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Don't judge new foods by their appearance! How visual and oral sensory cues affect sensory perception and liking of novel, heterogeneous foods

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A R T I C L E I N F O

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A B S T R A C T

This study investigated how exteroceptive and interoceptive cues influence sensory perception and liking of novel, heterogeneous foods. Twelve heterogeneous cheeses were prepared by adding bell pepper pieces to homogeneous processed cheese matrices. Bell pepper pieces differed in size, hardness, and concentration. Consumers (n = 73) evaluated cheeses in three conditions. In the first condition, subjects tasted cheeses and rated them on sensory properties and liking while being blindfolded (interoceptive condition). In the second condition, participants evaluated expected sensory properties and liking of cheeses presented as pictures together with product descriptions (exteroceptive condition). In the third condition, consumers tasted and evaluated cheeses while visual cues and product descriptions were provided (combined condition). The hardness and concentration of bell pepper pieces predominantly determined variations in sensory perception in the interoceptive and combined conditions, whereas bell pepper size or concentration influenced expected sensory properties in the exteroceptive condition the most. Consumers expected to like the cheeses with small-medium sized bell pepper pieces the most. However, from the other conditions, we observed that piece size does not play a role in determining liking, and that cheeses with soft pieces were actually preferred most. From the comparison of the three conditions, we conclude that both visual and oral sensory cues influence texture and flavour perception of heterogeneous cheeses. Consumers' liking was not influenced by the cheese's exteroceptive cues during the combined condition. In contrast, interoceptive cues as hardness played a large role in determining variations in consumer's hedonic responses. We conclude that for novel, heterogeneous foods liking after consumption is determined by textural product properties and depends to a large extent on the confirmation of consumers' sensory expectations.

1. Introduction

The acceptance of novel foods is determined by factors pertaining to both products and consumers (Szczesniak, 2002). From a product perspective, properties such as visual appearance, texture, and flavour are of primary importance to establish consumer sensory and hedonic responses (Pascua, Koc, & Foegeding, 2013; Wei, Ou, Luo, & Hutchings, 2012; Wilkinson, Dijksterhuis, & Minekus, 2001; Zellner, Lankford, Ambrose, & Locher, 2010). Such responses are mediated, however, by consumer physiological and psychological factors as well as socially and culturally learned expectations (Piqueras-Fiszman & Spence, 2015; Shankar, Levitan, Prescott, & Spence, 2009; Tan, Tibboel, & Stieger, 2017; Tuorila, Meiselman, Cardello, & Lesher, 1998). To successfully design novel food products, the dynamic interrelationship between these complementary aspects of food consumption should be taken into consideration.

The introduction of particles into a product is a common strategy used to create novel food products. The addition of macroscopic particles (i.e. pieces of vegetables or fruits, chocolate chips, nuts) provides the product with a new appearance, texture, and sensory profile. A composite food with dispersed particles often presents contrasting flavours and textures within a single bite. This contrast in flavours and textures might establish an intra-oral variation in perception that could help to prevent adaptation of the sensory stimulus and lead to an enhanced palatability (Hyde & Witherly, 1993; Szczesniak & Kahn, 1984). Soup with pasta and vegetable pieces and yoghurt with granola or fruit pieces are examples of commonly consumed heterogeneous composite

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foods that are well appreciated by consumers. The presence of structural heterogeneities not only influences the dynamic sensory perception (Devezeaux de Lavergne et al., 2015; Emorine et al., 2015; Emorine, Septier, Thomas-Danguin, & Salles, 2014; Santagiuliana, Piqueras-Fiszman, van der Linden, Stieger, & Scholten, 2018; Tang, Larsen, Ferguson, & James, 2017; van Eck, Fogliano, Galindo-Cuspinera, Scholten, & Stieger, 2018), but it also affects food oral processing behaviour and related satiation responses (Laguna & Sarkar, 2016; Larsen, Tang, Ferguson, Morgenstern, & James, 2016a, 2016b; Tang, Larsen, Ferguson, & James, 2016; van Eck et al., 2019).

In our previous studies, we investigated the effect of addition of particles on perception of model and commercial foods (Santagiuliana, Christaki, Piqueras-Fiszman, Scholten, & Stieger, 2018; Santagiuliana, van den Hoek, Stieger, Scholten, & Piqueras-Fiszman, 2019). We demonstrated that changes in size and fracture stress (hardness) of particles cause large differences in sensory profiles in model gels and soups. When unfamiliar gel pieces were added to such foods, liking of heterogeneous products decreased. However, when congruent and familiar pieces matching the consumers' expectations were added, the acceptance of soups increased (Santagiuliana et al., 2019). Sensory profiles of heterogeneous soups were closer to the consumers' 'ideal' than the profile of the plain homogeneous soup. Soups belong to a product category that is commonly consumed with added pieces. To boost palatability of such a familiar product, it was important that changes in the sensory profiles due to increased texture contrast matched consumers' expectations.

As the consumers already expect some degree of heterogeneity in soups, it makes food innovation by particle addition for such products easier than for novel foods for which the consumer has no previous experience and expectations with the product properties. For unfamiliar new products, expectations are based on other aspects, such as the properties of similar foods, the product's visual appearance, orthonasal olfactory cues, and descriptive information (Burgess, 2016; Shankar et al., 2009; Tuorila et al., 1998; Vidal, Barreiro, Gómez, Ares, & Giménez, 2013). In fact, the multisensory perception of food involves both cues that are stimulated prior (*exteroceptive*; e.g. product visual appearance) and during consumption (*interoceptive*; e.g. somatosensory and gustatory perception) (Piqueras-Fiszman & Spence, 2015). It is the confirmation or disconfirmation of expectations established on exteroceptive and/or interoceptive cues that mostly determines acceptance or rejection of food products (Burgess, 2016; Schifferstein, Kole, & Mojet, 1999).

Little is known about which factors contribute to the consumer's acceptance of novel heterogeneous foods. It is not clear how exteroceptive and interoceptive cues influence expected and perceived sensory properties and liking. For novel heterogeneous foods, we hypothesise that the expected sensory profile and liking are mainly related to exteroceptive cues, such as the visual appearance and recognition of particles present in the product. For product acceptance of novel food products, both exteroceptive and interoceptive cues have to be taken into account.

The aim of the study was to determine the influence of exteroceptive and interoceptive sensorial cues on consumer preferences and sensory perception of novel, heterogeneous cheeses. Model bell pepper pieces (bell pepper flavoured gellan gels differing in size and fracture stress) or real bell pepper pieces (varying in concentration) were added to processed cheeses to modify appearance, texture, and flavour. Cheeses were evaluated with a consumer test in three conditions (exteroceptive, interoceptive, and combined) using the Rate-All-That-Apply (RATA) method.

2. Materials and methods

2.1. Materials

K-carrageenan (GENUGEL type CHP-2) and low acyl gellan gum (KELCOGEL® gellan gum) were purchased from CP Kelco (Rotterdam, France). Food colourant (Paprika Oleoresin WS, E160c) was kindly donated by Holland Ingredients (Meppel, The Netherlands). Red bell pepper, salt, unsalted crackers (Hollandia® Matzes B.V.), La Vache qui rit® Mini Cubes Natural (Fromageries Bel, Suresnes, France) and sunflower oil were purchased from a local supermarket. Kiri® (processed cream cheese) was provided by Bel Group (Fromageries Bel, Suresnes, France). All ingredients were food grade and samples were prepared in food-safe conditions.

Table 1
Samples codes for homogeneous and heterogeneous processed cream cheeses. Homogeneous plain (HO) and homogeneous bell pepper flavoured cheese (HOF) were included. For cheeses containing pieces, the first letter of the sample code denotes particle size (Small S-; Medium M-; Large L-), while the second number denotes the hardness of the pieces added (hardness expressed as fracture stress σ_F; Soft −20; Medium −100; Hard −250). The sample codes starting with the letter R indicate samples with real bell pepper pieces. The second and third letters of samples with real bell pepper pieces denote the concentration of the added pieces (Low -Lo; Medium -Me; High -Hi).

Sample Code	Particle size (mm)		Particle fracture stress (σ_F)		Particle concentration	
HO	–	–	–	–	–	–
HOF	–	–	–	–	–	–
S20	Small	2 × 2 × 2	Soft	20 kPa	Medium	15%
S100	Small	2 × 2 × 2	Medium	100 kPa	Medium	15%
S250	Small	2 × 2 × 2	Hard	250 kPa	Medium	15%
M20	Medium	4 × 4 × 4	Soft	20 kPa	Medium	15%
M100	Medium	4 × 4 × 4	Medium	100 kPa	Medium	15%
M250	Medium	4 × 4 × 4	Hard	250 kPa	Medium	15%
L20	Large	6 × 6 × 6	Soft	20 kPa	Medium	15%
L100	Large	6 × 6 × 6	Medium	100 kPa	Medium	15%
L250	Large	6 × 6 × 6	Hard	250 kPa	Medium	15%
RLo	Medium	4 × 4 × 4	–	–	Low	7.5%
RMe	Medium	4 × 4 × 4	–	–	Medium	15%
RHi	Medium	4 × 4 × 4	–	–	High	30%

2.2. Study design

In this study, 2 homogeneous and 12 heterogeneous cheeses were prepared (Table 1). Kiri® (processed cream cheese) was used as matrix for all samples. Twelve heterogeneous cheeses were designed varying in appearance and texture. Nine cheeses contained bell pepper flavoured gel pieces varying in size and hardness (fracture stress), and three cheeses contained real bell pepper pieces varying in concentration. This allowed studying the effect of both particle fracture stress and particle concentration on sensory perception and liking. Two homogeneous cheeses, a homogeneous plain (HO) and a homogeneous bell pepper flavoured cheese (HOF) were also included. Table 1 reports the sample codes of all cheeses. For cheeses containing pieces, the first letter of the sample code denotes the particle size (Small S-; Medium M-; Large L-), while the second number denotes the hardness of the pieces added (hardness expressed as fracture stress σ_F; Soft −20; Medium −100; Hard −250). Cheeses containing real bell pepper pieces were all medium-sized. The samples codes for these samples start with the letter R, indicating that they were real bell pepper pieces. The second and third letters denote the concentration of the added pieces (Low -Lo; Medium -Me; High -Hi).

