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Modifying sensory perception of chocolate coated rice waffles through bite-to-bite contrast: an application case study using 3D inkjet printing

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Consumers expect perceptual constancy between multiple bites of the same food. In this study, we investigated how sweetness, creaminess, expected fullness and liking of chocolate coated rice waffles can be modified by bite-to-bite variation in chocolate thickness. 3D inkjet printing was used to accurately deposit the chocolate layers varying in thickness (0.8, 1.6 and 3.2 mm) onto rice waffles. In the first study, single bites of rice waffles with a homogeneous chocolate coating were evaluated. With increasing thickness of chocolate coating, the sweetness, creaminess, and expected fullness increased significantly. In the second study, we evaluated seven chocolate coated rice waffles containing a constant total chocolate amount but different chocolate thicknesses between three sequential bites. The order of chocolate thickness between bites had significant, but small effects on sweetness, expected fullness and liking. Interestingly, rice waffles with a homogeneous chocolate coating were preferred over rice waffles with an inhomogeneous chocolate coating. Neither recency nor primacy effects were sufficient to explain sweetness perception in this study. We conclude that the sweetness of chocolate coated rice waffles can be modified by bite-to-bite variation in chocolate thickness. This study demonstrates that 3D inkjet printing allows the production of foods with bite-to-bite contrast, which possibly might be used for healthier food product design.

1. Introduction

The Western diet, high in saturated fats and sucrose, is associated with increased occurrence of metabolic diseases such as diabetes and obesity.[1,2] In order to promote healthier dietary patterns, food manufactures continue to develop reduced sugar and fat products without sacrificing the sensory properties such as taste and texture. During the past years, several studies have explored how an inhomogeneous distribution of tastants in foods can be used to enhance sensory perception of single bites of foods and as an approach to design healthier foods. Noort *et al.* used encapsulated salt in bread to create taste contrast.[3] The saltiness intensity was maintained even though the total amount of salt was reduced by 50%. Emorine *et al.* observed a significant enhancement of saltiness in hot snacks with a heterogeneous salt distribution.[4,5] They demonstrated that a large contrast in salt concentrations within one bite was required to enhance saltiness, and that salt-associated aromas (ham aroma) could contribute to saltiness enhancement. The enhancement of sweetness has also been described in several other studies, using layered gels with sucrose concentration differences between layers.[6–8] Bitterness is also influenced by inhomogeneous distribution of bitter compounds. In the study of Hutchings *et al.*, the effect of an inhomogeneous distribution of quinine in gelatin–agar gels on bitterness was explored.[9] They concluded that a homogeneous distribution of bitter compounds is the most suitable structure for minimizing bitterness perception. Comparable results were also found for perception of fat related sensory attributes in emulsion filled gels. Mosca *et al.* reported the enhancement of fat related mouthfeel attributes (*e.g.* spreadable and melting) in gels with an inhomogeneous fat distribution.[10] All studies thus reveal the possibility to modulate saltiness, sweetness, bitterness and fattiness by manipulating the spatial distribution of tastants in foods within a bite.

Another strategy to manipulate consumer's sensory perception of foods is by designing "between bites heterogeneity", which in other words is by changing the composition of a food between bites. Mosca *et al.* investigated sweetness perception of gels and custards by varying the sucrose concentration between bites and the order of bites differing in sucrose con-

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centration.[11] Compared with homogeneous stimuli (all bites of gels and custards had the same sucrose concentration), sweetness enhancement was observed in sequences that ended with stimuli with high sucrose concentration, suggesting that recency effects influenced the overall sweetness perception. Dijksterhuis *et al.* performed a study using sandwiches which contained three regions differing in salt concentrations that were consumed in three sequential bites.[12] Sandwiches containing more salt in the first bite were perceived to be overall saltier than sandwiches with constant salt concentration throughout the three bites, suggesting that an "initial boost" effect (primacy effect) occurred. Another study performed by Le Berrre *et al.* used chocolate ice creams to which theobromine was added at different concentrations to vary the bitterness between bites.[13] When the first bite of the ice cream was of low bitterness, perception of subsequent bites tended to have lower bitterness intensity as well. This suggests that consumers expected bitterness perception to be consistent and constant from the first to the third bite (perceptual consistency). These three studies demonstrate that sensory perception of multiple bites of foods can be altered by changing the concentration of tastants between bites. The overall perception of taste and texture attributes can be enhanced or suppressed. Different psychological mechanisms (*e.g.* primacy effect, recency effect, and perceptual consistency) have been suggested to explain the observed effects.

