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Original Article

Modulating taste and trigeminal sensations in food models to assess individual variations in sensory and hedonic responses to food

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S U M M A R Y

Background & Aims: Adoption and maintenance of healthy diets among vulnerable populations, such as cancer patients, can be challenging. The preliminary study of sensory-hedonic responses through the modulation of key sensory properties in food models in healthy participants, could contribute to explore a new method to answer to nutrition in cancer's issue. Sensory and hedonic responses are affected, among other factors, by sensory responsiveness and psychological traits.

With the perspective of using the approach to investigate individual differences in sensory and hedonic responses in cancer patients undergoing chemotherapy experiencing taste alterations, two food models were designed and pre-tested with healthy participants.

Methods: 223 healthy participants (68% women, 18–70 y.o., 40 mean age; 118 from France and 105 from Italy) participated in the study. Sensory-hedonic responses to four apple juice samples, spiked with four increasing concentrations of mint syrup corresponding to variations in perceived coolness, and to four chickpea cream samples, spiked with glucose-fructose syrup to modulate the perception of sweetness in contrast to the sourness induced by citric acid, were measured. Food neophobia, disgust sensitivity,

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sensitivity to reward and PROP (6-n-propylthiouracil) responsiveness were measured.
Results: Sensory-hedonic responses to the food models were found to vary across participants and allowed to identify different groups. Two clusters were established for the apple juice differing in liking for the coolest sample: Moderate and Extreme Coolness Dislikers. Instead, three clusters were identified for the chickpea cream: 1) Sweet Likers – perceiving sweet as less intense in all samples and showing liking increments with increasing sweetness and decreasing sourness; 2) Sweet Dislikers – tended to perceive higher sweetness intensity and liking raised with increasing sourness and decreasing sweetness; 3) Inverted U-Shaped – with an optimum liking corresponding to intermediate concentrations. Clusters' differences were found in age and in sensitivity to reward, with Sweet Likers being the youngest and the most sensitive to reward. The approach allowed identifying the level of sensory properties that minimized rejection and maximized liking within and across clusters.
Conclusions: The two food models will be adopted to study the effect of cancer therapy on taste perception and liking responses, for the development of tailor-made products well accepted by patients experiencing taste alterations.

Introduction

Sensory-hedonic responses to food, constituted by a sensory (taste responsiveness) and a hedonic component (food liking), provide insights on individuals' food behaviour. Taste responsiveness is the supra-threshold substance concentration's perceived intensity [1] and affects the pleasure derived from orosensory stimulation of food: food liking [2,3]. The modulation of food prototypes key sensations' allows to study sensory-hedonic responses and consumer segmentation, providing information about food preferences among individuals.

Food models are food matrices where the modulation of target sensations produces perception and liking variations [3–10], providing a higher degree of ecological validity to aqueous solutions by considering more complex interaction of factors. Notwithstanding their efficacy in sensory-hedonic individual differences studies [3–6], their use to study sensory alterations in cancer patients' is scarce [11–13].

Interindividual variability in taste, smell and trigeminal sensations is a potential driver of food choices in sensory testing [14]. The response to the bitter taste of 6-n-propylthiouracil (PROP) is one of the most studied phenotypic markers of responsiveness to oral stimuli [15,16]. Indeed, responses to PROP reflect responses to other taste sensations and a variety of oral and olfactory irritant and textural attributes, in solutions and food/drinks [15]. Psychological traits, such as food neophobia, sensitivity to visceral disgust and sensitivity to reward, also affect food preferences [5,17–19] and might act as facilitators/barriers toward the consumption of certain products [19–26].

The adoption or maintenance of a healthy diet in vulnerable populations experiencing taste alterations is increasingly challenging. Among the aspects contributing to cancer patients' malnutrition, sensory alterations play a major role [27–29]. Sensory alterations can affect taste and/or smell in different ways, increasing or decreasing sensory perception (e.g. Ipergeusia/ipogeusia) [30]. During cancer treatment, changes in sweet perception are common [29,31,32], though not reported by all patients [11,12], while results on sour taste alterations are less clear [29]. Although alterations of the trigeminal system due to chemotherapy treatment have not been often reported, few studies showed that cancer patients suffering from alterations might seek flavor enhancement by using trigeminal sensations of burning and cooling [33–37].

The primary study aim was to design and preliminarily test in healthy participants two food models (apple juice and chickpea cream), developed within the context of the Mediterranean Diet, varying in taste and chemosensory target sensations, specifically designed to investigate sensory-hedonic responses in cancer patients. Principles of Mediterranean Diet pattern have first been described in the 1950–60s as a typical dietary habit of some populations bordering the Mediterranean Sea in the south of Europe characterized by frugal living style [38]. Mediterranean Diet principles have been associated to lower rates of mortality and incidence of cardiovascular disease [39] and could represent an ideal framework for the development of new solutions tailored to cancer patients.

This approach agrees with the adopted practice in medical studies in which new procedures are first tested on a healthy population to provide preliminary evidence for future development of the method to be applied with targeted patients [40–43]. Target sensations were identified as the basic taste of sweet and acid, based on previous studies reporting alterations in these tastes, and coolness was selected for being scarcely investigated.

As secondary objective, personality traits and PROP responsiveness' impact on sensory-hedonic responses was also considered to allow a finer analysis of interindividual differences.