2.3. Sample preparation

2.3.1. Model bell pepper gel particle preparation

Bell pepper model gels were designed to mimic real bell pepper pieces in terms of flavour, texture, and appearance (Fig. 1). Model pieces varied in hardness (fracture stress, σ_F) and size and were incorporated into processed cream cheese to obtain samples with controlled mechanical contrast. To mimic the flavour profile of real bell pepper, two aqueous phases, a "roasted" and "concentrated" bell

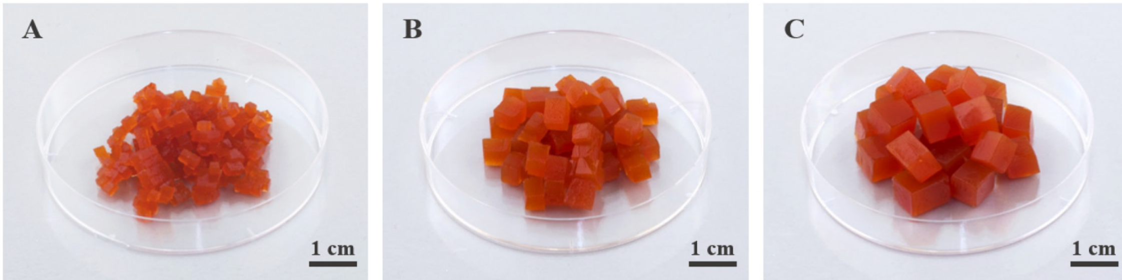

Fig. 1. Pictures of model bell pepper pieces varying in size. A. Small (2 × 2 × 2 mm); B. Medium (4 × 4 × 4 mm); C. Large (6 × 6 × 6 mm).

pepper juice, were combined. The flavour of the combined juices was found to be the closest to the flavour of real bell pepper during feasibility tests with consumers and discussions between researchers (data not shown).

2.3.1.1. Roasted bell pepper juice. To produce a "roasted" bell pepper juice, bell peppers were baked for 13 min at 270 °C in an electrical oven (Rational, Mod. SCC101, Barcelona, Spain). Roasted bell peppers were then slit open and cooled down to room temperature for about 1 h. After removal of skin and seeds, bell pepper flesh was blended into a puree using a hand blender (Braun Multiquick 7, Kronberg im Taunus, Germany) for 5 min. The obtained mash was then centrifuged at 3000 g for 15 min. The supernatant was collected, filtered with a sieve (64 µm mesh size) and stored at −18 °C for further use.

2.3.1.2. Concentrated bell pepper juice. For the preparation of the "concentrated" bell pepper juice, bell peppers were first peeled and deseeded. Their juice was extracted with a juicer (Philips HR 1861, Eindhoven, The Netherlands) and reduced to 66% of its initial weight by heating it in an open pan on a stove. The resulting concentrated juice was filtered with a sieve (64 µm mesh size) and cooled down in an ice bath for 20 min. A single batch was obtained and stored at −18 °C for further use.

2.3.1.3. Bell pepper model gel. A mixture of roasted and concentrated bell pepper juice in a ratio of 50:50 (w/w) was used as the liquid aqueous phase for all bell pepper model gels. As reported in Table 2, the liquid phase was mixed with red colourant, salt, and different concentrations of low acyl gellan gum. The acyl gellan gum concentration determined the gel fracture stress (target σ_F: 20, 100, 250 kPa). Acyl gellan solutions were placed in a water bath at 95 °C for 45 min under continuous stirring to dissolve all acyl gellan. They were then poured into plastic containers and cooled in an ice bath for 20 min to set the gel. For the instrumental characterization, cylindrical gel pieces with a diameter of 23 mm and height of 15 mm were used. For the sensory study, bell pepper gels were cut into cubes of 2 × 2 × 2 mm, 4 × 4 × 4 mm, and 6 × 6 × 6 mm (Fig. 1) using a Mandolin (Michel BRAS, Laguiole, France) and custom-made cutting frames.

2.3.2. Real bell pepper particle preparation

Real bell pepper pieces were obtained by cutting peeled and deseeded vegetables into quarters. Bell pepper pieces were placed in vacuum bags in which roasted bell pepper juice (10%, w/w) and salt (0.5%, w/w) were added. Bags were vacuum sealed at 95%, heated in a water bath at 90 °C for 15 min and then placed in an ice bath to cool for approx. 15 min. Cubes of 20 × 20 × 5 mm were cut for the analysis of the mechanical properties, whereas cubes of 4 × 4 × 4 mm were cut for the sensory study. All samples were stored at 4 °C and used within two days.

2.3.3. Preparation of homogeneous and heterogeneous processed cream cheeses

K-carrageenan was incorporated in the processed cream cheese (Kiri®) to control the mechanical properties of the plain homogenous (HO) and heterogeneous cheeses. The gelling agent was incorporated by preparing a 2% (w/w) solution of κ-carrageenan using tap water. K-carrageenan was added to water and the mixture was heated in a water bath at 90 °C for 30 min under continuous stirring to dissolve the κ-carrageenan. The solution was then placed in an ice bath for 20 min to cool and set. For the flavoured homogeneous sample (HFO), bell pepper flavour and colourant were added during this step to obtain a bell pepper flavoured κ-carrageenan gel. Also, a 3% (w/w) solution of κ-carrageenan was prepared, which was used for the HOF sample only. For this κ-carrageenan gel, the aqueous phase consisted of a mixture of roasted and concentrated bell pepper juice in a ratio of 50:50 (w/w) and 0.125% of red colourant was added. The solution was heated in a water bath at 90 °C for 30 min under continuous stirring. The solution was then placed in an ice bath for 20 min to cool and set.

Homogeneous and heterogeneous processed cream cheeses were prepared by adding the κ-carrageenan gel (12.5%, w/w) to the cream cheese in vacuum sealed bags. Samples were placed in a water bath at 65 °C for 20 min to allow the cream cheese and gel to melt. Then, the molten cheese was poured into a vessel kept at 65 °C and was manually mixed avoiding incorporation of air. For heterogeneous cheeses, model or real bell pepper pieces were incorporated at this point. The products were subsequently poured into squared petri dishes coated with a thin layer of sunflower oil and stored at 4 °C for 16–18 hrs. Cheeses were cut with a custom-made cutting frame to obtain 20 × 20 × 12 mm cubes of approx. 5 g and stored at 4 °C for a maximum of one week.

2.4. Mechanical properties of model bell pepper gels and homogenous cheeses

To characterize the mechanical properties of the bell pepper model gels, fracture stress and fracture strain was determined using uniaxial compression tests using a Texture Analyzer (TA.XT plus, Stable Micro

Table 2
Composition for model low acyl gellan gels with different target fracture stress (σ_F). All concentrations are expressed as % (w/w).

Particle Hardness	Target fracture stress (σ_F) / kPa	Low acyl gellan	Roasted bell pepper juice	Concentrated bell pepper juice	Paprika Oleoresin (red colourant)	Salt
Soft	20	0.60	49.35	49.35	0.50	0.20
Medium	100	1.70	48.80	48.80	0.50	0.20
Hard	250	3.80	47.75	47.75	0.50	0.20

Systems-SMS). All bell pepper model gels fractured under uniaxial compression. A compression plate of 100 mm was used as a probe and the device was equipped with a 50 kg load cell. Compression strain was set at 30% with a crosshead velocity of 1 mm/s. Each sample type was measured in six replicates at room temperature (20 ± 1 °C). Averaged true fracture stress (kPa) and true strain (−) were calculated from the measurements for all bell pepper model gels, as previously described by Peleg (1987).

In contrast to the bell pepper model gels, the homogenous cheeses (HO, HOF) and the real bell pepper pieces did not fracture under uniaxial compression (data not shown). Therefore, penetration tests were performed on homogenous cheeses (H, HOF) and bell pepper pieces to determine the force (N) needed to reach 30% penetration, allowing for a comparison of instrumentally quantified texture properties between these samples which did not fracture. This test was performed using a Texture Analyser equipped with a 5 kg load cell and a cylindrical flat probe (Ø:4 mm). A crosshead velocity of 1 mm/s was used. Six replicates of each sample type were measured at room temperature (20 ± 1 °C) for homogenous cheese (20 × 20 × 15 mm) as well as for real (20 × 20 × 5 mm) and bell pepper model gel pieces (Ø 23 mm × 5 mm).

2.5. Sensory analysis

2.5.1. Subjects

A total of 73 subjects (53 female/20 male, age: 18–31 years) were recruited. Subjects were pre-screened based on self-reported criteria such as overall good health, BMI (18.5–25 kg/m^2), dental health (no dental implants; no missing teeth except wisdom teeth; no dental braces or piercings), and origin (born and living in European Union). Participants were excluded if they were smokers, had allergies or intolerances to cheese or bell pepper. During the recruitment, participants were asked to rate their familiarity with processed cream cheese on a scale from 1 to 6 (1 = unfamiliar, 6 = highly familiar) and their consumption frequency of processed cheese (once a week, once a month, every 3 months, never). Only consumers who consumed processed cream cheese at least once every 3 months were included in the study. Subjects signed an informed consent form in advance and received financial compensation for their participation in the study.