Preparation of foods with taste contrast from bite to bite is not trivial. Mosca *et al.* used separate spoons with custards, or gel cubes to realize differences in the tastant concentration between successive bites.[11] While this approach allows one to control the tastant concentration per bite, it cannot be put into practice for consumers eating foods at home. Dijksterhuis *et al.* manually prepared sandwiches with different salt concentrations in spreads in different regions of the sandwiches.[12] In the study of Le Berrre *et al.*, ice creams were also shaped manually to obtain different bitter compound concentrations in different regions.[13] These studies demonstrated how tastant concentration differences between bites influence sensory perception in a variety of manually prepared foods. The question of how to achieve tastant concentration differences between bites of foods in a more realistic production environment still remains. Future applications in the food industry that involve foods with gradients in composition or tastants require alternative and more automated processing technologies. Therefore, in this study we introduced a 3D inkjet printing technology to facilitate the production of foods with bite to bite contrast in their composition. 3D inkjet food printing technology was developed by de Grood *et al.* and commercialized by the name of FoodJet printing.[14] 3D inkjet food printing uses an array of pneumatic membrane nozzle-jets which can jet droplets of foods with low viscosity (*e.g.* molten chocolates, jams, and sauces) onto a moving object.[15] Thicker layers of deposited materials can be obtained by going through multiple "printing–cooling–printing" cycles. As mentioned above, only few studies have explored the effect of tastant concentration differences between bites on sensory perception, and none of them applied a 3D printing technology for sample preparation. To the best of our knowledge, this is the first study to explore sensory perception of 3D printed foods.

The objective of this study was to investigate how bite-to-bite variation in the chocolate content of chocolate coated rice waffles influences consumers' sensory perception and liking. We hypothesized that the changes in the sensory intensity between successive stimuli play a role in the overall sensory perception of whole chocolate coated rice waffles. To prepare chocolate coated rice waffles with accurate and differing amounts of chocolate between bites, we used 3D inkjet printing. We characterized various chocolates and chocolate mixtures to obtain chocolates with desired flow properties of molten chocolate and solidification behavior to ensure a proper printing process. First, we determined sensory perception and liking of single bites of chocolate coated rice waffles differing in chocolate thickness. Secondly, we investigated how bite-to-bite variation in the chocolate content of chocolate coated rice waffles influenced the overall sensory perception and liking.

2. Materials and methods

2.1. Materials

Milk fountain chocolate (Barry Callebaut, Wieze, Belgium) was purchased from a local retailer. Dark chocolate "Easymelt coumpound coating dark" (Barry Callebaut, Wieze, Belgium) was kindly provided by FoodJet B.V. Biological rice waffles with quinoa (Albert Heijn B.V., The Netherlands) were purchased from a local supermarket.

2.2. Sample preparation

Milk fountain chocolate, dark chocolate, and a mixture of dark chocolate and milk fountain chocolate (2 : 1 ratio) were preheated and kept at 52 °C for at least 1 hour before rheological measurements. For sensory studies, the chocolate mixture (Easymelt dark chocolate:milk fountain chocolate at 2 : 1 ratio) was printed on rice waffles using a 3D FoodJet Pilot Depositor at FoodJet B.V. (Nijmegen, The Netherlands). The equipped depositor (FJ22.48) had a straight row of 48 nozzles to enable jetting of low-viscosity foods at high frequency. The chocolate mixture was premixed and maintained in a molten state in a big pot before transferring it to the printing tank. Chocolate was circulated in water-jacketed hoses which was heated using a water bath at 48 °C before printing. After printing, chocolate coated rice waffles were immediately placed in a 4 °C cooling room for 10 minutes to solidify the chocolate.

2.3 Rheological characterization

Rheological measurements were done using a MCR301 rheometer (Anton Paar, The Netherlands). The viscosity of molten chocolates was determined in rotational mode with a cylindrical geometry CC17 (16.7 mm probe diameter). 50 g of chocolates were preheated in a water bath at 52 °C for minimal 1 hour, based on the ICA standards. Viscosity measurements were performed according to the IOCCC guidelines at 40 °C. A pre-shear of 5 s^{-1} was applied for 5 min in order to homogenize the temperature throughout the sample, and then shearing was stopped for 10 s. Flow curves were measured by increasing the shear rate from 2 s^{-1} to 50 s^{-1} in 3 min, maintaining a shear rate of 50 s^{-1} for 1 min, and then decreasing the shear rate from 50 s^{-1} to 2 s^{-1} in 3 min. All samples were measured in duplicate.