Materials and methods

Participants

A total of 223 participants were recruited (68% women, 18–70 y.o.; 118 from France and 105 from Italy) with a mean age of 40 years old (SD = 13.4). 154 participants (67% women, mean age = 40 y.o., SD = 14) tasted the apple juice food model and 179 participants (66% women, mean age = 42 y.o., SD = 13.4) the chickpea cream. Some participants completed the test on both food models, while participants with time constraints were given the possibility to test just one food model. All participants completed the questionnaires and did the PROP test. Data were collected in three cities in different geographical areas of the Mediterranean region (France: Nice and Lyon; Italy: Florence). Inclusion criteria were being aged between 18-70 years old and living in the cities of data collection (Mediterranean area). Exclusion criteria were being less than 18 years old, more than 70 years old, pregnancy or breastfeeding at the time of testing and having allergies for the used ingredients. Participants were recruited by means of announcements, social networks, participant universities and research centers' websites. All participants provided informed, written consent prior to participation, in line with the General Data Protection Regulation (GDPR) 2016/679. The study was conducted according to the guidelines laid down by the Declaration of Helsinki for medical research involving humans and it was approved by the Research Protocol Committee of Institut Paul Bocuse according to the ethics guidelines (Loi Jardé, n∘ 2012-300, 12 March 2012). Participants received a gift card payment to motivate their participation in the study.

Methods of data collection

Participants were asked to fill in an online questionnaire before attending an in-person session (Sensory Lab – University of Florence, Institut Lyfe Research - Lyon, Antoine Lacassagne Hospital – Nice). The online questionnaires (10–20 minutes) included socio-demographic information (self-reported gender and age), Food Neophobia Scale, Disgust Scale and Sensitivity to Reward Questionnaire. Before starting the sensory procedures, participants were provided with specific instructions about the use of the scales and were familiarized with the target sensations. The experimenter explained orally how to use the scale and asked participants some examples for the target sensations to check they were correctly understood. The laboratory session (1 hour duration for both food models) was composed of sensory tests: evaluation of liking and intensity of sensations of the food models. Participants were free to evaluate one or two food ranges. Between the two food models (when the participants evaluated both) a 10-minute break was established. Participants completed the PROP test at the end (Table 1).

Sensory tests

Food models

Food model recipes were developed during a series of cooking sessions at the Institut Lyfe Research Center in Lyon in collaboration with the University of Florence team, using commercially available base ingredients. Recipes selection was based on the following constraints: the food model had to be easily replicable in time and different contexts, be as “standardized” and constant over time as possible, ingredients had to be largely consumed by the Mediterranean population both in France and Italy, and easy to handle. Furthermore, they were selected as the most appropriate food models to test the responses towards target sensations that were pointed out in literature as sensible for cancer patients experiencing sensory alterations (sweetness, sourness and coolness as a trigeminal sensation). Food model recipes are presented in Table 2.

Before the evaluation, participants were instructed on the recognition of target sensations and on the use of the Labeled Affective Magnitude Scale (LAM) [44] and Labeled Magnitude Scale (LMS) [45]. For the LAM, the scale anchors were spaced from the “greatest imaginable dislike” (0) to the “greatest imaginable like” (100), with “neither liked nor disliked” set at 50. For the LMS, the bottom of the scale reflected “no sensation” while the top of the scale represented the “strongest imaginable” referring to oral sensations that the participants could imagine experiencing. Participants were provided with examples for very strong sensations imagining the spicy of eating a handful of fresh chili pepper or a full spoon of wasabi and the sourness of squeezing a whole lemon in the mouth.

Apple juice (AJ). Preparation: samples – AJ0, AJ15, AJ60 and AJ240 – were prepared the same day/the day before the test and served at room temperature dissolving different concentrations of glucose-fructose syrup (AJ0 = 240; AJ15 = 226; AJ60 = 180; AJ240 = 0 g/Kg), in order to produce a constant level of sweetness across all the samples, and mint syrup (AJ0 = 0; AJ15 = 15; AJ60 = 60; AJ240 = 240 g/Kg), in order to produce a variation for coolness sensation. Texture and viscosity were maintained the same for all the different samples. The final amount of apple juice in the food model was the same (Table 2). The glucose-fructose syrup and the mint syrup had the same amount of sugar, with the difference that mint extract was present in the mint syrup. The ingredients were mixed using a magnetic stirrer and stored at room temperature two hours before the test began. Concentrations were selected to elicit a variation in the strength of coolness (from weak to strong), based on preliminary tests.

Testing procedure: participants were presented with the juice samples (25 g) at room temperature, served in small covered plastic glasses coded with a three-digit code. Samples presentation order was balanced. Participants were instructed to take a full sip, wait 10 sec then swallow and evaluate the liking of the sample. After the liking evaluation of the four samples, participants were instructed to take a second full sip, wait 7 seconds, then swallow and after 3 seconds evaluate the intensity of the sensations. The order of attribute evaluation was fixed: sweetness, sourness, apple flavour, mint flavour

Table 1
Methods of data collection

Study session	Assessment
Online (home)	Food Neophobia Scale Disgust Scale Sensitivity to Reward Questionnaire Sociodemographic data
Laboratory	Apple juice (liking – intensity) Chickpea cream (liking – intensity) PROP test

