiting the nozzle, the printer was placed in a cooling chamber KK-1000 CHLT (Kambic, Slovenia) set to 5 °C. G-codes were generated using Slic3r Prusa Edition software, while Repetier-Host software was used to control the printer. To prevent any further physical changes during storage, samples were kept at -40 °C for storage.

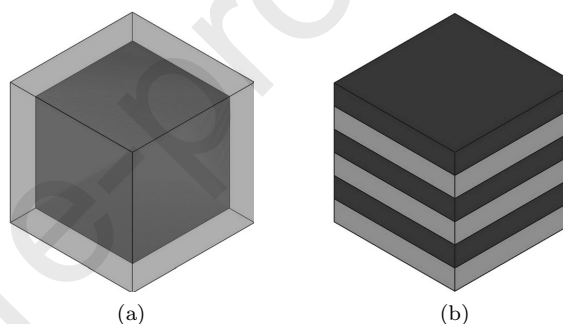
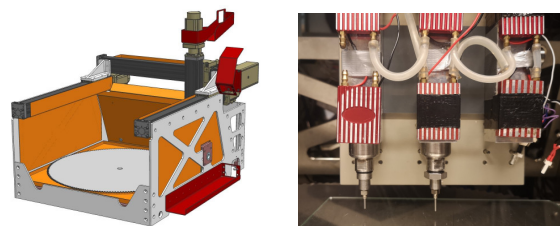


Figure 1: Schematics of the spatial arrangement of two masses with varying sugar concentration: a) Cube-in-cube and b) layered. The ratio of masses corresponds to 1:1 (w/w) in both cases

### 2.4. Rheological and penetration tests

Penetration force was recorded using a texture analyzer TA-XTplus (Micro Stable Systems, UK), with



(a) CAD Model of the printing stage used for sample preparation (b) Closeup of printhead with two nozzles installed

Figure 2: Printing setup

183 a 5 N load cell and equipped with a cylindrical probe  
184 with a diameter of 5 mm. The probe was lowered at  
185 a speed of 1 mm/s. At a trigger force of 2.0 g mea-  
186 surements were started and the probe was inserted 8  
187 mm into the sample.

188 To assess melt viscosity as well as gelling and melt-  
189 ing temperatures, oscillatory measurements were per-  
190 formed with a Physica MC302 (Anton Paar, Austria),  
191 equipped with a CC27 geometry. Experiments were  
192 performed with a strain of 0.5 % and a frequency of  
193 1 Hz at a temperature of 55 °C. The sample was first  
194 cooled to 5 °C using a linear temperature ramp with  
195 a gradient of 1.25 °C/min, hold for one hour and re-  
196 heating to 55 °C using the same linear temperature  
197 ramp.

### 198 2.5. Sensory evaluation

199 Sensory assessments were performed in two stages:  
200 A first simple descriptive test (DIN 10964:2014-11)  
201 followed by rating of sweetness intensity on a cate-  
202 gorical scale were performed with a selected group of  
203 5 to 7 employees of the institute to narrow down the  
204 number of samples to those considered most promis-  
205 ing and relevant. For the consecutive static and dy-  
206 namic sensory profiling, the external trained panel  
207 of the institute was invited to for six sessions. The  
208 panel was composed of 8 women, six of the panelists  
209 remained the same for all sessions, two panelists were  
210 replaced in between due to availability reasons. All  
211 panelists took part in two evaluations per session with  
212 a break in between. The establishment of the sensory  
213 profiling was carried out following the general guid-  
214 ance of the ISO 13299 norm. Training consisted of  
215 three sessions prior to the static evaluation and one  
216 additional session prior to the dynamic evaluation.  
217 As summarized in the table 1, the training ensured  
218 an alignment of the panelist on the attribute list and  
219 definition as well as on the oral processing protocol  
220 and the scale usage.