Solidification curves were determined in oscillatory mode using the same testing geometry as for the viscosity measurements. The temperature was decreased from 40 °C to 20 °C at a rate of 1 °C min^{-1}. The storage modulus (G') and loss modulus (G'') were determined at a frequency of 1 Hz and a strain amplitude of 0.5%. The solidification temperature (T_S) is defined as the temperature at which the storage modulus (G') is equal to the loss modulus (G'').[16] Measurements were performed in duplicate.

2.4 Single bite sensory evaluation of chocolate coated rice waffles

2.4.1 Stimuli. Single bites of rice waffles with a homogeneous thickness of chocolate coating were inkjet printed by depositing chocolate onto 7.5 × 5 × 0.66 cm rice waffles. Chocolate coatings were printed onto the rice waffles with chocolate thickness of 0.8, 1.6 or 3.2 mm. The printed waffles were cut into four pieces of 3.75 × 2.5 × 0.66 cm for single bite sensory evaluation (Fig. 1A). Examples of 3D inkjet printed chocolate coated rice waffles with homogeneous and heterogeneous chocolate thickness are shown in Fig. 1A and B.

2.4.2 Subjects. A total of n = 75 subjects (64 females; average age: 24 years; SD = 6) were recruited *via* flyers and social media to participate in this study. Subjects were generally of good health (self-reported) and did not have any taste or smell disorders (self-reported). Subjects were naive with respect to the purpose of the study and were not trained. Subjects were mainly the students of Wageningen University. All subjects provided written informed consent. Subjects were reimbursed after completion of the study.

2.4.3 Procedure. A sensory study was performed in a meeting room at Wageningen University with separators on tables. Three rice waffles with either 0.8, 1.6 or 3.2 mm chocolate coatings were evaluated by all subjects in a session of 15 minutes. The subjects were instructed to consume a single bite of a chocolate coated rice waffle (3.75 × 2.5 × 0.66 cm) with the chocolate coating facing downwards. A pilot study was performed with n = 15 participants to determine the bite size of chocolate coated rice waffles. The pilot study showed that the participants consumed chocolate coated rice waffles (3.75 × 5.0 × 0.66 cm) typically with two bites. Based on this study, we selected a bite size of 3.75 × 2.5 × 0.66 cm for the single bite sensory evaluation of this study. The thickness of the chocolate coating was therefore not visible to the subjects during sensory evaluation. After consumption of one bite of the rice waffle, the subjects were asked to evaluate sweetness, creaminess, expected fullness and liking on 100 mm line scales anchored with "Not" to "Very" at the end of the scale. Sweetness was defined as the basic taste sensation typically induced by sugars. Creaminess was defined as having a thick and smooth mouthfeel. Expected fullness was defined as the expected feeling of being full. Liking was defined as the feeling of enjoyment. Between the different waffles, a break of 3 min was given, and the participants were asked to rinse their mouth with water to clean the palate. The serving order of samples to the participants was completely randomized. The samples were coded with three digit codes. Data collection was performed on paper.

2.5 Multiple bite sensory evaluation of chocolate coated rice waffles with bite-to-bite variation in chocolate content

2.5.1 Stimuli. Seven types of chocolate coated rice waffles containing the same total amount of chocolate were designed. Rice waffles differed in the way the thickness of the chocolate coating was distributed on them between the first, second and third bites. The schematic designs of the seven chocolate coated rice waffles are shown in Fig. 2. The 3D inkjet printed waffles were cut into pieces of 7.5 × 2.5 × 0.66 cm for multiple bite sensory evaluation, so that each bite was approximately 2.5 × 2.5 × 0.66 cm. Fig. 1B shows an example of a 3D inkjet printed chocolate coated rice waffle differing in chocolate thickness between bites.

2.5.2 Subjects. A total of n = 70 subjects (56 females; average age: 24 years; SD = 6) were recruited *via* flyers and social media to participate in this study. N = 64 out of the n = 70 subjects also participated in the single bite evaluation of rice waffles with chocolate coatings. Subjects were generally of

