Layered food designs to create appetizing desserts

A proof-of-concept study

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Layered food designs to create appetizing desserts: A proof-of-concept study

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ABSTRACT

Creating layers in foods is a culinary technique commonly used to diversify sensory experiences, but it has not been reported scientifically on its effect on hedonic and appetitive responses. This study aimed to investigate the use of dynamic sensory contrasts in layered foods to stimulate liking and appetite, using lemon mousse as a model. A sensory panel evaluated the perceived sour taste intensity of lemon mousses acidified by various amounts of citric acid. Bilayer lemon mousses with unequal distribution of citric acid across the layers to deliver higher levels of intraoral sensory contrast were developed and evaluated. A consumer panel evaluated the liking and desire to eat lemon mousses (n = 66), and a selection of samples was further investigated in an ad libitum food intake setting (n = 30). In the consumer study, bilayer lemon mousses with a layer of low acidity (0.35% citric acid w/w) on top and higher acidity (1.58% or 2.8% citric acid w/w) at the bottom showed consistently higher liking and desire scores than their corresponding counterparts with identical acid levels equally distributed in a monolayer. In the ad libitum setting, the bilayer mousse (top: 0.35%; bottom: 1.58% citric acid w/w) had a significant 13% increase in intake compared to its monolayer counterpart. Modulating sensory properties across food layers with different configurations and layer compositions can be further explored as a tool to design appetizing foods for consumers at risk of undernutrition.

1. Introduction

The use of sensory contrast in layered foods to vary intraoral sensation is widely seen in different foods, e.g., chocolate coated on ice cream, dairy desserts with fruit toppings, and chips coated with cheese. Hyde & Witherly (1993) hypothesized that the dynamic contrast (i.e., the variety in orosensations) contributes to food palatability. However, research on the potential of layered foods to create greater hedonic and appetitive responses has received little attention. If such contrasts can be created, layered food designs could be a novel initiative to promote intake for people at nutritional risk by modulating products with desired sensory properties (Nieuwenhuizen et al., 2010; Schiffman & Warwick, 1993; Sorensen et al., 2012). Moreover, product developers may exploit these results to create more appetizing foods, as recent studies demonstrated the possibility of spatially arranging tastants or ingredients in food matrices using 3D printing technologies (Chow et al., 2021; Fahmy et al., 2021; Riantiningtyas et al., 2021; Zhu et al., 2020).

This study used lemon mousse as an example and investigated the potential of layered food designs for creating more appetizing desserts. Healthy adults were targeted in the study as proof-of-concept work. It was hypothesized that foods composed of layers of different sensory intensities could stimulate hedonic and appetitive responses by delivering higher levels of intraoral sensory contrast.

1.1. Layer arrangement of tastants in foods

Taste adaptation is a gradual decrease in sensitivity to a taste stimulus after prolonged exposure. The basic taste qualities of salt, sweet, sour, and bitter, could be subject to strong or complete adaptation (Abrahams et al., 1937; Gent & McBurney, 1978). These adaptive responses also occur during eating, but the taste of food would not disappear completely (Theunissen et al., 2000). In contrast to these phenomena, pulsatile stimulation could prevent taste adaptation from occurring (Burseg, Brattinga, et al., 2010; Burseg, Camacho, et al., 2010; Busch et al., 2009; Meiselman & Halpern, 1973). Arranging different concentrations of salts or sugars into layers could create an inhomogeneous spatial distribution of tastants in foods. Studies showed that these arrangements gave higher taste intensity than when the same concentration of tastant was homogeneously distributed in food matrices, such as bread, gels, and sausages (Dijksterhuis et al., 2014; Holm et al., 2009;
Modulating the distribution of tastants in layered food matrices might create a fluctuation in taste intensity during consumption (Mosca et al., 2012, 2013, 2014; Noort et al., 2010, 2012). Research on the temporal aspects of hedonic responses reported that food liking exhibited dynamic changes while eating, such as during a single bite or sip consumption event (Delarue & Blumenthal, 2015; Taylor & Pangborn, 1990). Veldhuizen et al. (2006) further observed that temporal changes in liking were linked to perceived taste intensity over time. Therefore, one could expect that the layer arrangement of tastants may affect the temporal food liking and desires while eating.