Table 2
Food models: food matrix (AJ = apple juice and CC = chickpea cream), target sensation, tastants, samples to be used for evaluation. Tastants were added to the base recipe composed by apple juice for AJ and by chickpeas, tahina, sunflower oil, lemon juice, salt, cumin, oregano, garlic for CC

Matrix	Target sensation	Added tastant	Samples			
			AJ0	**AJ15**	**AJ60**	**AJ240**
Apple juice (AJ)	coolness	Glucose-fructose syrup g/Kg	240	226	180	0
		Mint syrup g/Kg	0	15	60	240
	sweetness		**CC0**	**CC50**	**CC100**	**CC200**
Chickpea cream (CC)	sourness	Glucose-fructose syrup g/Kg	0	50	100	200
		Citric acid g/Kg	8	6	4	4

and coolness. Participants were provided with water and unsalted plain crackers for mouth-washing purposes during the breaks (30 seconds between each sample).

Chickpea cream (CC). Preparation: samples – CC0, CC50, CC10, CC200 – were prepared the same day/the day before of the test. A citric acid water solution of 8 g/Kg was prepared dissolving 400 g of citric acid in 1 Liter of water. Then a chickpea cream mix was prepared mixing 640 g/Kg of boiled chickpeas, 40 g/Kg of Thaina, 80 g/Kg of sunflower oil, 16 g/Kg of lemon juice, 2.4 g/Kg of salt, 0.6 g/Kg of garlic, 0.4 g/Kg of cumin, 0.4 g/Kg of oregano. Different quantities of citric acid solution (CC0 = 8; CC50 = 6; CC100 = 4; CC200 = 4 g/Kg), glucose-fructose syrup (CC0 = 0; CC50 = 50; CC100 = 100; C200 = 200 g/Kg) and water (CC0 = 200; CC50 = 155; CC100 = 110; CC200 = 10 g/Kg) were added to obtain the chickpea cream. The ingredients were mixed using a kitchen-use blender and stored at room temperature one hour before the test started. Concentrations were selected to elicit an inverse variation in the strength of sweetness and sourness (from weak to strong) based on preliminary tests. Texture and viscosity were maintained the same for all the different samples.

Testing procedure: Participants were presented with the chickpea cream samples (20 g) served in small covered plastic glasses coded with a three-digit code. Samples presentation order was randomized within and across participants. Participants were instructed to take a full teaspoon, wait 10 sec then swallow and evaluate the liking of the sample. After the liking evaluation of the four samples, participants were instructed to take a second full teaspoon, wait 7 seconds, then swallow and after 3 seconds evaluate the intensity of the sensations. The order of attribute evaluation was fixed: sweetness, sourness and overall flavour. Participants were provided with water and unsalted plain crackers for mouth-washing purposes during the breaks (30 seconds between each sample) (Figure 1).

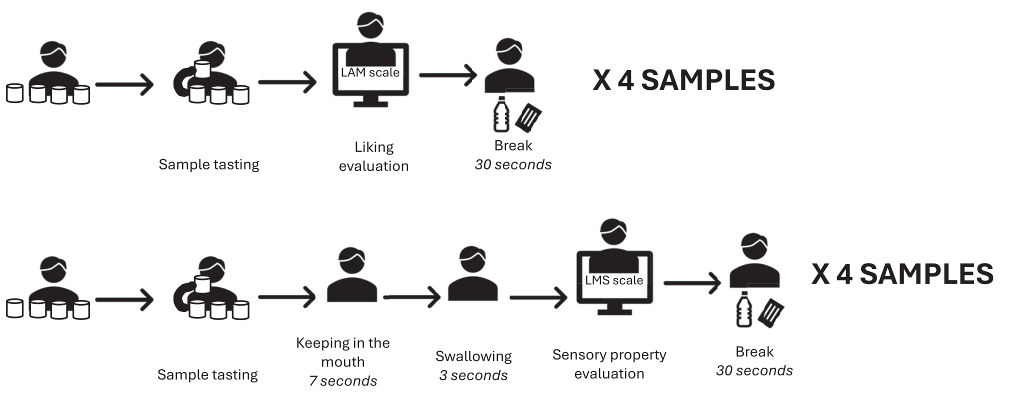

Figure 1. Flow chart of the sensory tests procedure.

PROP (6-N-Propyl-2-Thiouracil) test

Participants rated the perceived bitter intensity of 1.5 cm paper disks impregnated with 6-N-Propyl-2-Thiouracil. Disks preparation followed the procedure used in literature [46].

Participants were presented with one PROP paper disk on a Petri plate and shortly recalled about the use of the LMS scale to rate disk bitterness. Participants were instructed to put the paper disk on their tip of the tongue with the help of a small table mirror, wait until moistened with saliva (25 s), then to expectorate it, and after a further 20 s to rate bitterness intensity on the LMS.

Questionnaires

Food Neophobia Scale. Food neophobia was assessed using the Food Neophobia Scale (FNS) [20] validated in Italian [22] and in French [47]. FNS consists of ten statements rated with a 7-point scale of agreement ranging from 1 = “I strongly disagree” to 7 = “I strongly agree”. The individual FNS scores are calculated as the sum of the scores assigned to the ten statements, after the neophilic items have been reversed; thus, scores theoretically ranged from 10 to 70, with higher scores reflecting higher levels of food neophobia.