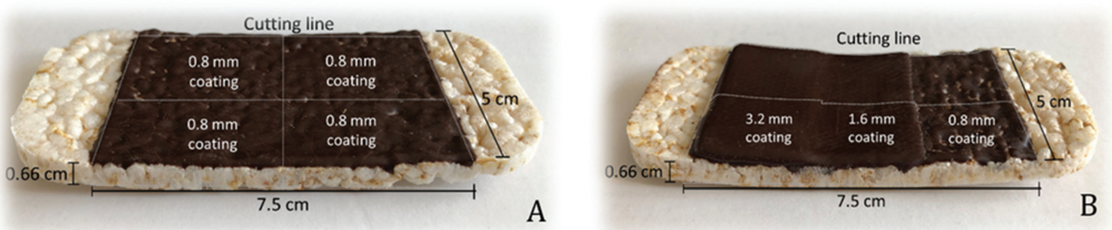

Fig. 1 Examples of 3D inkjet printed chocolate rice waffles. (A) Example of chocolate coated rice waffle with homogeneous chocolate coating of 0.8 mm. (B) Examples of chocolate coated rice waffles with a chocolate coating thickness of 3.2, 1.6 and 0.8 mm from left to right. Dashed lines represent the cutting lines for preparation of samples used in sensory evaluation.

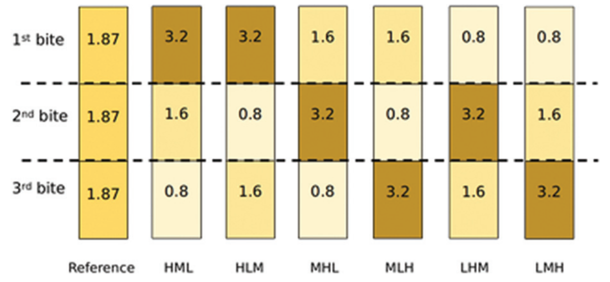

Fig. 2 Schematic representation of the seven chocolate coated rice waffles used in the multiple bite sensory evaluation. Each rice waffle consisted of three regions differing in the amount of chocolate coating. Numbers in the figure indicate the thickness of chocolate coating per region (mm). The total amount of chocolate per sample was constant. The three letter sample codes denote the amount of chocolate from the first to third bite as L = low (0.8 mm), M = medium (1.6 mm) and H = high (3.2 mm).

good health (self-reported) and did not have any taste or smell disorders (self-reported). Subjects were naive with respect to the purpose of the study and were not trained. Subjects were mainly the students of Wageningen University. All subjects provided written informed consent. Subjects were reimbursed after completion of the study.

2.5.3 **Procedure.** A sensory study was performed in sensory booths at Wageningen University. Seven chocolate coated rice waffles with various bite-to-bite designs (Fig. 2) were assessed by all subjects in a sensory session of 30 minutes. The subjects were instructed to consume the rice waffles (7.5 × 2.5 × 0.66 cm) with the chocolate coating facing downwards. The thickness of the chocolate coatings of multiple bites was therefore not visible to the subjects during sensory evaluation. When observing some of the subjects performing the sensory evaluation, it became apparent that the subjects followed the instructions well eating the waffles with the chocolate coating facing downwards. While we cannot provide the experimental proof with absolute certainty that the participants could not see the chocolate, we think that the vast majority of participants did not see the chocolate. The subjects were instructed to consume the entire waffle in three equal bites and to swallow after each bite. After the consumption of the whole rice waffle in three bites, the subjects were asked to evaluate the overall sweetness, creaminess, expected fullness and liking on 100 mm line scales anchored with "Not" to "Very" at the end of the scale. Sweetness, creaminess, expected fullness and liking were defined in section 2.4.3. Between the different waffles, a break of 3 min was given, and the participants were asked to rinse their mouth with water to clean the palate. The serving order of samples was completely randomized. The samples were coded with three digit codes. Data collection was performed on paper.

2.6 Data analysis

All data analysis (single bite and multiple bite sensory evaluations of chocolate coated rice waffles) was performed using R (version R 3.6.1). The sweetness, creaminess, expected fullness and liking were reported as mean values with standard error. Mixed-linear models were used with sweetness, creaminess, expected fullness and liking as response variables (fixed effects), sample as the predictor variable and subject as the random effect. A significance level of $p < 0.05$ was chosen and Tukey's HSD test was used for *post hoc* analysis.