1.2. Sensory properties and oral processing of lemon mousse

Previous studies indicated that seniors and patients have a preference for sour tastes, which is related to the refreshing and thirst-quenching properties (Bossola et al., 2007; Okkels et al., 2016; Sorensen et al., 2012) and subjects’ declined taste perception (Chauhan & Hawrysh, 1988; Zandstra & De Graaf, 1998). Manipulating the sour taste in lemon mousse, a traditional Danish dessert, can be highly relevant for addressing these consumers’ food sensory and nutritional needs.

Lemon mousse is a semisolid foam with an aerated gel structure (Campbell & Mougeot, 1999; Zúñiga & Aguilera, 2008). The product requires relatively small effort for oral processing; the main steps include placing the food in the oral cavity, tongue elevation, tongue-palate compression, formation of the bolus, and swallowing, and normal free oral processing typically leads to the most intense sensory perceptions (De Wijk et al., 2011). When consuming a spoon of mousse arranged with different acidity across layers, the layers were expected to be placed in different locations on the tongue, manipulated, and swallowed. Albeit the layers of mousse would be subject to a degree of mixing, a sour taste contrast could be created during a single-spoon consumption to deliver a more dynamic intraoral sensory perception (Fig. 1).
Table 1
Composition of the lemon mousse prepared with the recipe from the hospital, at citric acid levels of 0.7%, 1.4%, and 2.8% w/w. All concentrations are given in weight percentage (% w/w).

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>0.7% citric acid</th>
<th>1.4% citric acid</th>
<th>2.8% citric acid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gelatin</td>
<td>1.14</td>
<td>1.14</td>
<td>1.14</td>
</tr>
<tr>
<td>Whipped cream</td>
<td>46.6</td>
<td>46.6</td>
<td>46.6</td>
</tr>
<tr>
<td>Pasteurized whole egg</td>
<td>32</td>
<td>32</td>
<td>32</td>
</tr>
<tr>
<td>Sugar</td>
<td>11.4</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>Lemon juice</td>
<td>8.7</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Citric acid</td>
<td>–</td>
<td>0.7</td>
<td>1.4</td>
</tr>
<tr>
<td>Water</td>
<td>–</td>
<td>8.0</td>
<td>7.3</td>
</tr>
<tr>
<td>Lemon zest</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
</tr>
</tbody>
</table>

Acid is distributed homogeneously may create a more monotonous and possibly declining sour taste perception due to self-adaptation (Fig. 1).

In terms of appetitive responses, it was hypothesized that a bilayer lemon mousse could create a greater desire to eat than a monolayer mousse with an overall identical acid level due to this dynamic building up of sensory perception.

2. Materials and methods

Three successive studies on healthy subjects were set up to address the research aim. The perceived sourness of lemon mousse acidified by different levels of citric acid was first determined. Based on the perceived sensory contrast, bilayer lemon mousse with layers differing in citric acid levels were developed and evaluated by a consumer panel. Three of the samples were further investigated for ad libitum intake.

All studies took place at the Future Consumer Lab facilities at the University of Copenhagen, Denmark. Procedures were conducted following the Declaration of Helsinki Ethical Principles, and participants gave written informed consent to participate in each study. Trained panelists were recruited from the external sensory panel of the Department of Food Science, University of Copenhagen, and they were compensated for their participation. Untrained consumers were recruited from the greater Copenhagen area. They received a gift bag at the end of each study.

2.1. Sample preparation

Lemon mousse was used to create layered products. The recipe was provided by the Kulinarium Aalborg University Hospital (Denmark). Ingredients for the lemon mousse included whipping cream (38% fat), pasteurized whole eggs, sugar, gelatin (240 bloom value), fresh lemon juice, and lemon zest. Supplier information is given in Appendix A.