Disgust Scale - short form. Individual sensitivity to core disgust was assessed with the Disgust Scale - Short Form (DS-SF) [48,49] validated in Italian [19]. The French validated version of the scale was not available, and for this reason the questionnaire was translated to French by two different bilingual French native-speakers and then back translated into the source language (see supplementary material). This questionnaire is an abbreviated form of the Disgust Scale which aimed to measure disgust from animal origin, based on contamination and revulsion. This measure consisted of 8 items divided into 2 parts. In the first part, the statements were rated using a scale from 1 (strongly disagree-very false about me) to 5 (strongly agree-very true about me); for the second part, the statements were scored from 1 (not at all disgusting) to 5 (extremely disgusting). The total disgust sensitivity score is given by the sum of the scores after two items have been reversed and ranges from 8 to 40.

Sensitivity to Reward Questionnaire - short version. Sensitivity to reward was assessed using the subscale Reward Sensitivity from the Sensitivity to Punishment and Sensitivity to Reward Questionnaire (SPSRQ) [50], in the short form validated in French [51]; for the Italian version, the same items of the French version [51] were selected in the SPSRQ Italian version [52]. The questionnaire consisted of 17 items, with ratings on a 4-point Likert scale ranging from 1 "totally no" to 4 "totally yes".

Data analysis

For each food model (AJ and CC) the effect of samples (AJ0, 15, 60, 240; CC0, 50, 100, 200) on liking and perceived intensity of sensations (AJ: sweetness, sourness, apple flavour, mint flavour and coolness; CC: sweetness, sourness and overall flavour) was explored by separate two-way analyses of variance (ANOVAs), considering the participants as random factor. For significant ANOVA effects ($p < 0.05$) the post hoc LSD Fisher's test for multiple comparisons was then applied.

Pearson correlation coefficients (r) between individual sensory attribute ratings (AJ: sweetness, sourness, apple flavor, mint flavour and coolness; CC: sweetness, sourness, overall flavour) and hedonic scores were calculated for apple juice and chickpea cream following an already established procedure [6]. K-means cluster analyses on r values for each food model were applied and different solutions were explored. Two solutions were retained for the two food models; two clusters-solution for the apple juice and three clusters-solution for the chickpea cream, each characterized by a specific sensory-liking pattern for the main target sensation. For the apple juice, six participants were not considered for the cluster analysis because they rated zero for sourness, therefore the computation of the correlation coefficient was not possible.

Two-way analysis of variance (ANOVA) models were applied to explore the effect of sample, cluster and their interaction on liking and sensations responses to apple juice and chickpea cream samples. Type III Sum of Squares and Least Squares (LS) means were used and LSD Fisher post-hoc test was applied ($p = 0.05$).

Cronbach α was calculated for all the personality questionnaires. Factor analysis was conducted to evaluate the factor structure, reliability, and validity of the Italian and French version of the NS, DS and SPSRQ using Pearson correlation for NS and DS and polichoric correlation for SPSRQ.

One way ANOVA was run to study the effect of cluster on personality traits and age. Participants were classified for PROP status by calculating the first and third quartile of the percentile distribution of the PROP disk evaluation [5]. The upper limit of the first quartile and lower limit of the third quartile were 14 and 52 on LMS, respectively. These values are in good agreement with the cut-offs used in previous studies to categorize participants in Non Taster (arbitrary cut-off LMS < moderate, 17) and Super Taster (arbitrary cut-off LMS > very strong, 53) [53,54]. The association between cluster and, respectively, gender, country and PROP group were investigated using chi-square tests.

Data analysis was performed with XLSTAT v2020.5.1.1040 (Addinsoft, Paris, France).

Results

Food models' liking and perceived intensity of target sensations

In both food models the effect of sample (tastant concentration) was significant for all sensations and liking scores (Figures 2 and 3).

Mean liking ratings of apple juice (AJ, n = 154) decreased from 'like moderately' (AJ0, M = 66.6) to 'dislike slightly' (AJ240, M = 42.6) ($p < 0.0001$) (Figure 2).

Perceived intensity of AJ's mint flavour and coolness increased (mint: $p < 0.0001$; coolness: $p < 0.0001$) from 'weak' (mint: AJ0, M = 5.5; coolness: AJ0, M = 11.9) to 'very strong' (mint: AJ240, M = 50.8) and strong (coolness: AJ240, M = 39.1). Apple flavour decreased from 'strong' (AJ0, M = 38.2) to 'weak' (AJ240, M = 13.7) ($F_{(3,459)} = 91.03$, $p < 0.0001$), while the perceived sweetness was around 'strong' ($p < 0.0001$), and sourness around 'weak' ($p < 0.0001$) for all samples.

Mean liking ratings of chickpea cream (CC, n = 179) (Figure 3) were between 'dislike slightly' (CC0, M = 48.2) and 'like moderately' (CC100, M = 57.1) ($p < 0.0001$). Perceived intensity of CC's sweetness increased from 'weak' (CC0, M = 5.14) to 'strong' (CC200, M = 36.5) ($p < 0.0001$), while the sourness intensity decreased from 'strong' (CC0, M = 39.5) to 'weak' (CC200, M = 7.9) ($p < 0.0001$), and the overall flavour ranged between 'strong' (CC0, M = 35.2) and 'moderate' (CC100, M = 24.5) ($p < 0.0001$).