3. Results and discussion

3.1 Rheology

Fig. 3A shows the flow curves for molten dark chocolate, milk chocolate and a mixture of dark chocolate and milk chocolate (2 : 1 ratio) at 40 °C, and Fig. 3B shows the solidification curves of the temperature sweeps. All three molten chocolates show a shear-thinning behavior. Molten dark chocolate had the lowest viscosity of 810 mPa s at 50 s^{-1}, while milk chocolate had the highest viscosity of 1040 mPa s at 50 s^{-1}. The viscosity of the chocolate mixture was 930 mPa s at 50 s^{-1}, which is between the viscosities of dark chocolate and milk chocolate. The difference in viscosity between dark chocolate, milk chocolate and the chocolate mixture could be due to different particle sizes and distribution, surface characteristics, addition of emulsifiers, and the amount and nature of the lipid phase.[17] Probably in this study, the fat content of the used chocolates/chocolate mixture explains to a large extent the differences in the viscosity of molten chocolates. The fat content of dark chocolate, the chocolate mixture and milk chocolate were 37.3%, 38.2%, and 40.3%, respectively. Hartel *et al.* showed that the chocolate viscosity increased with the increasing fat content.[18] This was explained as follows: with more fat the distance between the fine solid particles present in chocolate is increased and their interactions during shear decrease. According to Guo *et al.*, shear thinning behavior is desirable during inkjet printing, as high shear rate within the printhead facilitates jetting of the liquid.[19] Once the drop detaches from the nozzle, the increased viscosity at decreased shear rate suppresses satellite drop formation.

Temperature sweeps were performed to characterize the solidification process of dark chocolate, milk chocolate and their mixture (Fig. 3B). Dark chocolate had the highest solidification temperature (T_S = 24.2 °C), followed by the chocolate mixture (T_S = 22.8 °C) and milk chocolate (T_S = 20.4 °C). It is widely known that milk fat has an inhibitory effect on crystallization of cocoa butter.[20] In this study, milk chocolate contained 5.6% milk fat, while dark chocolate had no milk fat in its composition, which may explain the lower crystallization temperature of milk chocolate. Apart from milk fat, the cocoa butter composition also can be expected to affect the crystallization temperature and rate.[20]

Even though milk chocolate may be more palatable to use as waffle coating compared with dark chocolate, it was not chosen in this study. The reason for this was that accurate inkjet printing with milk chocolate was not possible due to chocolate run-off from the waffle surface because of its low

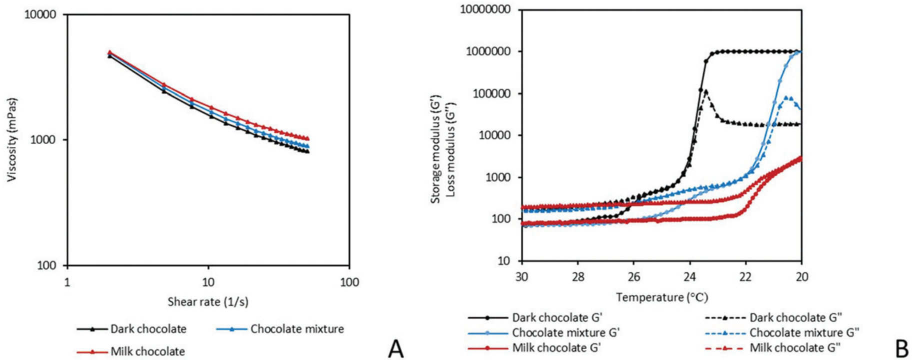

Fig. 3 Flow curves of (A) molten chocolates at 40 °C, and (B) temperature-dependent G' and G'' of dark chocolate (black), milk chocolate (red), and the mixture of dark chocolate and milk chocolate at 2 : 1 ratio (blue).

solidification temperature and slow solidification process. The rheological properties (*i.e.*, faster solidification) of dark chocolate were better suited for inkjet printing. Considering that the final product was expected to be sweet and creamy, it was decided to use the 2 : 1 mixture of dark and milk chocolates as the coating material rather than dark chocolate alone. This 2 : 1 mixture exhibited an increased shear thinning behavior and a faster solidification compared to milk chocolate, thus better printability than milk chocolate, and was perceived as sweeter and creamier than dark chocolate (feasibility study, data not shown).

3.2 Sensory perception and liking of single bites of rice waffles differing in the amount of chocolate coating

To evaluate the effect of the chocolate coating thickness on sweetness, creaminess, expected fullness and liking, single bites of the three homogeneously coated chocolate waffles were evaluated by the consumer panel (n = 75) (Fig. 4). The chocolate thickness had a significant effect on sweetness ($\chi^2(6)$ = 154.65, p < 0.001), creaminess ($\chi^2(6)$ = 189.71, p < 0.001), expected fullness ($\chi^2(6)$ = 161.51, p < 0.001) and liking ($\chi^2(6)$ = 34.53, p < 0.001). The sweetness, creaminess and expected fullness increased significantly with increasing chocolate layer thickness and differed significantly between the samples. This demonstrates that the variation in the amount of chocolate deposited on the rice waffle (thickness) was clearly sufficient to lead to changes in sensory perception. When the thickness of the chocolate coating was increased, the amount of sugar and fat consumed per bite increased, which consequently led to an increased intensity of sweetness, creaminess and expected fullness. These results are in line with the study of Prinz *et al.*, who observed that increasing bite size of custards increased fatty and creamy sensations.[21] An increase in the perceived sensory intensity can be explained by a spatial summation process, where the intensity is a function of the concentration of the compound and the area being stimulated.[22] In this study, the relative concentrations of sugar and fat in the chocolate coating were kept constant, but the total amount of consumed chocolate per bite was increased by increasing the chocolate coating thickness. For liking, significant differences were only observed between 0.8 and 1.6 mm chocolate coated waffles (p < 0.001), and between 0.8 and 3.2 mm chocolate coated waffles (p < 0.001). No significant difference was observed between 1.6 and 3.2 mm chocolate coated waffles (p = 0.143).