221 The training sessions were conducted in a training  
222 room allowing exchanges between panelists and panel  
223 leaders. The evaluation sessions were conducted in a  
224 sensory laboratory with panelists sitting at individ-  
225 ual booths equipped with red light and laptops for  
226 data entry. Samples were served to panelists on plas-  
227 tic trays with random three-digit codes. The oral

Table 1: Overview of training and evaluation sessions

Session Nr.	Training axes
1	Attribute list generation & Oral processing protocol
2	Training on sweetness perception & Attribute intensity training
3	Further training on oral processing protocol & Evaluation training
4	Static evaluations
5	Training on the dynamic evaluation
7	Dynamic evaluation

Table 2: Experimental design indicating samples which were analyzed in (t) technical, (s) static and (d) dynamic sensory trials

Gradient [%]	Sweet outside	Layered	Sweet inside
9.8/35.8	t/s/d	t/s/d	t/s/d
16.3/29.3	t	t	t
19.5/26.0	t/s/d	t	t

228 processing protocol for all evaluation sessions was:  
229 “Place the sample upright in your mouth, cut it in  
230 halves with your molar teeth and let it melt by tongue  
231 movements.”. No instructions were given concern-  
232 ing swallowing. Taste was neutralized between each  
233 sample evaluation with water and plain crackers. All  
234 panelists tested each of the five samples within one  
235 session but in varying order according to a William  
236 square design and the product sequences were ran-  
237 domly assigned to the panelists.

238 Static evaluation was performed by handing over  
239 trained panelists a sample and the homogenous refer-  
240 ence simultaneously and asking them to rate the  
241 sweetness perception of the sample compared to the  
242 reference on a unipolar linear scale (0 – 100, 0 = much  
243 weaker, 50 = reference, 100 = much stronger). For  
244 each new test sample, panelists received an additional  
245 reference sample.

246 Dynamic evaluation consisted of four test samples  
247 and only one homogeneous reference which was con-  
248 sidered like an individual sample (.lind reference).

249 The samples were presented in monadic sequence.  
 250 Panelists were asked to rate the sweetness perception  
 251 on a predefined scale (0 – 100, 0 = not sweet, 100 =  
 252 extremely sweet) at three distinct timepoints defined  
 253 as: **T1**: Sweetness intensity after the first bite and  
 254 two tongue movements (first impression), **T2**: Maxi-  
 255 mum sweetness intensity and **T3**: Sweetness intensity  
 256 before swallowing (last impression).

### 257 2.6. Statistical analysis

258 Data collection in the sensory laboratory was per-  
 259 formed with the EyeQuestion software (EyeQuestion,  
 260 Netherlands, v 4.11.20). Statistical analysis was per-  
 261 formed with R packages *nlme* and *emmeans* (Pin-  
 262 heiro et al., 2018; Lenth, 2019). Continuous sweetness  
 263 intensity ratings were analyzed by two-way ANOVA  
 264 with sweetness intensity as the dependent variable,  
 265 samples and time points were treated as fixed factors  
 266 whilst panelists and replicates were treated as ran-  
 267 dom factors. For significant results with  $p < 0.05$   
 268 a pairwise comparison was performed with a Tukey  
 269 test.

## 270 3. Results & Discussion

### 271 3.1. Characterization of basic masses

272 A physical characterization of the basic masses  
 273 BM<sub>9.8</sub>, BM<sub>19.5</sub>, BM<sub>22.8</sub>, BM<sub>26.0</sub>, BM<sub>35.8</sub> showed firm-  
 274 ness values of:  $2.70 \pm 0.50$  N,  $2.82 \pm 0.74$  N,  $2.94 \pm 0.76$   
 275 N,  $4.13 \pm 0.80$  N,  $7.5 \pm 1.9$  N, respectively. Rheological  
 276 measurements of viscosities at various temperatures  
 277 indicated that all masses are molten and liquid at  
 278 temperatures above 32 °C, whereas the viscosity in  
 279 the molten state increased with increasing sugar con-  
 280 centration.

281 To assess whether these firmness/viscosity differ-  
 282 ences caused effects in sweetness perception, a sweet-  
 283 eness assessment of the basic masses was performed by  
 284 the trained sensory panel. The perception of sweet-  
 285 ness intensity for the basic masses is shown in Fig. 3.  
 286 The masses could successfully be placed in order, all  
 287 masses except for BM<sub>19.5</sub> and BM<sub>22.8</sub> could be sig-  
 288 nificantly distinguished. Due to the correct ranking  
 289 of the masses as well as the melting at similar tem-  
 290 peratures, differences in firmness were concluded to  
 291 be low enough not to influence further experiments.