2.5.2. Sensory sessions

An information session of approx. 1 h was conducted at the beginning of the study to allow participants to become familiar with the different sessions, the sensory method, and the descriptors. A short demonstration was provided during that session to familiarize them with the different tasks and the proper evaluation procedures. Although participants were informed that the test consisted of an evaluation of processed cream cheeses that may contain bell pepper, no information was provided regarding the form (as pieces or juice), type (model or real) and possible variation of bell pepper (i.e., hardness, concentration) nor the order of cheese samples during the different sessions. An extra warm-up sample (La Vache qui rit Mini Cubes®) was provided to participants at the very beginning of the actual sensory test. The sensory test was divided into three subsequent conditions that were distributed over five test sessions of approx. 1 h. In each condition, consumers had to fill out a questionnaire using EyeQuestion® software (The Netherlands). They were first asked to evaluate the cheeses based on overall liking, texture liking, and flavour liking using a nine-point hedonic scale ranging from "Dislike extremely" (1) to "Like extremely" (9). Then, subjects evaluated textural and flavour attributes using a Rate-All-That-Apply (RATA) methodology with nine-box scales (Meyners, Jaeger, & Ares, 2016; Oppermann, de Graaf, Scholten, Stieger, & Piqueras-Fiszman, 2017). Participants could always refer to a brochure for the explanation of the sensory attributes (Appendix 1). Attributes and their definitions were generated through discussions of researchers and consumers during feasibility tests (data not shown).

In the first condition (interoceptive condition; first two sessions performed in two consecutive weeks with a break of one week between sessions), participants were blindfolded with a sleeping mask and were not allowed to see the cheeses. Each product was provided to them directly in the mouth by the researchers and, only after that, participants were permitted to remove their mask to fill out the questionnaire. In this condition, subjects were asked to evaluate the liking and sensory perception of cheeses based on their somatosensory and gustatory perception (interoceptive cues). Participants were allowed to ask up to two portions of the same sample. During each of these two sessions, seven of the fourteen products were served in a randomized monadic sequence.

After a break of one week, participants evaluated the cheeses in a randomized monadic sequence based on their visual appearance using pictures (Fig. 2, printed to scale 1:1) and related product descriptions (exteroceptive condition, third session). The product descriptions are provided in the caption of Fig. 2. These objective descriptions were provided to avoid creation of erroneous expectations (e.g. recognition of pieces as strawberry rather than bell pepper pieces). No tasting was performed in the exteroceptive condition.

The third condition (combined condition; fourth and fifth sessions performed in two consecutive weeks with a break of one week between sessions) was conducted after a break of two weeks. During the combined condition, participants assessed liking and the sensory profile of two portions of each sample presented along with the sample description (same description as in the second condition, see caption of Fig. 2). Thus, both visual and somatosensory and gustatory cues were involved. As in the first condition, seven of fourteen samples were given during each session in a randomized monadic sequence to avoid fatigue.

For all conditions, consumers were requested to refrain from eating 1 h before the session and were instructed to have a break of at least 1.5 min between sample evaluations. Participants were asked to rinse their mouths with water and the provided crackers between each sample. All the sessions were conducted in meeting facilities (Agrotechnology and Food Sciences Group, Wageningen University) in which the room was equipped with desk dividers. The order of the sensory attributes was randomized within each block of attribute category (texture and flavour) for each participant.

2.6. Data analysis

Analysis of Variance (ANOVA) was performed on the data obtained instrumentally with the measured instrumental value as dependent variable and sample type as independent variable (uniaxial compression tests and penetration tests). For the analysis of RATA outcomes were treated as continuous data as previously described (Meyners et al., 2016; Oppermann et al., 2017). To address the main objectives of the study, individual paired t-tests were performed between the different tested conditions to identify the effect of exteroceptive cues (combined minus interoceptive scores) and interoceptive cues (combined minus exteroceptive scores) on sensory perception and liking. To check how consumer perception and liking of processed cheese differed upon addition of particles or flavour, the sensory data obtained from the Interoceptive, Exteroceptive, and Combined conditions were analysed separately and, for each, an ANOVA was performed using sample as fixed factor and panellist as random factor. Such analysis was performed to allow a comparison between all products, and Tukey's HSD tests ($p < 0.05$) were conducted as post-hoc pairwise comparisons. In addition to these general analyses across products, for each condition, the effects of particle size, fracture stress, and concentration on sensory perception were investigated. ANOVAs were performed on sample subsets considering only applicable cheeses containing model or real bell pepper pieces for each condition separately: the effects of particle size and concentration were considered for the exteroceptive condition as particle fracture stress could not be visually evaluated; particle size, particle fracture stress, their interaction (for cheeses containing model bell pepper pieces), and particle concentration (for cheeses containing real bell pepper pieces) were used as factors for the interoceptive and

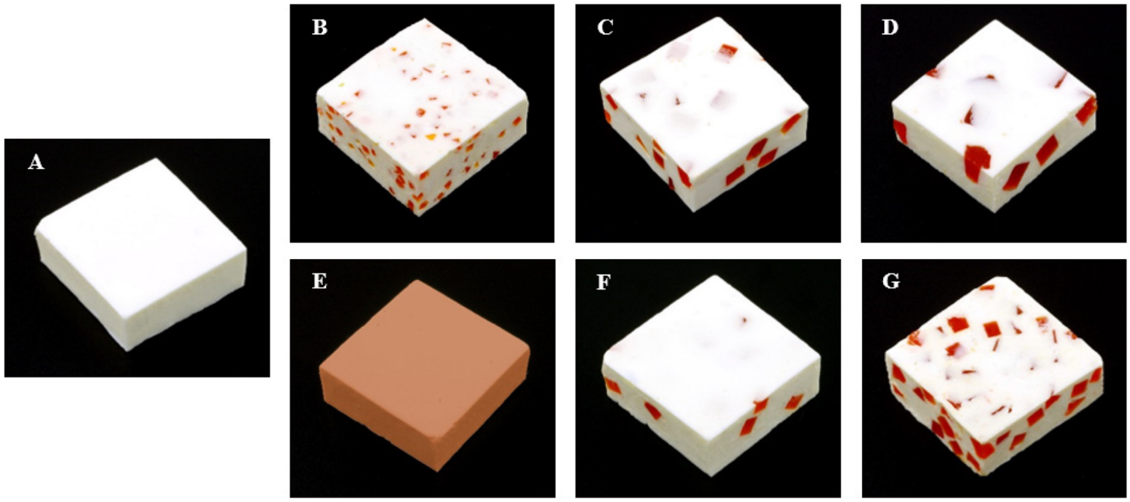

Fig. 2. Pictures of processed cream cheeses used during the exteroceptive condition. A. Homogeneous cream cheese (HO); B. Cream cheese with small red bell pepper pieces at medium concentration (S-); C. Cream cheese with medium red bell pepper pieces at medium concentration (M-); D. Cream cheese with large red bell pepper pieces at medium concentration (L-); E. Homogenous cream cheese with red bell pepper flavour (HFO); F. Cream cheese with medium red bell pepper pieces at low concentration (RLo); G. Cream cheese with medium red bell pepper pieces at high concentration (RHi). Pictures were printed to scale 1:1 relative to the real processed cheese product.

combined conditions. RStudio (version 3.4.0) with the use of the packages SensoMineR and FactoMineR was used for the data analysis.

3. Results

3.1. Mechanical properties of bell pepper model gels and homogenous cheeses

For the soft, medium, and hard model gels, the measured fracture stress values were relatively close to the target values (σ_F: 20, 100, 250 kPa) (Table 3). For all samples, Table 3 also reports the measured maximum force at 30% penetration depth. For bell pepper gels, the max force ranged from 0.9 N to 7.5 N. The instrumental hardness of real bell pepper was found to be 2.3 ± 0.8 N, which is within the range of the bell pepper model gels. The fracture force of the real bell pepper was found to be closest to the medium hard model gel (−100, 3.3 N). The soft bell pepper model gel, homogeneous cream cheese (HO) and homogeneous cream cheese with flavour (HFO) presented comparable mechanical properties with a maximum penetration force of approx. 0.7–0.9 N.

3.2. Sensory analysis

3.2.1. Interoceptive condition: Sensory perception of homogeneous and heterogeneous processed cheeses

In the interoceptive condition, consumers based their evaluations only on somatosensory and gustatory perception (interoceptive cues). The homogeneous cheese (HO) received the highest intensity scores for creamy, mouth coating, melting, smooth, and dairy flavour (see Appendix 2). Flavour addition to the homogenous cheese (HFO) significantly increased intensity of bell pepper flavour and decreased dairy flavour intensity. When pieces were added to processed cheeses, significant differences for all textural attributes were found (Table 4, see the first column: product effect). For flavour attributes, bell pepper flavour, dairy flavour and sweetness were significantly different, while savouriness, sourness, and saltiness did not differ significantly.

Most attributes were affected by particle fracture stress, and fewer attributes were affected by particle size. Particle size had a significant effect on chewiness, lumpiness, perceived particle size and grittiness perception (Table 4, see the size effect). Grittiness was most affected, as cheeses containing small pieces (S-) were perceived as more gritty than cheeses with medium (M-) and large-sized pieces (L-). For samples containing soft particles, an increase in particle size from small (S-) to large (L-) increased lumpiness perception significantly. No other effects on perception were observed when the size of added pieces was varied.

An increase in particle fracture stress from 20 kPa (−20) to 250 kPa (−250) led to several significant changes in the samples' sensory profile. Chewiness, crumbliness, crunchiness, hardness, lumpiness, particle size, mouthfeel heterogeneity and grittiness (for S- samples) increased with particle fracture stress, whereas creaminess, melting, smoothness, mouth coating and dairy flavour perception decreased (Table 4, see fracture stress effect). Significant interactions between particle size and fracture stress were found for chewiness, crumbliness, lumpiness, particle size, mouthfeel heterogeneity and grittiness, indicating that the perception of such attributes was not affected by size

Table 3
Mean values (± S.D.) for measured fracture stress and fracture strain of model bell pepper gels together with maximum force (N) needed to penetrate to 30% deformation of bell pepper model gels, real bell pepper and homogeneous cheeses (HO and HOF). Values within a column having the same superscript letters do not differ significantly (p > 0.05).