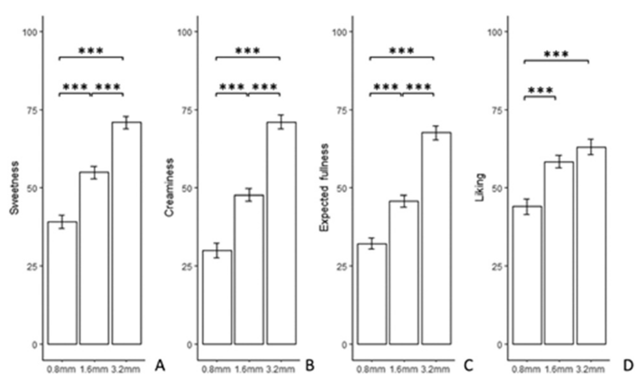

Fig. 4 Sweetness (A), creaminess (B), expected fullness (C), and liking (D) of rice waffles evaluated by n = 75 naive subjects. Rice waffles were coated with 0.8, 1.6 and 3.2 mm thick chocolate. Error bars indicate standard error. Significant differences are indicated by *** (p < 0.001).

3.3 Sensory perception and liking of multiple bites of rice waffles with bite-to-bite variation in the chocolate amount

Fig. 5 shows the sweetness, creaminess, expected fullness and liking scores of the homogeneous waffle and the six rice waffles with bite-to-bite variation in the chocolate content. The distribution of chocolate coating from the first to the third bite significantly influenced the sweetness ($\chi^2(10)$ = 17.52, p = 0.008), expected fullness ($\chi^2(10)$ = 14.60, p = 0.02), and liking ($\chi^2(10)$ = 19.02, p = 0.004). No significant effect of the distribution of chocolate coating from the first to the third bite on creaminess ($\chi^2(10)$ = 9.34, p = 0.15) was observed. While we observed several significant differences in sweetness, expected fullness and liking between chocolate coated rice waffles differing in chocolate thickness from the first to the third bite, we emphasize that the magnitude of the differences between samples was small. It is noted that all averaged intensity