In order to standardize the acidity level in lemon mousse, the fresh lemon juice from the original recipe was replaced by a citric acid solution, and the concentration of 0.7% w/w was determined using titration techniques. The solution was prepared by dissolving weighted citric acid granules in tap water. The concentration of citric acid in the solution was varied to obtain lemon mousse with different target acidities for each study. Table 1 shows the composition of lemon mousse with citric acid levels of 0.7, 1.4, and 2.8% w/w as examples. Lemon mousse samples were similar in macronutrient composition and energy density (protein: 5.6%, fat: 20.5%, carbohydrate: 12.2%, energy: 1069 kJ per 100 g).

Lemon mousse were prepared manually under food-safe conditions. First, eggs and sugar were mixed. The cream was whipped until the volume was doubled with soft consistency (100% overrun) and kept at 5 °C. A gelatin stock solution was prepared by boiling the gelatin sheets in cold water for 5 min, squeezing excess water from the sheets, and melting the sheets over a bain-marie with half of the citric acid solution. The other half of the citric acid solution was added to the egg-sugar mixture with the lemon zest. The gelatin stock was cooled to 30 °C and stirred into the egg-sugar mix to form a homogenous paste. Then, the paste was gently folded with the whipped cream.

Monolayer samples were made by piping the lemon mousse into disposable cups (100 mL) with a portion size of 40 ± 2 g. Bilayer samples were created by piping a single layer of lemon mousse (20 ± 2 g) into the bottom of the cups, which was refrigerated at 5 °C for one hour, then piping the next layer of lemon mousse on top of the existing layer. All samples were covered with lids and refrigerated overnight (24 h) at 5 °C.

2.2. Screening of acidification range for composing contrasting bilayer lemon mousse

A dose–response relationship for sour taste intensity in lemon mousse was established for citric acid levels of 0.7, 1.4, and 2.8% w/w. Fourteen trained panelists (3 males, 11 females; mean age: 31 ± 8 years) rated the sour taste intensity of the lemon mousse on a 15-cm line scale between the anchors of ‘not at all’ and ‘extremely.’ The samples were presented in random order. From the relationship between perceived sourness and citric acid level, concentration levels were estimated to create appropriate acidity contrasts for the subsequent studies.

2.3. Consumer test on bilayer lemon mousse

2.3.1. Samples

Four bilayer lemon mousse samples were initially developed based on the perceived sour taste contrast across layers. Fig. 2 shows the schematic representations of the final bilayer samples and their corresponding monolayer counterparts included in the consumer test. The bilayer sample with a top layer of 2.8% citric acid w/w was reported to be very unpleasant during a pilot study (n = 15) and therefore excluded for further evaluation.

The bilayer configuration in samples bi-LM and bi-ML combined...
layers with 0.35 and 1.58% citric acid w/w; they had an overall composition identical to mono-97 (i.e., total citric acid level: 0.97%). The bi-LH and bi-HL combined layers with 0.35 and 2.8% citric acid w/w; it had an overall composition identical to mono-158 (i.e., total citric acid level: 1.58%).

Three The layer thickness in bilayer samples was of equal size. The serving temperature of the lemon mousse was 5 °C. Table 2 shows the pH stability of the lemon mousse samples after production and at the time of serving (24 h refrigeration). For each sample, measurements for the individual layer(s) were conducted in triplicate (pH meter FiveEasy, Metter Toledo, USA).