Sample	Target fracture stress (kPa)	Measured fracture stress (kPa)	Measured fracture strain (-)	Maximum force (N) at 30% deformation
Bell pepper gels	20	24 ± 3^a	0.21 ± 0.01^a	0.9 ± 0.1^d
	100	108 ± 4^b	0.25 ± 0.01^b	3.3 ± 0.1^b
	250	258 ± 9^c	0.31 ± 0.01^c	7.5 ± 0.1^a
Real bell pepper	–	–	–	2.3 ± 0.8^c
Homogeneous cream cheese (HO)	–	–	–	0.7 ± 0.7^d
Homogeneous flavoured cream cheese (HOF)	–	–	–	0.7 ± 0.1^d

Table 4
ANOVA of sensory attributes during interoceptive condition. All 14 cheeses were included in the analysis of the product effect with panellist as a random factor. The stars indicate significant differences between samples (* = p < 0.05, ** = p < 0.01, *** = p < 0.001). The + and − signs indicate that an increase of the considered variable lead to an increase (+) or decrease (−) of intensity of the sensory attribute.

	Product effect	Size[a]	Fracture stress[a]	Size*Fracture stress[a]	Concentration[b]
Chewiness	***	+*	+***	+**	
Crumbliness	***		+***	+*	
Crunchiness	***		+***		
Creaminess	***		−***		
Hardness	***		+***		
Lumpiness	***	+ *	+***	+*	+***
Mouth coating	***		−*		
Melting	***		−***		
Particle size	***	+ ***	+***	+*	+***
Stickiness	***				
Mouthfeel heterogeneity	***		+***	+***	+**
Smoothness	***		−***		
Grittiness	***	−***	+***	+***	+**
Bell pepper flavour	***				+***
Dairy flavour	***		−**		
Savoury	***				
Sourness					
Sweetness	***				
Saltiness					

[a] : In these ANOVAs considering the particle size, fracture stress, and their interaction, only cheeses containing model bell pepper pieces were included.
[b] : In this ANOVA considering the particle concentration, only cheeses containing real bell pepper pieces were included.

itself only, but that the evaluation was also influenced by changes in particle hardness.

For cheeses containing real bell pepper pieces, the variation in concentration significantly affected crunchiness and bell pepper flavour (Table 4, see the concentration effect). Intensity of these attributes increased with increasing concentration of bell pepper pieces (RHi). With an increase in concentration of real pieces from 7.5% (RLo) to 30% (RHi), attributes such as lumpiness, particle size, and mouthfeel heterogeneity also showed a significant increase.

These results indicate that consumer sensory perception of novel, heterogeneous cheeses based on somatosensory and gustatory perception was mainly influenced by changes in particle fracture stress (hardness) and concentration, whereas particle size variations affected only few attributes (e.g. grittiness, chewiness and lumpiness).

3.2.2. Exteroceptive condition: Sensory perception of homogeneous and heterogeneous processed cheeses

In the exteroceptive condition, subjects evaluated images of homogeneous and heterogeneous cheeses (Fig. 2) without tasting them, thus ratings were solely based on exteroceptive cues (samples' visual appearance and product description). Almost all attributes were significantly different between cheeses (Table 5, see the first column: product effect). The only exceptions were the attributes sweetness and sourness, which were not significantly different between cheeses. The homogeneous cheese (HO) received the highest expected scores in terms of creaminess, mouth coating, melting, stickiness, smoothness (see Appendix 2). The different colour and description of HOF compared to that of HO led to significantly higher expectations of bell pepper flavour, savouriness and sweetness, and significant lower expectations of creaminess, dairy flavour, and sourness.

Upon addition of model bell pepper pieces (S-; M-; L-), consumers' expected sensory perception of heterogeneous products was largely influenced by the size of added pieces (Table 5, see the size effect). The attributes chewiness, crunchiness, hardness, lumpiness, particle size, mouthfeel heterogeneity and bell pepper flavour showed significantly higher ratings with increasing particle size from small (S-) to large (L-). Only the attributes grittiness and smoothness increased with decreasing particle size. These results indicate that variation in particle size in novel, heterogeneous cheeses can largely affect the expected sensory product properties.

For cheeses containing real pieces, an increase in concentration from 7.5% (RLo) to 30% (RHi) was associated to a significant increase of several attributes such as chewiness, crumbliness, crunchiness, hardness, lumpiness, particle size, mouthfeel heterogeneity and bell pepper flavour (Table 5, see the concentration effect). Conversely, creaminess, smoothness, melting, mouth coating and dairy flavour perception decrease significantly as a result of higher pieces concentration.

We conclude that visual cues as the visual recognition of particles, their size and concentration in combination with product description can largely affect consumer expected perception of novel, heterogeneous products.

Table 5
ANOVA of sensory attributes during exteroceptive condition. All 14 cheeses were included in the analysis of the product effect with panellist as a random factor. The stars indicate significant differences between the samples (* = p < 0.05, ** = p < 0.01, *** = p < 0.001). The + and − signs indicate that an increase of the considered variable lead to an increase (+) or decrease (−) of intensity of the sensory attribute.

	Product effect	Size[a]	Concentration[b]
Chewiness	**	+***	+***
Crumbliness	***		+**
Crunchiness	***	+***	+***
Creaminess	***		−***
Hardness	***	+***	+***
Lumpiness	***	+***	+***
Mouth coating	***		−*
Melting	***		−***
Particle size	***	+***	+***
Stickiness	***		
Mouthfeel heterogeneity	***	+**	+***
Smoothness	***	−**	−***
Grittiness	***	−***	
Bell pepper flavour	***	+***	+***
Dairy flavour	***		−***
Savoury	**		
Sourness			
Sweetness			
Saltiness	**		

[a] : In these ANOVAs considering the particle size, only cheeses containing model bell pepper pieces varying in size (S-; M-; L-) were included.
[b] : In this ANOVA considering the particle concentration, only cheeses containing real bell pepper pieces were included.

Table 6
ANOVA of sensory attributes during Combined condition. All 14 cheeses were included in the analysis of the product effect with panellist as a random factor. The stars indicate significant differences between the samples (* = p < 0.05, ** = p < 0.01, *** = p < 0.001). The + and − signs indicate that an increase of the considered variable lead to an increase (+) or decrease (−) of intensity of the sensory attribute.

	Product effect	Size[a]	Fracture stress[a]	Size*Fracture stress[a]	Concentration[b]
Chewiness	***	+**	+***	+**	+**
Crumbliness	***		+*		+**
Crunchiness	***		+***		+**
Creaminess	***		−***		−*
Hardness	***	+**	+***	+*	
Lumpiness	***	+**	+***		+***
Mouth coating	***		−***	−*	−**
Melting	***		−***		
Particle size	***	+***	+***	+***	+***
Stickiness	***		−*		
Mouthfeel heterogeneity	***		+***		+***
Smoothness	***		−***	−*	−***
Grittiness	***	−***	+**	+**	+*
Bell pepper flavour	***				+***
Dairy flavour	***				−**
Savoury	***				
Sourness	***				
Sweetness	***				+ **
Saltiness	***				

[a] : In these ANOVAs considering the particle size, fracture stress, and their interaction, only cheeses containing model bell pepper pieces were included.
[b] : In this ANOVA considering the particle concentration, only cheeses containing real bell pepper pieces were included.

3.2.3. Combined condition: Sensory perception of homogeneous and heterogeneous processed cheeses

During the third and last condition, participants tasted and evaluated all cheeses while seeing them and having the product description available (combined condition). The evaluation was a result of the visual, somatosensory and gustatory perception, which means that consumers based their evaluations on both exteroceptive and interoceptive cues. All attributes showed significant differences between cheeses (Table 6, see the first column: product effect). As observed for the exteroceptive and interoceptive condition, the attributes creaminess, smoothness and dairy flavour had the highest intensities for the homogeneous sample (HO, see Appendix 3). The addition of bell pepper flavour into the homogenous sample (HFO) decreased the perception of creaminess, mouth coating, melting, stickiness, smoothness and dairy flavour significantly.

In this condition, an increase in size of model bell pepper pieces significantly increased chewiness, hardness, lumpiness, and particle size, while it significantly decreased grittiness perception (Table 6, see the size effect). These results are in line with the ones seen for the interoceptive condition with the exception of the attribute hardness, which was not found to be significantly affected during the interoceptive condition. This suggests that oral hardness evaluation might be influenced by visual cues.

An increase in fracture stress of added pieces from 20 kPa (−20) to 250 kPa (−250) led to significantly higher scores for the attributes chewiness, crumbliness, crunchiness, hardness, lumpiness, particle size, mouthfeel heterogeneity and grittiness and lower values for the attributes creaminess, mouth coating, melting, stickiness and smoothness (Table 6, see fracture stress effect). In line with the interoceptive condition, grittiness was mainly perceived for cheeses containing small pieces (S100, S250). Chewiness, hardness, particle size, and grittiness were significantly augmented by interactions between particle size and fracture stress during the combined condition, whereas perception of mouth coating and smoothness decreased significantly. These results indicate that pieces hardness (fracture stress) can significantly change oral sensory perception of heterogeneous cheeses, independently from the presence of visual cues.