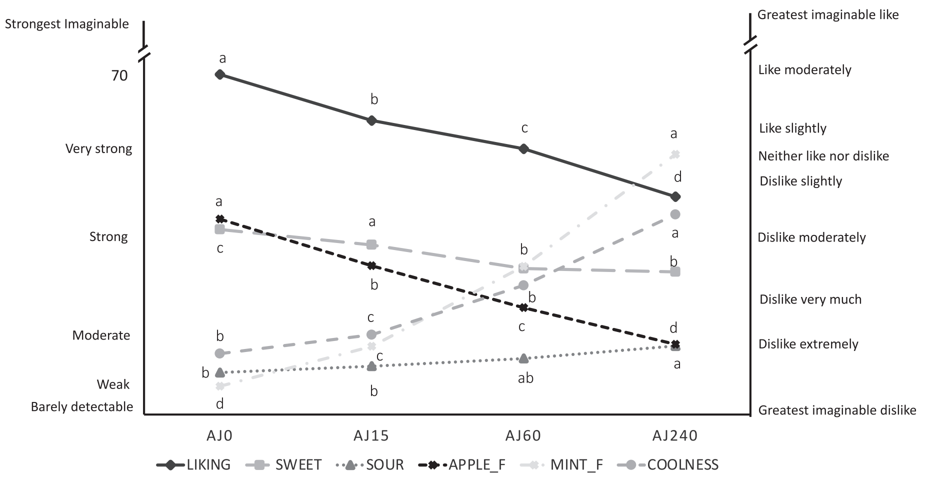

Figure 2. Apple juice liking and intensity of the sensory properties. Mean scores of liking and of sweetness, sourness, apple flavour, mint flavour and coolness for the apple juice samples (AJ0, 15, 60, 240), (n = 154, $p < 0.0001$). Different letters indicate significant differences for each sensation/liking ($p < 0.05$).

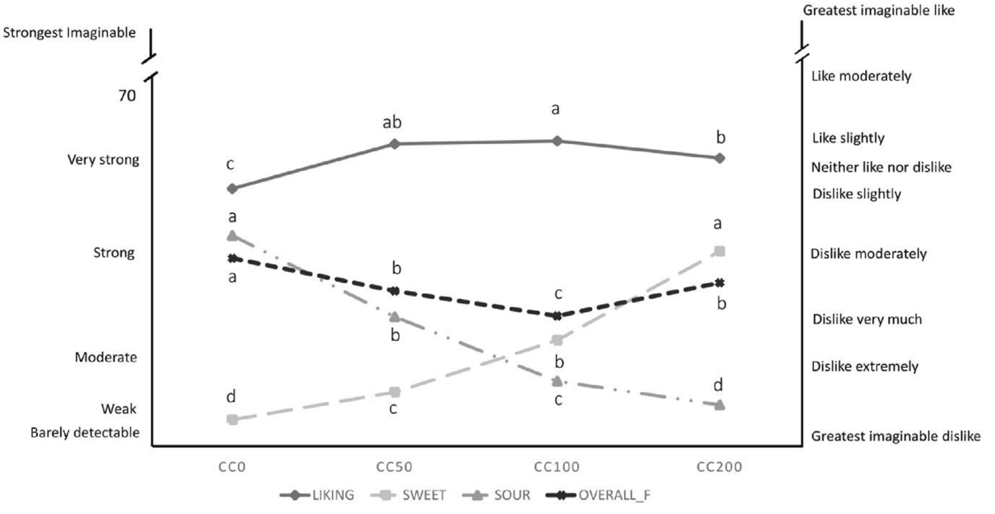

Figure 3. Chickpea cream liking and intensity of the sensory properties. Mean scores of liking and of sweetness, sourness and overall flavour for the chickpea cream samples (CC0, 50, 100, 200) ($n = 179$, $p < 0.0001$). Different letters indicate significant differences for each sensation/liking ($p < 0.05$).

Individual differences in sensory-hedonic responses

Two clusters were identified, based on participants' sensory-hedonic scores, and named after their differences in liking for AJ240, for the apple juice: Moderate Coolness Dislikers (MCD; n = 68, 46%) and Extreme Coolness Dislikers (ECD; n = 80, 54%) (Table 3). In both clusters liking was positively correlated with apple flavour (r = 0.41 and 0.59, respectively) and negatively correlated with coolness (r = - 0.10 and - 0.56, respectively) and mint flavour (r = - 0.36 and - 0.64, respectively), more strongly in the case of ECD. In MCD liking was positively correlated to sourness and sweetness (r = 0.55 and 0.55), while in ECD liking was positively correlated to sweetness and negatively to sourness (r = 0.27 and - 0.57). A main effect of sample ($p < 0.0001$), of cluster ($p = 0.021$) and an interaction between sample and cluster ($p = 0.029$) on liking of the apple juices were observed (Figure 4). Liking patterns in the two groups followed the same trend, with MCD reporting higher liking scores for AJ240 compared to ECD.