2.3.2. Subjects and study design
Sixty-six healthy adults (20 males, 46 females; mean age: 43 ± 13 years) were recruited for the study. They came for a one-hour session to perform product evaluations individually in the sensory booths. Subjects were asked to evaluate each sample in terms of liking and desire to eat the next spoonful of the dessert (hereafter referred to as ‘desire to eat’) on a 15-cm line scale. The scale for liking evaluation was anchored with ‘dislike very much’ and ‘like very much’ at the two ends and ‘neither like nor dislike’ at the center. The scale for evaluating the desire to eat was anchored from ‘very weak’ to ‘very strong.’ The five samples were served randomly across subjects. Before the evaluation, subjects were instructed in scale use and spooning the sample to the bottom of the cup. The spooning method ensured that subjects consumed the bilayer samples on a spoon with both layers in approximately equal proportions. The spooning reversed the order in which the layers entered the mouth, i.e., the bottom layer entered furthest in the mouth and the top layer more at the entrance (Fig. 1).

2.4. Ad libitum intake of bilayer lemon mousse
2.4.1. Samples
Three lemon mousse samples were further investigated for ad libitum intake. They were bi-LM (top: 0.35; bottom: 1.58% citric acid w/w), mono-97 (monolayer counterpart of bi-LM), and the sample prepared with the standard recipe (0.7% citric acid w/w). The samples were produced in batches every three days throughout the study period. They were refrigerated at 5 °C before serving to maintain palatability and microbiological safety.

2.4.2. Subjects
Thirty healthy female adults (mean age: 39 ± 12 years; BMI = 22.8 ± 2.9) with no aversion to lemon dairy desserts participated in the study. Exclusion criteria were having an energy-restricted diet, a loss of appetite, diabetes, gastrointestinal problems, food allergies to dairy or egg products, and being pregnant or lactating.

2.4.3. Study design
The study followed a crossover design. Subjects visited the Stimulation Lab three times, with at least two days between visits. They reported to the laboratory at 10:00, 11:30, 14:00, 15:30, or 17:00 and were tested alone. Subjects were instructed to refrain from eating or drinking except water two hours before the test.

During each visit, subjects consumed one sample type in a randomized order. They first received a spoon of the sample (6 ± 1 g) and evaluated their liking and desire to eat. They were also asked to rate the intensity of sweetness and sourness. After that, they had a light meal for 30 min to standardize the individual state of satiety. The meal consisted of a tomato and mozzarella panini (1154 kJ) and a glass of 150 mL water. After the meal, they received 10 cups of the lemon mousse sample (40 g each) and were asked to eat as much as they liked until they felt comfortably full. Water was not provided throughout the eating process. Before and after consuming the lemon mousse, the subjects rated their hunger, fullness, overall desire to eat, and prospective consumption.

The subject’s ad libitum intake was constantly measured by a Universal Eating Monitor connecting to a computer with a concealed balance (Sartorius Cubis® MSU). The study ran through the Sussex Ingestion Pattern Monitor program (SIPM), which allowed an automated collection of ratings and intake data (M. R. Yeomans, 2000). Experimental procedures and instructions were presented through the program. All ratings were made on computerized VAS and presented through the SIPM program, scoring from 0 to 100. The scale consisted of a horizontal line with the anchors of ‘not at all’ to ‘extremely’ or ‘very weak’ to ‘very strong’ at the two ends. Subjects rated their responses by moving the slide bar.

2.5. Data analysis
Analysis of the perceived sourness was conducted by a GLM ANOVA with samples and subjects as independent variables. The results were used for screening the acidification range for composing contrasting bilayer lemon mousse.

Data from the consumer test were subset to focus on acidity level and layering design factors. Analysis of the hedonic and appetitive effects of the bi-layering (top: low-bottom: high-acidity) was conducted by GLM ANOVA. The model considered liking and desire to eat scores of four samples (mono-97, bi-LM, mono-158, and bi-LH) as the outcome and samples and subjects as independent variables. The same statistical model was used to compare differences between the three samples (mono-97, bi-LM, and bi-ML), which had the same acidity level but a different configuration of monolayer and two bilayers. If the effect of samples was significant, least significant difference (LSD) test was used for post hoc comparisons.