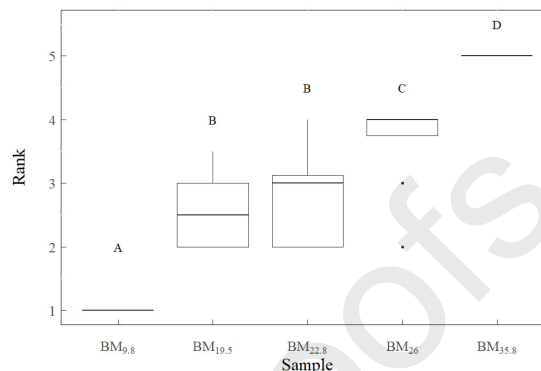


Figure 3: Sweetness intensity ranking of basic masses with varying sugar content. Numerical values in sample names represent sugar concentration in wt%.

### 292 3.2. Multiphase Samples

293 Samples In<sub>19.5</sub>Out<sub>26.0</sub>, In<sub>35.8</sub>Out<sub>9.8</sub>, as well as  
 294 L<sub>9.8/35.8</sub> did not show sweetness intensities sig-  
 295 nificantly higher than the homogeneous reference.  
 296 In<sub>9.8</sub>Out<sub>35.8</sub> however showed a mean sweetness in-  
 297 tensity 33% higher than the reference sample, indi-  
 298 cating an overall effect caused by the first contact  
 299 surface. As seen in Fig. 1, the first contact surface  
 300 of the layered sample, is comprised of both phases in  
 301 a 1:1 ratio. This causes an averaged first impression,  
 302 as the sweetness intensity difference of the sample is  
 303 ranked between significance group A and B. A con-  
 304 trasting negative first layer effect due to a low sucrose  
 305 first contact layer for sample In<sub>35.8</sub>Out<sub>9.8</sub> was not ob-  
 306 served. We assume that the sweet core of the sample  
 307 was able to compensate a low initial sweetness impres-  
 308 sion for the overall sample perception. The increased  
 309 sweetness perception of sample L<sub>9.8/35.8</sub> could also  
 310 be explained by the varying viscosities of the two ba-  
 311 sic masses. As BM<sub>35.8</sub> shows a higher viscosity than  
 312 BM<sub>9.8</sub>, it could have remained in the mouth for a  
 313 longer period and thus influenced the overall percep-  
 314 tion recorded at the end of consumption. In sample  
 315 In<sub>35.8</sub>Out<sub>9.8</sub>, no such effect could be observed, indi-  
 316 cating that the effect of the first contact layer could  
 317 be more dominant for the overall sweetness percep-  
 318 tion.

319 Similar sweetness increases for cubes of gelled su-

crose ( $20 \times 20 \times 20 \text{ mm}^3$ ) were shown by Mosca et al. (2010) where a sweetness increase of 20% was achieved in cubes with inhomogeneously distributed sucrose content. While Mosca used layered structures which did not show the reported effects in this study, a similar correlation between the sweetness gradient and the sweetness enhancement was also demonstrated. The variation in structure dependency and maximum sweetness enhancement from 15 to 20 % could be related to the different oral processing protocols applied. Samples were completely chewed in the trials performed by Mosca, in this study panelists were asked to bite the sample once into two halves and then let it melt. This protocol was chosen in order to reduce variance resulting from heterogeneous chewing processes, although it does not entirely reflect realistic consumption situations. This kind of oral processing also gives less effect to different gel breaking properties upon chewing as this has also been shown potentially be a significant effect to cause altered sweetness perception Mosca et al. (2015).

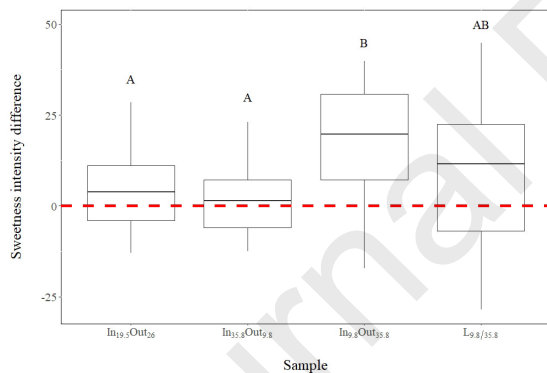


Figure 4: Sweetness enhancement of multiphase samples, all samples were compared to a homogeneous reference which was anchored at a sweetness value of 50 (red, dashed line); data in the graph represents the deviation from this value. Numerical values in sample names represent sugar concentration in wt%.