When the concentration of real pieces increased from 7.5% (RLo) to 30% (RHi), hardness, melting, stickiness, savoury, sourness and saltiness showed no significant difference (Table 6, see the concentration effect). In contrast, an increase in particle concentration to 30% led to significantly higher scores for the attributes chewiness, crumbliness, crunchiness, lumpiness, particle size, mouthfeel heterogeneity, grittiness, bell pepper flavour and sweetness, whereas significantly lower scores were found for the perception of creaminess, mouth coating, smoothness, and dairy flavour.

These results show that consumer' sensory perception of heterogeneous processed cheeses was largely influenced by the presence of particles, their fracture stress and concentration when both visual and oral sensorial cues were present. Size of added pieces also affected product hardness perception in such combined inform, which was not observed in the interoceptive condition, suggesting that visual cues may have influenced consumers' texture perception.

3.2.4. Comparison of sensory perception of processed cheeses between exteroceptive, interoceptive and combined condition

3.2.4.1. Influence of exteroceptive cues on sensory properties of novel, heterogeneous cheeses. To investigate how exteroceptive cues affected the sensory properties of novel, heterogeneous cheeses, the attribute scores of the interoceptive condition were subtracted from the ratings of the combined condition. Fig. 3 summarizes the number of cheeses that were found to be significantly different between the two conditions (combined – interoceptive) for all attributes. The presence of exteroceptive cues led to significant differences for texture-related attributes (e.g. crunchiness, particle size, hardness) in several products. For instance, crunchiness increased significantly for eleven out of twelve cheeses containing pieces when comparing the combined with the interoceptive condition. This indicates that exteroceptive cues (i.e. visual recognition of pieces and their descriptions) led to a more intense perception of crunchiness. Similarly, visual and descriptive information affected perception of the attribute "particle size" as five cheeses presented significantly higher scores, while one cheese presented significantly lower scores when the ratings from the combined condition were compared to the ones from the interoceptive condition. These results indicate that the presence of visual cues and product description can significantly influence textural perception. Exteroceptive cues did not affect flavour or taste-related attributes as savouriness, sweetness, saltiness, bell pepper flavour and had a limited effect on the ratings of dairy flavour. We conclude that congruent visual and descriptive cues can influence texture perception

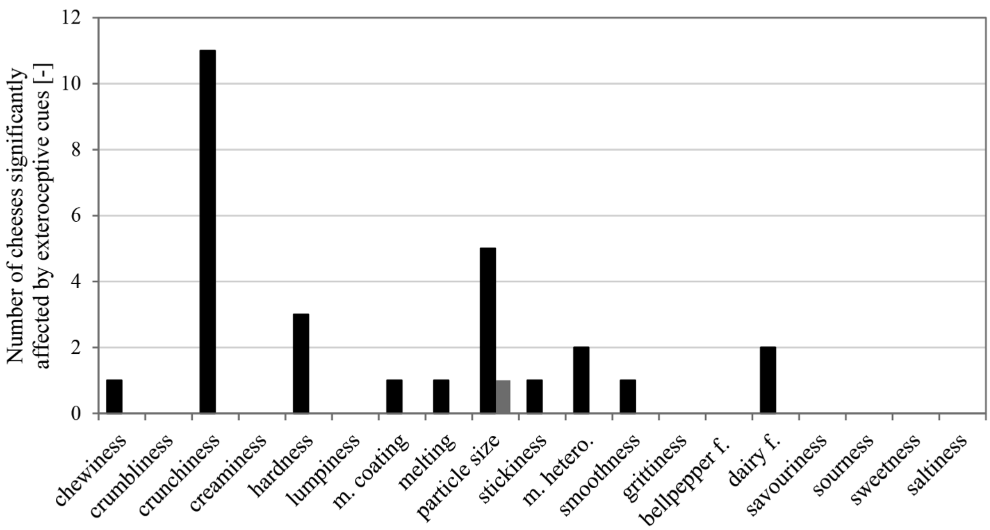

Fig. 3. Effect of exteroceptive cues on the sensory perception of novel, heterogeneous cheeses. Bars indicate the number of cheeses that were found to be significantly different ($p < 0.05$) between combined and interoceptive condition (combined – interoceptive) per attribute. In total, twelve cheeses were evaluated. Black bars indicate the number of cheeses with a positive difference between combined and interoceptive condition per attribute and grey bars indicate the number of cheeses with a negative difference between combined and interoceptive condition per attribute.

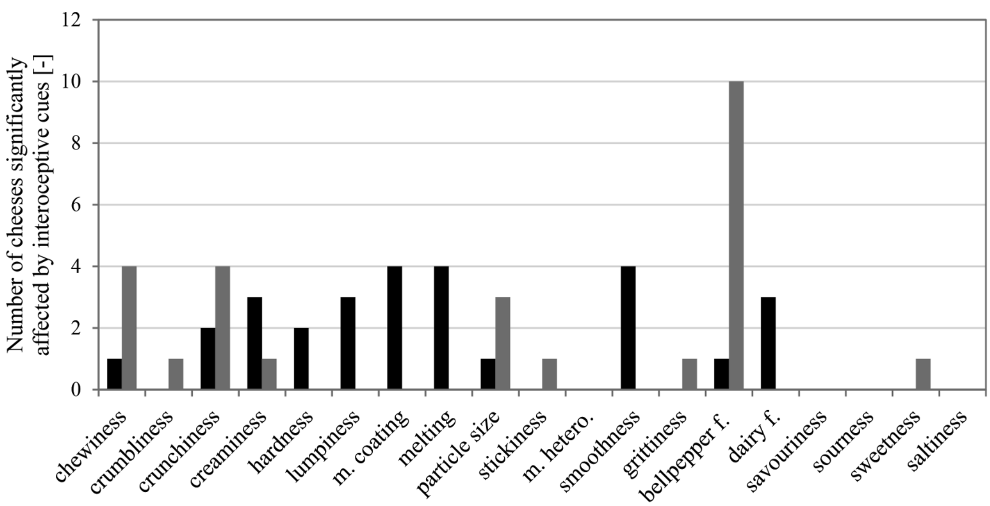

Fig. 4. Effect of interoceptive cues on the sensory perception of novel, heterogeneous cheeses. Bars indicate the number of cheeses that were found to be significantly different ($p < 0.05$) between combined and exteroceptive condition (combined – exteroceptive) per attribute. In total, twelve cheeses were evaluated. Black bars indicate the number of cheeses with a positive difference between combined and interoceptive condition per attribute and grey bars indicate the number of cheeses with a negative difference between combined and exteroceptive condition per attribute.

Table 7
Mean difference in overall liking, flavour liking, texture liking evaluated under interoceptive, exteroceptive and combined conditions. (C-I) denotes Combined minus Interoceptive liking scores; (C-E) denotes Combined minus Expected liking scores. Stars depict significant differences between liking scores at $p < 0.05$.

		Product													
Effect due to:		HO	HOF	S20	S100	S250	M20	M100	M250	L20	L100	L250	RLo	RMe	RHi
Overall liking	exteroceptive cues (C-I)	−0.3	−0.5	0.3	0.4	0.1	0.3	0.5	0.8	0.4	0.0	−0.2	0.4	0.5	0.3
	interoceptive cues (C-E)	**−0.5***	−0.3	0.1	−0.1	−0.6	**0.8***	0.5	0.1	**1.0***	0.3	0.0	0.4	0.3	0.5
Flavour liking	exteroceptive cues (C-I)	−0.4	−0.4	0.4	0.4	0.1	0.2	0.2	**0.6***	0.3	0.0	−0.3	0.2	0.3	0.2
	interoceptive cues (C-E)	**−0.7***	−0.3	0.1	0.0	−0.2	**0.6***	0.5	0.2	0.6	0.3	−0.1	0.1	0.2	0.4
Texture liking	exteroceptive cues (C-I)	−0.1	−0.4	0.5	0.4	0.2	0.6	0.4	**0.9***	**0.7***	0.4	0.3	**0.6***	0.6	0.6
	interoceptive cues (C-E)	−0.5	**−0.7***	0.4	−0.3	−0.7	**1.0***	0.2	−0.1	**1.6***	0.6	0.1	**0.6***	0.2	**0.7***

of heterogeneous processed cheeses, but their contribution to flavour perception is limited.

3.2.4.2. Influence of interoceptive cues on sensory properties of novel, heterogeneous cheeses. The influence of interoceptive cues on sensory properties of novel, heterogeneous cheeses was investigated by subtracting the attribute scores of the exteroceptive condition from the ratings of the combined condition. Fig. 4 shows that interoceptive cues (e.g. textural and flavour properties) played an important role in determining differences in texture and flavour attributes between exteroceptive and combined conditions. A variation of product properties such as particle fracture stress and concentration led to a significant increase (e.g. mouth coating, melting, smoothness, creaminess) or decrease (e.g. chewiness, crunchiness, particle size) of many textural attributes in comparison to what they expected. We relate these differences mainly to the variation in fracture stress of added pieces as this property could not be easily judged from the cheeses' visual appearance.

Differences between the exteroceptive and combined profiles were also seen for flavour attributes, as bell pepper flavour was found to be significantly different for eleven cheeses (Fig. 4). Significant negative differences were found for ten cheeses, meaning that the perceived bell pepper flavour was lower than expected. This possibly indicates that the visual recognition of red bell pepper pieces and related descriptions provoked higher expected perceptions of such flavour during exteroceptive condition than the combined condition. Such large discrepancy in scores was not observed for other flavour attributes as savouriness, sourness, sweetness, saltiness, which differed only between a limited number of cheeses. For these flavour attributes, no descriptive information was provided during the exteroceptive condition and therefore their evaluation was based on visual cues. We conclude that visual and descriptive information regarding product flavour attributes can significantly affect expected perception, although the actual perception will depend on the product properties (interoceptive cues).