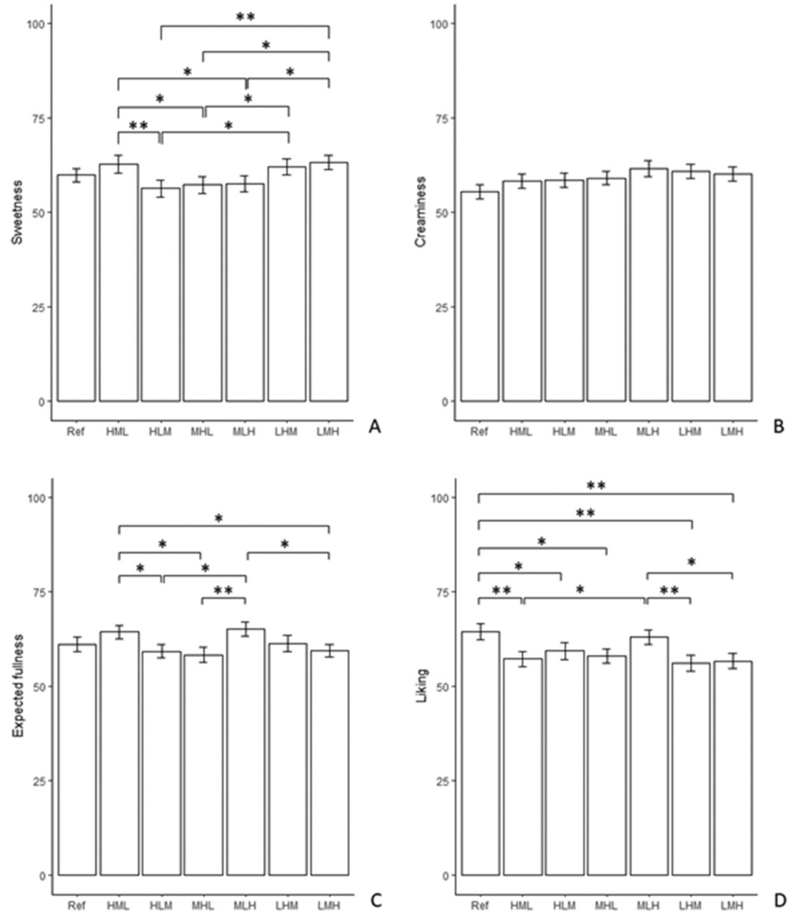

Fig. 5 Sweetness (A), creaminess (B), expected fullness (C), and liking (D) of rice waffles with bite-to-bite variation in the chocolate content evaluated by naive consumers (n = 70). The three letter sample codes denote the amount of chocolate from the first to third bite as L = low (0.8 mm), M = medium (1.6 mm) and H = high (3.2 mm). Error bars indicate standard error. Significant differences are indicated by * ($p < 0.05$) and ** ($p < 0.01$).

scores of the four attributes ranged from 50–60, indicating that participants used only a very narrow range of the scale. This is in sharp contrast to the single bite evaluations which showed average intensity scores ranging from 25 to 75. We suggest two possible explanations for these observations. The results might indicate that the waffles coated with chocolate varying in thickness from bite-to-bite were actually perceived fairly similar, so that the variation in the chocolate thickness from bite-to-bite has only a minor effect on sweetness, creaminess, expected fullness and liking. It should be noted that the total chocolate content consumed with three bites was the same for all waffles, only the distribution between bites differed. This is in contrast to the single bite evaluations, where the total chocolate content differed between the waffles. This might explain why the differences in sweetness, creaminess, expected fullness and liking were small in the multiple bite evaluations. Alternatively, the results might show that it was difficult for the naive consumers to integrate their sensory response over multiple subsequent bites into one overall intensity score. Participants tasted three subsequent bites of which each bite tasted differently (Fig. 2), but they were asked to provide only one intensity score per attribute after tasting three bites. It is possible that the task of averaging perceived intensity over three consecutive bites was difficult to perform for the participants. Participants might have been uncertain how to report their response and how to integrate intensity differences between bites into a single intensity score. Therefore, participants might have avoided to use the entire line scale and might have tended to use only a relatively small part around the middle of the scale. Mosca *et al.* also observed that participants tended to use the middle part of the line scale when asked to assess the overall sweetness intensity of multiple bites with bite-to-bite variation in sweetness.[11] In contrast, when performing time-intensity evaluations, Mosca *et al.* observed clear differences between separate bites and participants used a broader range of the scale to report their perception.[11]

For sweetness, HML was significantly sweeter than HLM (p = 0.006), MHL (p = 0.018), and MLH (p = 0.028); LHM was significantly sweeter than HLM (p = 0.014) and MHL (p = 0.038); LMH was significantly sweeter than HLM (p = 0.003), MHL (p = 0.011), and MLH (p = 0.016). No significant difference in sweetness was observed between the homogeneously distributed chocolate coating waffles and samples with bite-to-bite variation in chocolate thickness. Recency effects were not observed for sweetness, since not all samples with the thickest chocolate as the third bite were perceived as the sweetest (*e.g.* MLH was perceived less sweet than HML). Primacy effects were not observed either, since sequences starting with high chocolate amounts at the first bite (*e.g.* HLM) were not consistently evaluated as more sweet than the ones starting with less chocolate (*e.g.* LMH).

Another way to interpret the obtained results is to consider the changes in the sweetness, creaminess, and expected fullness intensity between bites and to consider whether these changes influence the overall perception. With the results being described in section 3.2, we applied another way of coding the six rice waffles with bite to bite variation in chocolate thickness (Table 1). The new coding is based on the expected changes in the sensory intensity and liking between the first, second and third bites.

We noticed that the sweetness intensity decreased when there was an abrupt decrease in sweetness either between the first and second bites or between the second and third bites (HLM (↘↗) and MHL (↗↘)), compared to waffles having a more gradual change in sweetness between bites (LMH (↗↗) and HML (↘↘)). This may be explained by a "contrast effect" which suggests that a stimulus might be perceived as less intense in the presence of a stronger stimulus.[23] When a thin layer of chocolate is consumed right after a thicker layer, the bite with the thin layer could be perceived less sweet than it would normally have been, and this may possibly influence the sweetness perception of the entire rice waffle.