By comparing the sweetness intensity between In<sub>19.5</sub>Out<sub>26.0</sub> and In<sub>9.8</sub>Out<sub>35.8</sub>, the importance of the gradient is demonstrated. Samples with the same phase allocation regarding high and low sweetness

phases do not show altered sugar perceptions when small gradients are applied whereas larger gradients show a significant effect. The impact of size of the gradient has already been shown for liquid systems by Burség, Camacho, Knoop and Bult (2010), where larger sweetness gradients are linked with increased sweetness perception under pulsatile stimulation conditions. Obtained results further confirmed the influence of the gradient on the sweetness enhancement. In<sub>19.5</sub>Out<sub>26.0</sub> was not perceived significantly sweeter than the homogenous reference, while In<sub>9.8</sub>Out<sub>35.8</sub> was. Burség has also shown that the pulsation period in sugary liquid systems has a strong effect on the sweetness perception. The pulsation period in solid foods cannot be properly defined, however it can be argued that the spacial arrangement together with melting, breakup and mastication behavior are the most determining factors that account for a pulsation behavior in foods with inhomogeneous sucrose distribution. To achieve this pulsatile stimulation, the approach was to produce layered samples such as L<sub>9.8/35.8</sub>. However, the first contact layer was a mix of both phases, such mixed impression does not occur for all In<sub>XX</sub>Out<sub>YY</sub> samples, which can thus be viewed as samples consisting of a single pulse. Consequently, samples with multiple pulses (alternating shells of high/low concentrated masses) could be produced to simulate real pulsatile stimulation in future.

### 3.3. Dynamic evaluation

To compare the sweetness intensity over consumption time, progressive profiles with three time points (initial impression, maximum, final impression) were recorded. Figure 5 shows the resulting profiles for all 5 samples. The structure was not expected to be destroyed entirely after the first bite, therefore an effect from the first contact layer was expected, as discussed in the static evaluation. At T1, the first impression, no significant difference between the samples was recorded. As melting and subsequent sucrose diffusion are required to allow the sucrose to reach the receptors and induce a sweetness perception, some time is required to sense the full sweetness. It is probable that in the period up to T1 (first bite and two tongue movements) not enough melting/diffusion occurred for a significant amount of su-

390 crose to reach receptors, and therefore results remain  
 391 insignificant. Similarly, the maximum sweetness im-  
 392 pression at time-point T2 also showed no significant  
 393 difference between samples, in contrast to time-point  
 394 T3 with significant differences. The sample with a  
 395 low sweetness core and the layered sample were per-  
 396 ceived less sweet. We explain this by the fact that  
 397 last bolus will contain mostly the inner phase and  
 398 therefore consists of a low sugar mass. In a similar  
 399 study performed by Holm et al. (2009), significant  
 400 differences between different samples were found at  
 401 the beginning of consumption which evened out over  
 402 time, this strongly contrasts current results, show-  
 403 ing differences appearing at the end of consumption  
 404 time. These differences are likely caused by differing  
 405 oral processing (chewing versus no chewing). T3 is  
 406 the only time point at which significant differences  
 407 were recorded. However, the ranking order of the  
 408 samples does not reflect the ranking of the samples  
 409 of the static evaluation. This could indicate that the  
 410 final perception is less decisive for the overall sweet-  
 411 ness perception compared to other factors such as the  
 412 first impression and pulsatile effects. The static eval-  
 413 uations were performed by comparing each sample to  
 414 a reference, while the dynamic evaluation contained  
 415 the reference as a sample and no reference for the  
 416 scale, such differences have also been show to impact  
 417 the evaluation in sensory studies by Larson-Powers  
 418 and Pangborn (1978). Additionally, is worth men-  
 419 tioning that the progressive profiling task was very  
 420 difficult to perform for the panel, which was also  
 421 noted by several panelists during trials. To deepen  
 422 the understanding of the relationship between static  
 423 and dynamic results, data points from T2 of dynamic  
 424 sensory experiments were compared to those of static  
 425 experiments. In Fig.6, all samples show a lower value,  
 426 with the exception of In<sub>19.5</sub>Out<sub>26.0</sub>. Along with the  
 427 added complexity and time requirements, this raises  
 428 the question if dynamic studies of this type are re-  
 429 quired to assess the overall sweetness perception in  
 430 further product development. For screening purposes  
 431 the static evaluation seems to be faster, easier and  
 432 sufficient to gain insight into the sweetness percep-  
 433 tion. To gain a more detailed insight into sweetness  
 434 development, dynamic methods can be very interest-  
 435 ing, however the increased requirement of resources