In the ad libitum intake trials, analysis of the total consumption, liking, desire to eat, perceived sourness, and sweetness was conducted by a GLM ANOVA that included samples, visit order, and subjects as independent variables. The effect of visit order was removed in the final models if not significant. Changes in appetite ratings (i.e., hunger, fullness, overall desire to eat, and prospective consumption) before and after each intake trial were calculated and analyzed using the same statistical model. The least significant difference (LSD) test was used for post hoc comparisons when appropriate.

Data analyses were performed using IBM SPSS Statistic 28.0. Significance was set at p < 0.05 for all analyses. Unless otherwise indicated, data are presented as estimated marginal means and standard errors.
3. Results

3.1. Sensory characteristics of the acidified lemon mousses

The level of citric acid added to lemon mousse had a significant effect on the perceived sourness (p < 0.001). The perceived sourness of lemon mousses acidified by 0.7, 1.4, and 2.8% citric acid w/w was 8.1 (SE 0.4), 11.5 (SE 0.4), and 14.0 (SE 0.4) on the 15-cm line scale, respectively. The dose–response relationship obtained from these results was used to create appropriate acidity contrasts in bilayer lemon mousses.

3.2. Hedonic and appetitive effect of bilayer lemon mousses

3.2.1. Liking and desire to eat

Three bilayer lemon mousse samples were subsequently developed based on the acidity contrasts and evaluated by a consumer panel compared to the monolayer samples (Fig. 2).

The effects of bi-layering (top: low- bottom: high acidity) on liking and desire to eat was first investigated by comparing the bilayer samples with their corresponding monolayer counterparts. The results showed significant differences in liking and desire scores between samples (p < 0.001; Table 3). At the 0.97% citric acid level, bi-LM showed significantly higher liking (p = 0.021) and desire (p = 0.002) scores than mono-97. Consistent with these results, a significant effect of layering was observed at the higher critic level of 1.58%. Bi-LM had higher scores of liking and desire to eat compared to the monolayer samples (Fig. 2).

To compare the effects of the two configurations of bilayer samples (top: low- bottom: high acidity or reversed layering), the liking and desire scores of the three samples (bi-LM, bi-ML, and mono-97) at the same acidity level of 0.97% were analyzed. Table 4 shows the results of ANOVA on the dataset of the three samples. A significant sample effect was found on liking (p = 0.017) and desire to eat (p = 0.002). Bi-LM showed significantly higher scores of liking and desire to eat than mono-97. For the reversed bilayer configuration, the liking score of bi-ML was not statistically different from mono-97 or bi-ML. It showed a higher desire to eat score than mono-97 but to a smaller significant extent than the bi-LM configuration (p = 0.033).

3.2.2. Ad libitum intake

Bi-LM (top: 0.35 and bottom: 1.58% citric acid w/w) showed the highest liking and desire scores in the consumer test. Together with its monolayer counterpart mono-97 (0.97% citric acid w/w) and the lemon mousse prepared with the standard recipe (0.7% citric acid w/w), the three samples were selected for the ad libitum intake trials.

Ad libitum intake was 160 g (1713 kJ) for bi-LM, 142 g (1517 kJ) for mono-97, and 136 g (1452 kJ) for the standard recipe (0.7% citric acid w/w). Differences between samples were significant (p < 0.001). Bi-LM showed a significant increase of 13% in total consumption compared to mono-97 (p = 0.002), corresponding to an average increase in energy intake of 196 kJ. It also had a significant (p < 0.001) increase of 18% in total consumption compared to the standard recipe, with an average increase in energy intake of 262 kJ. There was a significant effect of the order of visit on intake (p = 0.009). The average intake in the second and third visits was higher than in the first visit.

Changes in appetite before and after ad libitum intake, measured as hunger, overall desire to eat, and prospective consumption, were not significantly different between samples (data not shown).