Significant effects of cluster, sample and cluster*sample interaction on intensity ratings of AJ were found (Figure 5). A main effect of cluster was found for apple flavour (p= 0.022) (Figure 5c) and sourness ($p = 0.039$) with ECD that perceived more intensely these sensations. A trend in the same direction was observed for coolness ($p = 0.053$) while no significant effect of cluster on sweetness ($p = 0.168$) and mint flavour (p = 0,070) were found. An interaction between sample and cluster was found for sourness ($p < 0.0001$) (Figure 5b) and sweetness ($p = 0.051$). Sweetness and sourness remained constant for all the samples for MCD (Figure 5a, b), while sweetness decreased, and sourness increased for ECD with increasing concentration of mint syrup. ECD rated the least cool sample (AJ0) as sweeter, and the coolest sample as sourer than cluster MCD. The other interactions were not significant ($p > 0.05$) Figure 5c-d). The effect of sample was significant for all sensory properties; mint flavour ($p < 0.0001$) coolness ($p < 0.0001$), apple flavour ($p < 0.0001$), sweetness ($p = 0.001$) and sourness ($p = 0.09$) (Figure 5).

Three clusters, differing in sensory-hedonic responses for sweetness, sourness perception and liking, were identified for the chickpea cream: Sweet Likers (SL, n = 84, 46.92 %), Inverted U-shaped (IU, n = 44, 24.58%) and Sweet Dislikers (SD, n = 51, 28.49%) (Table 3). In SL liking was strongly positively correlated to sweetness and negatively correlated to sourness (r = 0.68 and - 0.75); for IU liking was strongly negatively correlated to sweetness and moderately to sourness (r = - 0.69 and - 0.33); for SD

Table 3
For each food model, the number of participants, Pearson correlation coefficients of the class centroids between sensations and liking, gender distribution, mean age and country are reported for all clusters. Significant differences are presented in bold ($p < 0.05$). Different letters by raw indicate significant differences between clusters

Clusters							
	Apple juice			Chickpea cream			
	1	2		1	2	3	
	Moderate coolness dislikers (MCD)	Extreme coolness dislikers (ECD)	*p*-value	Sweet likers (SL)	Inverted U-shaped (IU)	Sweet dislikers (SD)	*p*-value
N (%) 179	68	80		84	44	51	
Class centroid							
Sweet	0.05	0.27		0.68	-0.69	-0.69	
Sour	0.55	-0.57		-0.75	-0.33	0.62	
Overall flavour				-0.27	-0.32	0.19	
Apple flavour	0.41	0.59					
Mint flavour	-0.36	-0.64					
Coolness	-0.10	-0.56					
Gender (Women%)	28.37%	15.54%	0.22	29.05	18.99	17.87	0.18
Age	41.03 a	38.52 a	0.28	39.14 b	45.27 a	43.05 ab	**0.03**
Country (%)							
France	22.29%	27.70%	0.74	20.11%	8.93%	12.29%	0.74
Italy	23.64%	26.35%		26.81%	15.64%	16.20%	

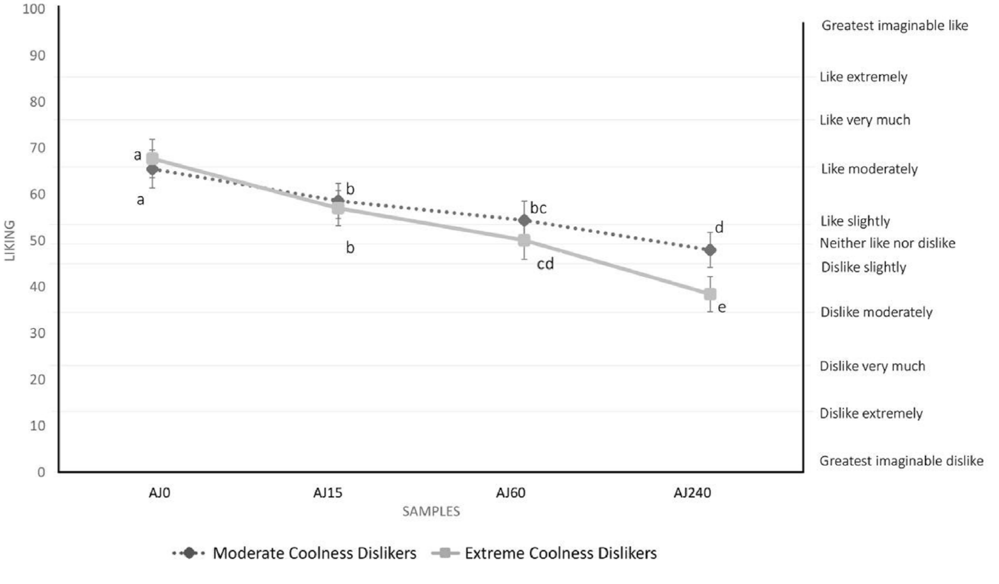

Figure 4. Apple juice's clusters liking. Mean liking ratings for each of the two clusters for apple juice samples (AJ0-AJ240). Different letters indicate a significant difference in the Fisher post hoc test ($p < 0.05$).

liking was strongly negatively correlated to sweetness and positively correlated to sourness (r = - 0.69 and 0.62).