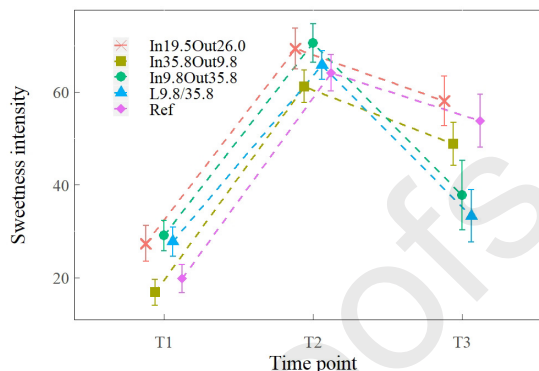


Figure 5: Dynamic evaluation of sweetness intensity on a scale 1-100 for time points T1-3, initial impression, maximum sweetness, and final impression. Dashed lines are there to guide the eye and do not represent measurements. Numerical values in sample names represent sugar concentration in wt%.

needs to be considered. It would also be beneficial to increase the amount of measuring points to potentially lead to more significant results.

#### 4. Conclusions

Results show differing sweetness perceptions in a model confectionery product when inhomogenous sucrose distribution are applied. The sample with a high sucrose shell and a low sucrose core and a high gradient was perceived as significantly sweeter than the homogeneous reference sample, indicating that the first impression of a product influences the overall perception. However this seems to require strong sucrose gradients. A number of effects which can potentially effect sweetness perception are also superimposed on such measurements and have to be taken into account, e.g. the viscosity of basic masses, their melting behavior and how they influence the final impression.

To mimic the pulsatile stimulation as demonstrated in liquid systems, further more intricate designs will be considered. The design with a layered structure does not seem to cause a relevant pulsation of the sweetness sensation. The cube-in-cube



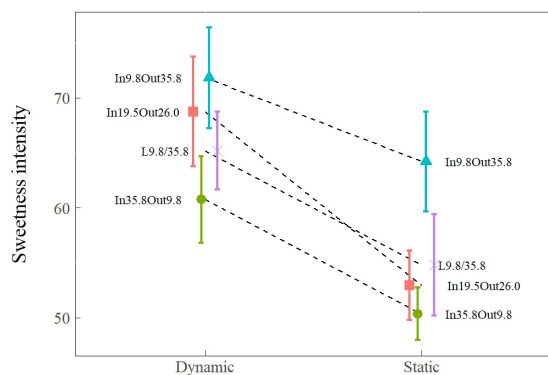


Figure 6: Comparison of the maximum perceived sweetness during the static and dynamic evaluation (time point T2) of the two-phased samples. Dashed lines are there to guide the eye and do not represent measurements. Numerical values in sample names represent sugar concentration in wt%.

design seems to be more suitable to adjust increased sweetness perception. By increasing the number of alternating high/low sugar shells in the cubic sample, it could be possible to increase the number of pulses from one to many and get to a true pulsatile stimulation. If such a 3D-arrangement would further increase the overall sweetness perception to a superior level compared to the cube-in-cube adjustment will be the question of a consecutive study. The 3D-printing technology will enable the production of complex arbitrary structures.

Due to the complex nature of the products and their sensory characterization, a simple protocol for the oral processing was applied. In order to get more generally applicable results, trials have to be conducted using more realistic eating protocols in future, and should include higher time-wise resolution of sweetness perception. Additionally, acceptance trials with real customers need to be performed, to translate results from the lab environment to consumers everyday life.

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