3.2.5. *Liking*

In the interoceptive condition, the homogenous cheeses (HO; HOF) had the highest scores for liking overall and liking texture, although these did not differ significantly from cheeses containing soft pieces (see Appendix 5). Flavour liking showed no significant differences for any of the cheeses suggesting that the presence or absence of particles did not affect product flavour appreciation. In the case of texture liking or overall liking, the addition of particles had an effect. Only particle hardness (fracture stress) seemed to play an important role. Overall, for heterogeneous cheeses the presence of hard pieces (high σ_F, −250) led to significantly lower liking scores than the presence of softer pieces. With respect to particle size and particle concentration, the hedonic responses were not influenced.

In the exteroceptive condition, the homogeneous cheese (HO) presented higher values for all hedonic responses (see Appendix 5). Cheeses containing bell pepper flavour (HOF), small pieces (S-) or a low concentration of real bell pepper pieces (RL) were not significantly different from the homogeneous product (HO), and therefore equally liked. An increase in size from small (S-) to large (L-), significantly decreased the expected hedonic response in terms of liking overall and texture. However, for a small increase in particle size from small (S-) to medium (M-), liking overall, flavour, and texture was not significantly different. The hedonic responses were not influenced by a variation in particle concentration. This result suggests that particle size significantly affect the expected palatability of heterogeneous processed cheeses.

In the combined condition, most cheeses showed no significant difference in terms of overall liking (see Appendix 5). Only cheeses containing medium and large sized hard pieces (M250; L250) were liked significantly less (4.7–4.9) than cheeses with small and soft pieces (S20, L20) with scores of 6.1–6.2. The particle size of these soft pieces (−20) did not have an influence on the liking scores, as these were not significantly different from the homogeneous cheeses (HO; HFO). Also with respect to particle concentration, no significant differences in hedonic responses were found. We conclude that consumer hedonic responses for novel, heterogeneous cheeses during interoceptive and combined conditions were similarly affected by product variations as an increase in fracture stress of added pieces resulted in a decrease in liking in both conditions.

3.2.5.1. Influence of exteroceptive and interoceptive cues on liking perceived over the three different conditions. The hedonic responses of the three conditions were compared to investigate the influence of exteroceptive and interoceptive cues on consumer's liking ratings. The results of the comparisons for overall liking, flavour liking and texture liking are summarized in Table 7. Table 7 shows that exteroceptive cues (i.e. product visual appearance and product description) did not significantly contribute to modify overall liking, as none of the C-I values were found to be significantly different. However, overall liking was affected by interoceptive cues, as sample HO, M20 and L20 showed values above 0.5, which were found to be significantly different. In fact, the somatosensory and gustatory cues (i.e. textural and flavour oral sensory perceptions) negatively affected the overall liking rating of the homogeneous cheese (HO) and positively influenced the rating of cheeses containing medium- and large-sized soft pieces (M20, L20). For flavour liking and texture liking, both interoceptive and exteroceptive cues showed an effect by either decreasing (HO, HFO) or increasing (e.g. M250, L20, RLo) their rated scores. Considering that no significant differences were found in terms of overall liking as effect of exteroceptive cues, we conclude that the congruent product visual appearance and product description did not contribute to consumer's hedonic response of homogeneous and novel heterogeneous cheeses. On the contrary, somatosensory and gustatory cues had a relatively large role in determining positive (e.g. cheese containing soft pieces) or negative (homogeneous cheeses) contribution to overall liking, flavour liking and especially texture liking.

4. Discussion

The present study aimed to determine the influence of exteroceptive and interoceptive sensorial cues on consumer preferences and sensory perception of novel, heterogeneous cheeses. Addition of pieces varying in fracture stress and concentration changed significantly the expected and perceived perception of texture and flavour attributes. A variation in particle size mainly influenced the expected profile, while the contribution to product sensory perception was limited during the interoceptive and combined conditions. During these latter conditions, an increase in particle fracture stress or concentration led to lower perceived intensities for attributes mostly related to homogeneity (e.g. creaminess, mouth coating, smoothness), whereas the intensity increased with an increase in particle fracture stress for heterogeneity-related attributes (e.g. chewiness, crunchiness, lumpiness) as previously found in our studies on heterogeneous foods (Santagiuliana et al., 2018, 2019). The paired comparisons of the different conditions have shown that both visual cues and somatosensory and gustatory cues can significantly influence texture and flavour perception of homogeneous and heterogeneous cheeses, indicating that both visual and oral sensorial cues can be used to tune the perception of a heterogeneous product. These findings support the notion that perception of foods depends on the integration of multisensory cues (Prescott, 2015; Spence & Shankar, 2010; Spence, 2016; Verhagen & Engelen, 2006; Zampini & Spence, 2005; Zampini, Wantling, Phillips, & Spence, 2008) and they prove that visual cues affect consumer texture perception.

The hedonic results suggest that exteroceptive cues provided in this experiment (visual recognition of particle and objective product description) had no effect on perceived liking of the tested cheeses. However, it should be considered that a significant decrease in the expected hedonic responses was observed when the particle size increased from small to large. These findings suggest that for novel heterogeneous foods, the selection of particle size will impact the consumer hedonic expectations and possibly affect the consumer's willingness to try the novel product. We conclude that for the development of novel, heterogeneous cheeses, small-medium sized particles should be used to increase willingness of people to try the new product.

Particle fracture stress significantly affected product liking as the presence of hard pieces (σ_F: 250) decreased significantly the consumer' hedonic response. The product used in our study (processed cream cheese) is usually homogeneous in texture. Hence, consumers expect its texture to be homogeneous. Before the sensory test, consumers were informed that they were about to assess a processed cream cheese that may contain bell pepper (no information regarding the form of bell pepper was provided). We observed that consumers preferred products that were closer to the familiar texture of the original product as large differences from the original product gave rise to a decrease in liking. This observation is supported by the study of Hong et al. (2014), in which it was shown that texture preferences of traditional Korean cookies were strongly correlated with familiarity scores of consumers from different countries (Korea, Japan and France). The authors suggested that the preferences for certain textural properties of food depend on the consumers' previous experience with similar products. We demonstrated that for cheeses containing pieces with no/little mechanical contrast, not only product liking was maintained, but disconfirmations of sensory expectations (e.g. expected bell pepper flavour) did not give rise to a decrease in hedonic responses. Although this study did not show large variations in liking of the novel products between the first and last condition, longer periods of repeated exposure could possibly further improve the appreciation for the novel cheeses by the consumers (Hekkert, Thurgood, & Whitfield, 2013; Pliner, 1982).

This study not only provides important insights into the variables to take into account when designing novel heterogeneous products, but it highlights important consequences of macro particles addition (i.e., pieces) on consumer perception. When model bell pepper or real bell pepper pieces were added into the processed cheese, the perception of some positive attributes (e.g. creaminess, smoothness) was reduced, although this did not affect product liking for most cheeses. The incorporation of pieces could be used to design products for a specific purpose. For example, healthier products could be obtained by engineering gel pieces with specific macro/micronutrients (e.g. protein, fibres, vitamins, dietary minerals) that can be easily added into a homogeneous matrix to obtain target nutrition for specific consumer groups (i.e. elderlies). Furthermore, the addition of pieces could beneficially affect oral processing behaviour, i.e. a prolonged oral processing time (van Eck et al., 2019). A prolongation of oral processing time could possibly yield different oro-sensory exposures, which might eventually influence satiation (Morell, Tárrega, Foegeding, & Fiszman, 2018; Tarrega, Marcano, & Fiszman, 2016).

5. Conclusions

This study discussed the effect of addition of bell pepper pieces varying in size, hardness (fracture stress), and concentration into processed cheeses on sensory perception and liking, while decoupling the influence of visual and oral sensory cues on consumer' response. Sensory perception of heterogeneities in a processed cheese was largely dominated by the fracture stress and concentration of the added bell pepper pieces. An increase in fracture stress from 20 to 250 kPa led to an increase in perception of a variety of heterogeneity-related attributes (chewiness, crumbliness, crunchiness, hardness, lumpiness and mouthfeel heterogeneity). A variation in particle size influenced the expected product sensory profile but had a minor role in varying actual sensory perception. With respect to liking, consumers preferred homogeneous cheeses and heterogeneous cheeses containing soft pieces independently from their size. An increase in particle size from $2 \times 2 \times 2$ mm to $6 \times 6 \times 6$ mm significantly decreased the expected palatability of heterogeneous processed cheeses. Through the comparison of the tested conditions (interoceptive, exteroceptive, combined), we determined that both exteroceptive cues (visual information) and interoceptive cues (somatosensory and gustatory) can significantly influence texture and flavour perception of heterogeneous processed cheeses. On the contrary, visual appearance and product description did not contribute to the consumer's hedonic response of novel, heterogeneous cheeses. Somatosensory and gustatory cues, which were mainly determined by properties of the bell pepper pieces (fracture stress, concentration), had a large role in determining the consumer's hedonic responses. We conclude that for novel heterogeneous processed cheeses, the size of added pieces mainly determined the expected liking and possibly affect consumer's attractiveness to the new product. However, actual product liking of such novel products was determined by particle texture and matching of consumers' expectation for the specific product type.

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Declaration of Competing Interest

The authors have declared that no competing interests exist.

Appendix

Appendix 1
Explanation of attribute descriptors used during the sensory study.