A main effect of cluster ($p = 0.000001$), of sample ($p = 0.0002$) and sample*cluster interaction ($p < 0.0001$) on liking of the chickpea creams were observed (Figure 6). The three clusters differed in their optima; in SL liking increased as sweetness intensity increased; in IU liking increased as concentration

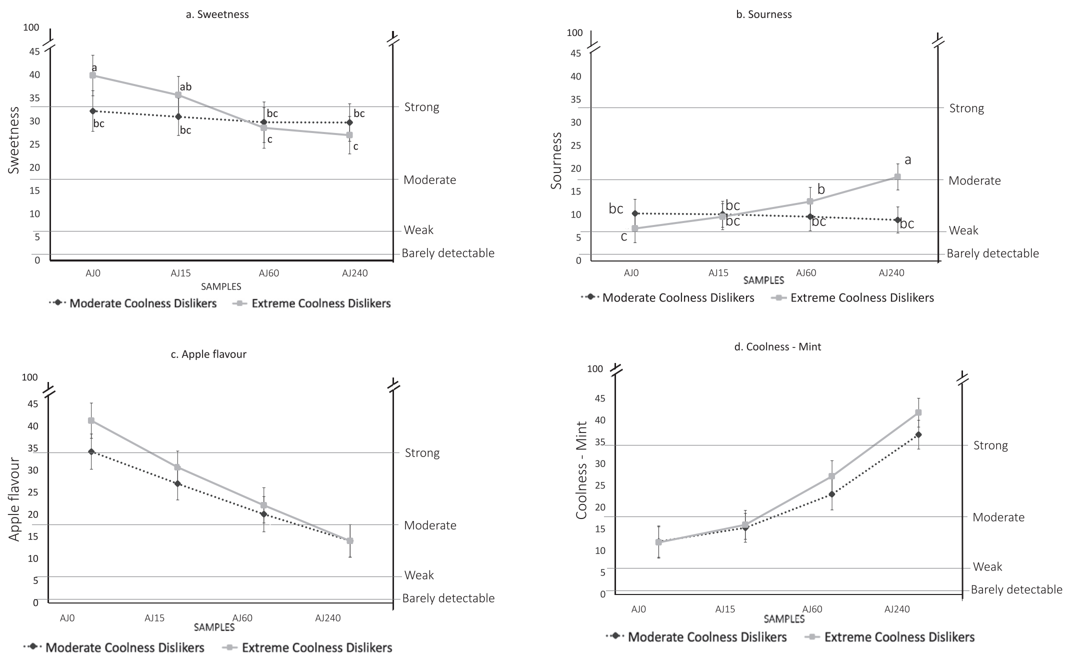

Figure 5. (a, b, c, d). Apple juice's clusters sensations intensity. Clusters and apple juice samples (AJ0-AJ240) effect on mean intensity ratings of sweetness, sourness, apple flavour and mint flavour-coolness. Different letters indicate a significant difference in the Fisher post hoc test ($p < 0.05$).

increased in CC50 and CC100 and then decreased; in SD liking decreased as sweetness intensity increased.

The effect of sample was significant on all sensory properties($p < 0.0001$).

A main effect of the cluster was found on sweetness ($p = 0.002$), and an interaction between sample and cluster was found for sourness ($p = 0.008$) (Figure 7), while no significant intercation effect was found on sweetness ($p > 0.741$). The rated intensity of sweetness and sourness followed a similar pattern in the three clusters: increasing, in the case of sweetness, and decreasing in the case of sourness.

However, Sweet Likers perceive lower sweetness compared to sweet dislikers. SL and IU perceived higher sourness levels in CC0 than SD.

Clusters characteristics: socio-demographics, PROP responsiveness and personality

Clusters of both food models did not differ by gender and country, and no difference in age were found for AJ clusters. Instead, CC clusters showed differences in terms of age: Sweet Likers were significantly younger (mean age = 39.14) compared to Inverted U-shaped (mean age = 45.27), while sweet dislikers did not differ in age compared to the other two (Table 3).

Adequacy of the factor structure of the personality scales was good based on the Kaiser-Meyer-Olkin [55] for FNS and acceptable for DS and for RS. The FNS showed a good internal reliability both in Italian and in French (Cronbach's alpha respectively of 0.83 and 0.87). DS displayed a lower internal reliability both in Italian and in French (Cronbach's alpha respectively of 0.62 and 0.64). The SR showed a good internal reliability both in Italian and in French (Cronbach's alpha respectively of 0.87 and 0.84). Cluster characteristics for personality and PROP responsiveness are summarized in Table 4. AJ clusters showed a difference close to the significance for PROP responsiveness ($p = 0.057$). Extreme Coolness Dislikers were characterized by perceiving a higher PROP bitterness (mean = 42.55) compared to Moderate Coolness Dislikers (mean = 32.93). A difference close to the significance level was also found for sensitivity to reward ($p = 0.086$), showing that MCD were characterized by higher levels of sensitivity to reward (mean = 5.28) than ECD (mean = 4.31). No differences between AJ clusters were found for food neophobia and disgust sensitivity. Sweet Likers and Inverted U-shaped CC clusters were found to significantly differ for sensitivity to reward ($p < 0.05$). Sweet Likers were found to be higher in sensitivity to reward (M = 5.63), while Inverted U-shaped cluster showed inferior levels of sensitivity to reward (mean = 3.91). CC clusters did not significantly differ for food neophobia, disgust sensitivity and PROP responsiveness.