Table 5 shows the liking, desire to eat, and sensory ratings of the three samples. Scores of liking, desire to eat, and perceived sourness significantly differed between samples (p < 0.05). Consistent with the consumer test results, bi-LM showed a significantly higher desire score than mono-97 (p = 0.031). However, their liking scores were not

---

Table 3

<table>
<thead>
<tr>
<th>Attribute</th>
<th>mono-97</th>
<th>bi-LM</th>
<th>mono-158</th>
<th>bi-LH</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liking</td>
<td>9.0 ± 0.3\textsuperscript{a}</td>
<td>10.0 ± 0.3\textsuperscript{b}</td>
<td>8.0 ± 0.3\textsuperscript{b}</td>
<td>8.7 ± 0.3\textsuperscript{c}</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Desire to eat</td>
<td>7.7 ± 0.3\textsuperscript{a}</td>
<td>9.2 ± 0.3\textsuperscript{b}</td>
<td>7.2 ± 0.3\textsuperscript{b}</td>
<td>8.7 ± 0.3\textsuperscript{c}</td>
<td>&lt; 0.001</td>
</tr>
</tbody>
</table>

The letter codes L (0.35%), M (1.58%), and H (2.80%) refer to the citric acid level added to the layers of the bilayer samples. LM: low-medium, and LH: low-high refer to the sequence of the citric acid level from top to bottom (see also Fig. 2). Data with different superscript letters within the same row indicate significant differences determined by LSD post hoc analysis (p < 0.05).

Table 4

<table>
<thead>
<tr>
<th>Attribute</th>
<th>mono-97</th>
<th>bi-LM</th>
<th>bi-ML</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liking</td>
<td>9.0 ± 0.2\textsuperscript{a}</td>
<td>10.0 ± 0.2\textsuperscript{b}</td>
<td>9.6 ± 0.2\textsuperscript{b}</td>
<td>0.017</td>
</tr>
<tr>
<td>Desire to eat</td>
<td>7.7 ± 0.3\textsuperscript{a}</td>
<td>9.2 ± 0.3\textsuperscript{b}</td>
<td>8.6 ± 0.3\textsuperscript{b}</td>
<td>0.002</td>
</tr>
</tbody>
</table>

The letter codes L (0.35%) and M (1.58%) refer to the citric acid level added to the layers of the bilayer samples. LM: low-medium, and ML: medium-low refer to the sequence of the citric acid level from top to bottom (see also Fig. 2). Data with different superscript letters within the same row indicate significant differences determined by LSD post hoc analysis (p < 0.05).

Table 5

<table>
<thead>
<tr>
<th>Attributes</th>
<th>standard recipe (0.7%)</th>
<th>mono-97 (0.97%)</th>
<th>bi-LM (top: 0.35; bottom: 1.58%)</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Liking</td>
<td>9.2 ± 1.6\textsuperscript{a}</td>
<td>7.9 ± 1.6\textsuperscript{b}</td>
<td>8.1 ± 1.6\textsuperscript{b}</td>
<td>0.003</td>
</tr>
<tr>
<td>Desire to eat</td>
<td>7.5 ± 1.8\textsuperscript{a}</td>
<td>7.6 ± 1.7\textsuperscript{b}</td>
<td>8.1 ± 1.7\textsuperscript{b}</td>
<td>0.023</td>
</tr>
<tr>
<td>Sweetness</td>
<td>52 ± 1.7\textsuperscript{a}</td>
<td>52 ± 1.3\textsuperscript{b}</td>
<td>52 ± 1.3\textsuperscript{b}</td>
<td>0.99</td>
</tr>
<tr>
<td>Sourness</td>
<td>49 ± 2.6\textsuperscript{a}</td>
<td>58 ± 2.6\textsuperscript{b}</td>
<td>59 ± 2.6\textsuperscript{bc}</td>
<td>0.014</td>
</tr>
</tbody>
</table>

The percentage given is in w/w of the added citric acid. Samples bi-LM and mono-97 had an overall identical composition. Data with different letters within the same row indicate significant differences determined by LSD post hoc analysis (p < 0.05).
different from each other. The perceived sourness of these two samples was significantly higher than the standard recipe ($p < 0.05$).