For creaminess, even though no significant differences between samples were observed, we tend to observe a non-significant trend that creaminess of MLH and LHM might be higher than the homogeneous reference waffle (Fig. 5B). If that was a significant effect, the increased creaminess of LMH and MLH could be due to a recency effect. According to Bireta *et al.*, recency effects dominate over primacy effects when the retention interval is short.[24] It could be that intervals between the three bites were sufficiently short in our study, and therefore only recency effects were observed. Taking bite-to-bite contrast into consideration, it seems that waffles tend to be perceived creamier (not significant) when the chocolate thickness between the bites increased sharply (LHM (↗↘) and MLH (↘↗)). A perceptual contrast mechanism may be used to explain our observations, as suggested by de Wijk *et al.* who reported similar observations in thickness perception of desserts.[25] Panels were asked in that study to first consume five bites of thin low fat custards before another five bites of thick full fat custards. An enhancement in thickness rating of thick full fat custards was observed in their study.

For expected fullness, HML is perceived as significantly more full than HLM (p = 0.031), MHL (p = 0.010), and LMH (p = 0.034). MLH is perceived as significantly more full than HLM (p = 0.012), MHL(p = 0.004), and LMH (p = 0.014). No significant differences in expected fullness were observed between the waffle with homogeneously distributed chocolate coating and other waffles. Even though significant differences were found, we do not observe a consistent pattern in the data and can therefore not provide a reasonable explanation. An inconsistent pattern in the data is probably due to the difficulty for subjects to assess expected fullness based on consuming three small bites of rice waffles, as was mentioned by several subjects after evaluation.

For liking, the waffle with homogeneously distributed chocolate coating was significantly more liked than HML (p = 0.005), HLM (p = 0.049), MHL (p = 0.012), LHM (p = 0.001), and LMH (p = 0.002); MLH was significantly more liked than HML(p = 0.023), LHM (p = 0.007) and LMH (p = 0.012). In general, consumers liked rice waffles with homogeneously distributed chocolate coatings over waffles with bite-to-bite variation in chocolate content (except for MLH which was not significantly different from the waffle with homogeneously distributed chocolate coating). Coatings with higher liking score in the first bite and the last bite (MLH (↘↗)) were preferred over coatings of either low liking score in the first bite (LHM (↗=) and LMH (↗=)) or coatings of low liking score in the last bite (HML (=↘) and MHL (=↘)). The results of the single bite evaluation (Fig. 4) indicate significant differences in liking only between 0.8 and 1.6 mm chocolate thickness and between 0.8 and 3.2 mm thickness; no significant differences were found in liking between 1.6 and 3.2 mm chocolate thickness. It seems that the combination of an "initial boost effect" and a "recency effect" played an important role in one's preference toward the chocolate coated rice waffles.

In this study, 3D inkjet printing showed its advantages in preparing food products of different compositional designs. Conventionally, one can only achieve various chocolate layer thickness by manually shaping foods. Such procedures are usually time consuming, material demanding (*e.g.* requires molds) and not always precise. Here we demonstrated that 3D inkjet food printing can be a powerful tool to prepare foods with modified composition between bites and has the potential to be used for healthy product design.

Table 1 Chocolate coated rice waffles with bite-to-bite variation in the chocolate thickness (L: 0.8 mm; M: 1.6 mm; and H: 3.2 mm). Symbols (↗, ↘, and =) represent the intensity differences (increase, decrease, and no change) between the first and second bites and between the second and third bites, based on the results of the single bite evaluations (section 3.2). The green/red arrows indicate small/large differences

	Sweetness, creaminess, and fullness	Liking
HML	↘↘	=↘
HLM	↘↗	↘↗
MHL	↗↘	=↘
MLH	↘↗	↘↗
LHM	↗↘	↗=
LMH	↗↗	↗=

4. Conclusions

Sweetness, expected fullness and liking of chocolate coated rice waffles were influenced by bite-to-bite variation in chocolate content without changing the overall amount of chocolate consumed. Neither clear recency nor primacy effects were able to explain the variation in sweetness perception, while a contrast effect seems to play a role. A combination of an initial boost effect and a recency effect played an important role in scoring liking. The results suggest that sweetness perception can be modified by different bite-to-bite variations. Compared to a homogeneously coated chocolate rice waffle, waffles with bite-to-bite variations in coating thickness were less preferred (except for MLH), though they had similar sweetness and creaminess to a homogeneously coated waffle. This study shows the potential application of 3D inkjet printing for creating advanced food designs with variations in composition between bites.

Conflicts of interest

There are no conflicts to declare.

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