Descriptor	Definition
Texture	
Chewiness	The amount of work required to masticate the sample (or its components) into a state ready for swallowing
Creaminess	Sensation of a thick, smooth and velvety texture in the mouth
Crunchiness	Making a loud sound when chewed or crushed
Crumbliness	The extent to which the samples breaks into smaller pieces or fragments
Hardness	Force required to compress and/or break the sample (or its components) between the teeth
Lumpiness	Perception of lumps (large irregularity) in the sample
Grittiness	Perception of small granules (sandy/grainy) in the sample
Melting	The degree to which the sample melts during mastication
Mouth coating	Sensation of a layer covering the mouth (film sensation inside the mouth)
Mouthfeel heterogeneity	Perception of texture contrast in the mouth. Sensory perception of different structures in the mouth during consumption (i.e. one sample contains soft and hard parts)
Smooth	A uniform perception of the product in the mouth during mastication
Sticky	The degree to which the sample sticks in the mouth or between the teeth
Particle size	Perception of the particles dimension in the mouth on a scale from small to large
Flavour	
Bell pepper flavour	Perception of bell pepper aroma
Dairy flavour	Perception of milky/creamy aroma
Saltiness	Perception of a salty flavour in the mouth (salt-like)
Savouriness	Perception of glutamate (umami), spices and herbs (broth-like)
Sourness	Perception of a sour flavour in the mouth
Sweetness	Perception of a sweet flavour in the mouth (sugar-like)

Appendix 2

Mean perceived intensity scores of all attributes in the exteroceptive condition. The superscript letters obtained from Tukey's HSD indicate a significant difference between samples ($p < 0.05$) for an attribute.

		Chewiness	Crumbliness	Crunchiness	Creaminess	Hardness	Lumpiness	Mouth coating	Melting	Particle size
Control samples	HO	2.0^{e}	1.3^{c}	0.4^{d}	7.1^{a}	1.4^{c}	1.0^{c}	6.2^{a}	6.1^{a}	0.9^{e}
	HOF	2.2^{de}	1.5^{c}	0.6^{d}	6.5^{b}	1.6^{bc}	1.2^{c}	6.0^{a}	6.0^{a}	1.0^{e}
Bell pepper gels	S-	2.9^{bc}	3.3^{ab}	1.9^{bc}	5.5^{c}	1.8^{bc}	3.9^{b}	4.7^{bc}	4.5^{bc}	3.1^{d}
	M-	3.2^{ab}	3.1^{ab}	2.4^{b}	5.1^{cd}	2.6^{a}	4.9^{a}	4.5^{bc}	4.1^{cd}	5.3^{b}
	L-	3.9^{a}	3.2^{ab}	3.1^{a}	5.2^{cd}	2.9^{a}	5.3^{a}	4.4^{bc}	4.3^{cd}	6.8^{a}
Real bell pepper particles	RLo	2.7^{cd}	2.6^{b}	1.7^{c}	6.0^{b}	2.1^{b}	3.7^{b}	4.9^{b}	5.0^{b}	4.1^{c}
	RHi	3.9^{a}	3.6^{a}	3.1^{a}	4.7^{d}	3.0^{a}	5.5^{a}	4.2^{c}	3.8^{d}	6.1^{a}

	Stickiness	Mouthfeel heteroge-neity	Smoothness	Grittiness	Bell pepper flavour	Dairy flavour	Savoury	Sourness	Sweetness	Saltiness
Control samples	4.8^{a}	1.1^{d}	7.0^{a}	1.2^{c}	0.4^{e}	7.5^{a}	2.8^{b}	2.9	2.8^{b}	3.3
	4.8^{a}	1.8^{d}	6.9^{a}	1.3^{c}	6.4^{bc}	5.3^{de}	3.8^{a}	2.5	3.7^{a}	3.2
Bell pepper gels	3.9^{b}	5.7^{b}	4.1^{bc}	3.7^{a}	5.8^{c}	5.9^{bc}	3.5^{a}	2.7	3.3^{ab}	3.1
	3.6^{b}	5.9^{ab}	3.6^{cd}	2.3^{b}	6.2^{bc}	5.7^{cd}	3.7^{a}	2.7	3.4^{ab}	3.1
	3.8^{b}	6.3^{ab}	3.6^{cd}	2.4^{b}	6.7^{b}	5.8^{cd}	3.6^{a}	2.6	3.7^{a}	3.2
Real bell pepper particles	3.9^{b}	4.8^{c}	4.7^{b}	2.4^{b}	4.6^{d}	6.4^{b}	3.2^{ab}	2.7	3.1^{b}	3.0
	3.5^{b}	6.7^{a}	3.2^{d}	2.9^{b}	7.4^{a}	5.1^{e}	3.6^{a}	2.6	3.7^{a}	3.1

Appendix 3

Mean perceived intensity scores of all attributes in the interoceptive condition. The superscript letters obtained from Tukey's HSD indicate a significant difference between samples ($p < 0.05$) for an attribute.

		Chewiness	Crumbliness	Crunchiness	Creaminess	Hardness	Lumpiness	Mouth coating	Melting	Particle size
Control samples	HO	1.9^{cd}	1.1^{g}	0.4^{g}	6.8^{a}	1.2^{f}	1.4^{f}	5.9^{a}	5.5^{a}	1.4^{g}
	HOF	2.1^{cd}	1.2^{fg}	0.3^{g}	6.2^{ab}	1.6^{bcdef}	1.4^{f}	5.6^{ab}	4.8^{ab}	1.4^{g}
Small sized bell pepper gels	S20	1.7^{d}	2.5^{bcde}	0.5^{fg}	5.6^{bcde}	1.5^{cdef}	2.5^{f}	4.9^{bcd}	4.7^{abc}	2.4^{f}
	S100	2.2^{bcd}	3.2^{ab}	0.9^{defg}	5.5^{bcde}	1.6^{bcdef}	4.1^{bcd}	4.6^{cd}	4.6^{bc}	3.2^{def}
	S250	2.7^{abc}	3.6^{a}	1.2^{def}	4.9^{ef}	1.9^{abcde}	4.5^{abc}	4.6^{cd}	4.2^{bcd}	3.8^{cde}
Medium sized bell pepper gels	M20	2.1^{cd}	2.2^{de}	0.8^{efg}	5.8^{bc}	1.3^{def}	3.3^{de}	4.8^{bcd}	4.8^{ab}	2.8^{ef}
	M100	2.6^{abc}	3.0^{abcd}	1.2^{def}	5.2^{cdef}	2.0^{abcd}	4.5^{abc}	4.8^{bcd}	4.3^{bcd}	4.5^{abc}
	M250	3.1^{a}	3.3^{ab}	1.2^{de}	4.5^{f}	2.2^{ab}	5.3^{a}	4.1^{d}	3.8^{d}	4.8^{ad}
Large sized bell pepper gels	L20	2.0^{cd}	2.3^{cde}	0.7^{efg}	5.8^{bc}	1.3^{ef}	3.0^{e}	4.7^{cd}	4.8^{ab}	3.1^{def}
	L100	2.5^{abc}	3.0^{abcd}	1.2^{def}	5.2^{cdef}	2.2^{abc}	4.6^{abc}	4.6^{cd}	4.4^{bcd}	4.6^{abc}
	L250	3.2^{a}	3.2^{abc}	1.5^{cd}	4.9^{ef}	2.2^{ab}	4.6^{abc}	4.3^{d}	3.9^{cd}	4.9^{a}
Real bell pepper particles	RLo	2.6^{abc}	2.0^{ef}	2.0^{bc}	5.7^{bcd}	1.9^{abcde}	3.3^{de}	5.0^{bc}	4.6^{bcd}	3.9^{bcd}
	RMe	3.0^{ab}	2.4^{bcde}	2.3^{ab}	5.4^{cde}	2.3^{a}	3.9^{cd}	4.8^{cd}	4.4^{bcd}	4.4^{abc}
	RHi	3.3^{a}	2.7^{abcde}	2.7^{a}	5.0^{def}	1.8^{abcdef}	5.0^{ab}	4.5^{cd}	4.3^{bcd}	5.3^{a}

	Stickiness	Mouthfeel heterogeneity	Smoothness	Grittiness	Bell pepper flavour	Dairy flavour	Savoury	Sourness	Sweetness	Saltiness
Control samples	4.4^{a}	1.8^{e}	6.4^{a}	1.3^{e}	1.3^{d}	6.9^{a}	3.2	2.7	2.5^{b}	3.6
	4.0^{ab}	2.3^{e}	6.1^{ab}	1.3^{e}	3.2^{c}	6.1^{b}	3.4	2.7	2.9^{ab}	3.2
Small sized bell pepper gels	3.2^{bcd}	3.8^{d}	4.9^{cd}	3.1^{b}	3.8^{bc}	5.9^{bcd}	3.5	2.7	3.0^{ab}	3.1
	3.2^{bcd}	5.0^{abc}	4.1^{defg}	4.7^{a}	4.4^{b}	5.8^{bcd}	3.8	2.6	3.2^{ab}	3.4
	2.8^{d}	5.3^{ab}	3.6^{fg}	4.6^{a}	4.3^{b}	5.4^{bcd}	3.8	2.6	2.8^{ab}	3.3
Medium sized bell pepper gels	3.3^{bcd}	4.2^{cd}	5.2^{bc}	2.5^{bcd}	4.5^{b}	5.8^{bcd}	3.6	2.6	3.3^{a}	3.4
	3.3^{bcd}	5.3^{ab}	4.1^{defg}	2.9^{bc}	4.6^{b}	5.8^{bcd}	3.8	2.7	3.1^{ab}	3.4
	3.0^{cd}	5.6^{ad}	3.3^{g}	3.4^{b}	4.2^{b}	5.2^{d}	3.0	3.4	2.4^{ab}	3.0
Large sized bell pepper gels	3.3^{bcd}	3.8^{d}	4.8^{cde}	2.1^{cde}	4.5^{b}	5.8^{bcd}	3.2	2.9	3.1^{ab}	3.0
	3.1^{cd}	5.1^{abc}	4.0^{defg}	2.8^{bc}	4.3^{b}	5.6^{bcd}	3.5	2.7	3.1^{ab}	3.3
	3.1^{cd}	5.3^{ab}	3.5^{fg}	2.8^{bc}	4.5^{b}	5.2^{cd}	3.3	2.6	3.2^{ab}	3.4
Real bell pepper particles	3.7^{abc}	4.7^{bcd}	4.5^{cde}	1.8^{de}	4.6^{b}	5.8^{bcd}	3.7	2.7	2.9^{ab}	3.5
	3.4^{bcd}	5.4^{ab}	4.2^{def}	2.8^{bc}	5.6^{a}	5.4^{bcd}	4.0	2.5	3.0^{ab}	3.3
	3.0^{cd}	5.8^{a}	3.9^{efg}	2.7^{bcd}	6.4^{a}	5.4^{bcd}	3.9	2.7	3.2^{a}	3.1

Appendix 4

Mean perceived intensity scores of all attributes in the combined condition. The superscript letters obtained from Tukey's HSD indicate a significant difference between samples ($p < 0.05$) for an attribute.