4. Discussion

The concept of layering foods is known but has not been reported scientifically on its effect on hedonic and appetitive responses. The present study used lemon mousse to demonstrate the potential of layered food designs to stimulate the desire to eat and intake by contrasting acidity across the layers.

In the consumer test, bilayer lemon mousses with a layer of low acidity on top and a layer of high acidity at the bottom (bi-LM and bi-LH) showed consistently higher scores of liking and desire to eat than their corresponding monolayer counterparts (Table 3). Mono-158 received the lowest scores for liking and desire to eat. The results were consistent with previous studies that preferences decreased with increasing levels of citric acid, which were perceived as unpleasant in adult subjects (Chauhan & Hawrysh, 1988; Liem & Mennella, 2003; Zandstra & De Graaf, 1998). Nevertheless, the bilayer configuration in bi-LH could mask the unpleasantness of strong sourness and significantly improve the liking and desire scores to the level comparable to samples at a lower level of acidity (i.e., mono-97 and bi-LM).

The ad libitum intake trials showed a significant increase in consumption of the bilayer lemon mousse (bi-LM) compared to its monolayer counterpart (mono-97). The appetitive effect of such bilayer configuration was not due to differences in energy or macronutrient content since the lemon mousse samples were all identical. This finding was consistent with the review by Sorensen et al. (2003) indicating that food intake increased as palatability increased.

The ad libitum intake of lemon mousses was evaluated using a smaller consumer panel ($n = 30$). The liking of bi-LM was not significantly different from its monolayer counterpart; however, bi-LM scored consistently higher for the desire to eat (Table 5). The desire to eat rating showed predictive validity to food intake and a procedure’s simplicity (Rogers & Hardman, 2015). Moreover, changes in satiety ratings (e.g., hunger, fullness, and prospective consumption) were not different between samples. As shown by Zijlstra et al. (2008), the ratings could be the same when the amount of food consumed was different.

Hyde & Witherly (1993) hypothesized that foods and beverages having higher levels of ‘dynamic contrast’, experienced as moment-to-moment sensory contrast from the everchanging properties of foods during oral processing, contribute to their palatability. In this study, it was expected that when consuming a spoon of lemon mousse, the specific bilayer configuration (top: low- bottom: high acidity) could create a more dynamic progression of sour taste intensity compared to the monolayer version, where the citric acid was distributed evenly across the matrix. The layer of high acidity at the bottom would enter the mouth first, whereas the layer of low acidity on top would enter more at the entrance and be swallowed later (Fig. 1). Albeit the two layers of lemon mousse are subject to a degree of mixing in the mouth, the citric acid gradient established may deliver a spike of high-intensity sour taste following a more rapid decline over the sequence of a spoonful.

Interestingly, at the same overall acidity level, the reversed bilayer configuration (i.e., bi-ML, top: high- bottom: low acidity) could also give a higher desire score than its monolayer counterpart, but to a smaller extent than the specific bilayer configuration above-discussed (Table 4). The reversed configuration was expected to create a longer duration of sour taste perception since the top layer of high acidity would enter the mouth more at the entrance and be swallowed later. A clear explanation for these findings is lacking. In both cases, the bilayer configuration might enhance the perceived complexity of the lemon mousse, which was described as an increased fluctuation of dominant sensory attributes (Palczak et al., 2019). It could be that the combination of acidity levels of 0.35 and 1.58% citric acid w/w in lemon mousse, regardless of the different configurations, could establish a dynamic sour taste perception over the sequence of a spoonful consumption that was within subjects’ acceptance ranges. Contrarily, at a higher level of citric acid (i.e., 1.58% w/w overall), the reversed bilayer configuration gave a strong residual sour taste as the high acidity layer (2.8% citric acid w/w) was located on top. Subjects reported this configuration to be very unpleasant during the pilot study.

In order to elucidate the hedonic or appetitive effects of bilayer configurations in lemon mousses, further investigation on the dynamic sensory perception and its relationship with hedonic and appetitive responses during a spoonful consumption is needed (Delarue & Blumenthal, 2015). For instance, Veldhuizen et al. (2006) performed time-intensity and time-hedonic scaling on orange lemonade stimuli and suggested that taste intensity responses were in serial and preceded hedonic responses. However, the evaluation for lemon mousse may face practical challenges as the sensory perception during a single-spoon consumption can be only a few seconds short and requires further development in dynamic sensory methods.

Layering foods is a culinary technique commonly used to diversify the sensory experiences of consuming dairy desserts (Palczak et al., 2019). This study demonstrated that the technique could be readily applied in food service settings by converting a monolayer dairy dessert, such as lemon mousse, into specific bilayer configurations to develop more appetizing foods.

This study used an unequal distribution of citric acid to develop sour taste contrasts in bilayer lemon mousses. Individual differences in sour taste perception and preference may influence subjects’ hedonic and appetitive responses (Törnwall et al., 2012; Zhang et al., 2022), but these variables were not measured in the studies. Moreover, specific consumer groups such as seniors and patients may experience changes in taste perception, preferences, and oral processing (Bosso et al., 2007; Doets & Kremer, 2016; Zandstra & De Graaf, 1998). Future studies will need to investigate the appropriate ranges of taste differences for developing effective layering foods for consumers in need of greater food intake.

5. Conclusion

This study evaluated layered acidified lemon mousses on their appetizing potentials compared to their counterparts with identical acid levels equally distributed in a monolayer. For specific bilayer configuration in the mousses, where the lower layer of the dessert was made more acidic than the upper layer, a significantly higher desire to eat and intake could be achieved than for the monolayer counterparts.

Further investigation on the time course of sensory perceptions in bilayer food configurations and its relation with appetitive responses is needed to understand the effects of dynamic sensory contrast. Also, it could be interesting to implement the concept of layering in other food matrices, sensory dimensions, and nutrition formulations, especially for developing foods for people at nutritional risk.

Ethical statement

Based on the “Danish Act on Research Ethics Review of Health Research Projects; Section 2”, no formal documentation process is available for sensory-consumer research in Denmark. Therefore, the study was initiated without the need for approval from The Committees on Health Research Ethics for the Capital Region of Denmark.

The study was conducted in accordance with the Declaration of Helsinki Ethical Principles. For each study, participants gave written informed consent for their participation and processing of personal information via the statement “I confirm that I have read the study information sheet and that this forms the basis on which I consent to the participation and processing of my personal data by the project”, providing name, date, and signature.

All participants acknowledged an informed consent statement in order to participate in the study. The study was explained to the
Participants before they signed the consent form. They were free to withdraw at any time without giving a reason. The products tested were produced in food-grade facilities and safe for human consumption.

There was no health risk associated with taking part in the studies.

The processing of personal data was in accordance with the rules of the General Data Protection Regulation, Regulation 2016/679. All data were anonymized and only reported in the aggregate.

Trained panelists were financially compensated for their participation in the sensory characterization of acidified lemon mousses (study 1) in the amount of 200 DKK (approx. 27 EUR). Participants in the consumer test on 3D-printed lemon mousses (study 4) were not financially compensated for their participation.

Participants in the consumer test on 3D-printed lemon mousses (study 4) were financially compensated with a gift bag worth 200 DKK (approx. 27 EUR). Participants in the ad libitum intake trials (study 3) were financially compensated with a gift bag worth 600 DKK (approx. 81 EUR). Participants in the consumer test on 3D-printed lemon mousses (study 4) were not financially compensated for their participation.

CRediT authorship contribution statement

Ching Yue Chow: Methodology, Formal analysis, Investigation, Writing – original draft. Raquel M. Rodríguez: Methodology, Formal analysis, Investigation, Writing – review & editing. Reysia R. Riantiningtyas: Methodology, Investigation. Merete B. Munk: Methodology, Writing – review & editing, Supervision. Lilia Ahrné: Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration, Funding acquisition. Wender L.P. Bredei: Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A

See Appendix Table A.