		Chewiness	Crumbliness	Crunchiness	Creaminess	Hardness	Lumpiness	Mouth coating	Melting	Particle size
Control samples	HO	2.1^{hi}	1.1^{f}	0.4^{h}	7.2^{a}	1.4^{fg}	0.9^{f}	6.1^{a}	5.8^{a}	0.6^{g}
	HOF	2.2^{ghi}	1.8^{ef}	0.5^{h}	5.2^{efg}	1.9^{cdefg}	1.2^{f}	5.1^{bcde}	4.3^{de}	0.9^{g}
Small sized bell pepper gels	S20	1.9^{i}	2.9^{abc}	1.1^{gh}	6.1^{bc}	1.3^{g}	2.9^{e}	5.4^{bc}	5.4^{ab}	2.5^{f}
	S100	2.7^{defgh}	3.5^{a}	1.9^{def}	5.2^{fg}	2.1^{cde}	4^{bc}	4.6^{de}	4.8^{bcde}	2.7^{f}
	S250	3.1^{cdef}	3.3^{ab}	2.1^{de}	4.8^{g}	2.3^{bcd}	3.9^{bcd}	4.4^{e}	4.1^{e}	2.9^{ef}
Medium sized bell pepper gels	M20	2.3^{fghi}	2.6^{bcd}	1.4^{efg}	6^{bcd}	1.6^{defg}	3.3^{cde}	5.3^{bcd}	5.2^{abc}	3.8^{d}
	M100	3.1^{bcde}	2.9^{abc}	2.3^{cd}	5.4^{cdefg}	2.5^{abc}	4.4^{ab}	4.5^{de}	4.4^{cde}	4.8^{c}
	M250	3.5^{abc}	3.3^{ab}	2.5^{cd}	4.9^{fg}	2.9^{ab}	4.9^{a}	4.6^{de}	4.1^{e}	5.1^{bc}
Large sized bell pepper gels	L20	2.3^{efghi}	2.7^{bcd}	1.3^{fg}	6.2^{b}	1.5^{efg}	3.3^{cde}	5.5^{ab}	5.4^{ab}	4.9^{c}
	L100	3.2^{bcd}	3.0^{abc}	2.3^{cd}	5.3^{defg}	2.4^{abc}	4.8^{ab}	4.8^{cde}	4.5^{cde}	5.9^{ab}
	L250	3.8^{ab}	3.3^{ab}	2.8^{bc}	4.9^{fg}	3.0^{a}	5.1^{a}	4.5^{de}	4.2^{e}	6.3^{a}
Real bell pepper particles	RLo	2.9^{cdefg}	1.9^{de}	2.5^{cd}	5.9^{bcde}	2^{cdef}	3.1^{de}	5.6^{ab}	5.1^{bcd}	3.7^{de}
	RMe	3.5^{abcd}	2.3^{cde}	3.4^{ab}	5.6^{bcdef}	2.4^{abc}	4.3^{ab}	5.1^{bcde}	4.8^{bcde}	4.9^{c}
	RHi	4.1^{a}	2.9^{abc}	3.8^{a}	5.2^{fg}	2.5^{abc}	4.8^{ab}	4.5^{e}	4.6^{cde}	6.0^{a}

	Stickiness	Mouthfeel heterogeneity	Smoothness	Grittiness	Bell pepper flavour	Dairy flavour	Savoury	Sourness	Sweetness	Saltiness
Control samples	4.6^{a}	1.0^{c}	7.2^{a}	0.8^{e}	0.3^{e}	7.3^{a}	2.8^{b}	3.8^{a}	2.2^{d}	3.7^{a}
	3.7^{b}	1.6^{c}	5.6^{b}	2.2^{cd}	4.9^{bcd}	5.4^{d}	3.6^{a}	2.9^{b}	3.2^{bc}	3.6^{ab}
Small sized bell pepper gels	3.7^{b}	4.1^{b}	5.4^{b}	3.3^{b}	4.4^{cd}	6.5^{b}	3.7^{a}	2.9^{b}	3.4^{abc}	3.3^{abc}
	3.5^{b}	5.7^{a}	4.2^{d}	4.2^{a}	4.8^{cd}	6.2^{bc}	3.5^{a}	2.7^{b}	3.7^{ab}	3.5^{ab}
	3.2^{b}	6.1^{a}	3.5^{d}	4.5^{a}	4.8^{cd}	6.1^{bc}	3.5^{a}	2.5^{b}	3.3^{bc}	2.9^{bc}
Medium sized bell pepper gels	3.9^{ab}	3.9^{b}	5.2^{b}	2.3^{cd}	4.8^{cd}	6.2^{b}	3.6^{a}	2.7^{b}	3.6^{abc}	3.4^{abc}
	3.4^{b}	5.6^{a}	4.0^{d}	2.9^{bc}	5.1^{bcd}	6.2^{bc}	3.6^{a}	3.1^{b}	3.4^{abc}	3.5^{ab}
	3.3^{b}	6.1^{a}	3.5^{d}	2.6^{bcd}	4.6^{cd}	6.0^{bcd}	3.4^{a}	3.5^{b}	2.9^{bc}	3.3^{abc}
Large sized bell pepper gels	3.8^{b}	4.1^{b}	5.4^{b}	2^{cd}	4.9^{bcd}	6.4^{b}	$3.^{5a}$	2.7^{b}	3.7^{ab}	3.2^{abc}
	3.7^{b}	5.5^{a}	4.3^{cd}	2.5^{bcd}	5.2^{bc}	6.1^{bc}	3.6^{a}	3.0^{b}	3.4^{abc}	3.2^{abc}
	3.6^{b}	6.1^{a}	3.7^{d}	2.4^{cd}	4.9^{bcd}	6.1^{bc}	3.5^{a}	3.0^{b}	3.4^{abc}	3.3^{abc}
Real bell pepper particles	3.9^{ab}	4.0^{b}	5.2^{bc}	1.8^{d}	4.3^{d}	6.5^{b}	3.3^{ab}	3.0^{b}	2.9^{c}	3.4^{abc}
	3.8^{b}	5.4^{a}	4.2^{d}	2.2^{cd}	5.7^{b}	5.9^{bcd}	3.6^{a}	2.6^{b}	3.6^{ab}	2.9^{bc}
	3.2^{b}	6.2^{a}	3.9^{d}	2.6^{bcd}	6.8^{a}	5.5^{cd}	3.6^{a}	2.6^{b}	4.0^{a}	2.8^{c}

Appendix 5

Mean perceived liking intensity scores of the different attributes obtained with ANOVA for the Interoceptive, Expected and Combined condition. The superscript letters obtained from Tukey's HSD indicate significant difference between the samples ($p < 0.05$).

	Interoceptive			Exteroceptive			Combined		
	Liking Overall	Liking Flavour	Liking Texture	Liking Overall	Liking Flavour	Liking Texture	Liking Overall	Liking Flavour	Liking Texture
HO	6.5^{a}	6.4	6.3^{a}	6.7^{a}	6.7^{a}	6.8^{a}	6.2^{a}	6.0	6.3^{a}
HOF	6.3^{ab}	6.3	5.9^{ab}	6.1^{abc}	6.2^{ab}	6.2^{ab}	5.8^{ab}	5.9	5.5^{ab}
S20	6.1^{ab}	6.2	5.6^{abc}	6.3^{ab}	6.6^{ab}	5.7^{bc}	6.4^{ab}	6.7	6.1^{abc}
S100	5.8^{abc}	6.1	5.0^{cd}				6.2^{abc}	6.6	5.4^{bc}
S250	5.7^{abc}	6.3	4.7^{cde}				5.8^{abc}	6.4	5.0^{cd}
M20	6.^{1ab}	6.3	5.5^{abc}	5.7^{bc}	6.1^{ab}	5.0^{cd}	6.4^{ab}	6.6	6.1^{abc}
M100	5.7^{abc}	6.3	4.8^{cde}				6.2^{abc}	6.6	5.2^{cde}
M250	5.0^{c}	6.1	4.0^{e}				5.0^{c}	5.7	4.0^{e}
L20	6.1^{ab}	6.2	5.5^{abc}	5.4^{c}	5.9^{b}	4.6^{d}	6.5^{ab}	6.5	6.2^{abc}
L100	5.8^{abc}	6.2	4.8^{cde}				5.7^{abc}	6.2	5.2^{cde}
L250	5.6^{bc}	6.2	4.4^{de}				5.4^{bc}	5.9	4.7^{de}
RLo	6.0^{ab}	6.2	5.3^{bc}	6.0^{abc}	6.3^{ab}	5.4^{cd}	6.4^{ab}	6.4	5.9^{bc}
RMe	5.8^{ab}	6.2	5.0^{cd}	–	–	–	6.3^{ab}	6.5	5.6^{cd}
RHi	5.6^{bc}	6.2	4.8^{cde}	5.4^{c}	6.0^{b}	4.6^{d}	5.9^{bc}	6.4	5.3^{cd}

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