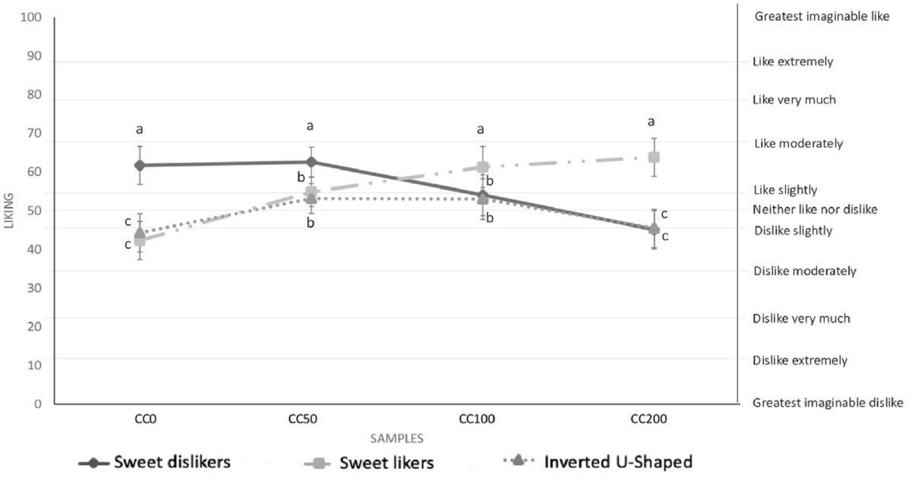

Figure 6. Chickpea cream's clusters liking. Mean liking ratings for each of the three clusters for CC samples (CC0 – CC200). Different letters indicate a significant difference in the Fisher post hoc test ($p < 0.05$).

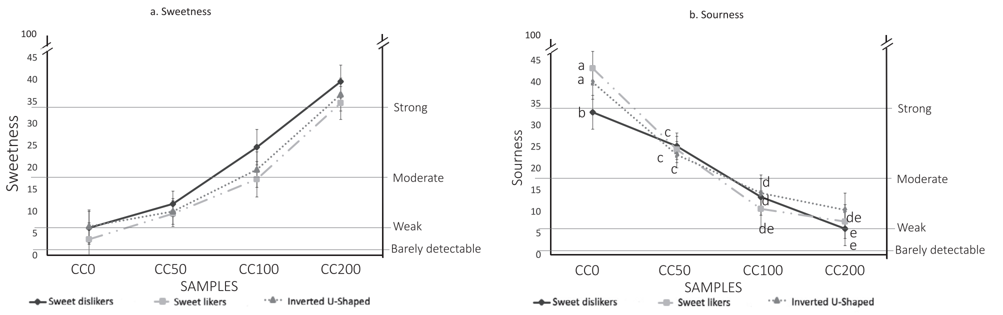

Figure 7. (a, b). Chickpea cream's clusters sensations intensity. Clusters and chickpea cream samples (CC0 – CC200) effect on mean intensity ratings of sweetness and sourness. Different letters indicate a significant difference in the Fisher post hoc test ($p < 0.05$).

Table 4
Cluster characteristics expressed in mean values. Significant differences are presented in bold ($p < 0.05$). Different letters by raw indicate significant differences between clusters.

Variables	Apple juice			Chickpea cream			
	Moderate coolness dislikers	Extreme coolness dislikers	*p*-value	Sweet likers	Inverted U-Shaped	Sweet dislikers	*p*-value
Personality Traits							
Food Neophobia	25.28	24.01	0.52	23.93	25.27	24.52	0.81
Disgust Sensitivity	29.87	29.75	0.89	30.67	30.24	30.45	0.95
Sensitivity to Reward	5.28	4.31	0.08	**5.63 a**	**3.91 b**	**4.79 ab**	**0.03**
PROP	32.93	42.55	0.06	38.86	41.77	36.43	0.68

Discussion

In this study an approach to assess sensory-hedonic responses to foods was developed and tested with healthy participants in the Mediterranean Diet area (Italy and South of France). Two food models were developed, an apple juice and a chickpea cream, varying in specific target sensations that have been found to be altered or under-investigated in cancer patients undergoing chemotherapy [29–32,37]. Food matrices in this study were chosen for being familiar products for the considered group, as food products belonging to the Mediterranean diet and highly consumed in the Mediterranean region [38].

Our results indicated that the two food models can be used to efficiently capture individual variability of sensory-hedonic responses in coolness sensation (AJ), sweet and sour taste (CC), suggesting that they could also be used to collect data with people experiencing taste alterations (e.g., cancer patients). In the present study the protocol was preliminarily tested in healthy participants as common practice in medical studies with new measurement [40–43].

Coolness and mint flavour perception increased in the apple juice as mint syrup increased, while liking decreased. Overall, sample AJ0 (without mint syrup) was the most liked, but samples with 15 and 60 g of mint syrup were also accepted.

Despite the trigeminal sensation of burning (capsaicin/chili) in water solutions or food models have been studied [19,21,56], the trigeminal sensation triggered by menthol is under-investigated. Consideration of trigeminal sensations in cancer is growing as patients use ingredients which trigger trigeminal nerve in order to compensate for the lack of perceived sensations and to enhance flavor from foods [33,34,37]. Liking for oral nutritional supplements triggering hot (capsaicin) and cold (menthol) trigeminal sensations in cancer patients undergoing therapy were previously explored, finding that taste alterations were associated with an increase in overall liking for the cold variant [37].

Our preliminary study on the sensory-hedonic responses to a food model varied for cooling sensation showed smaller interindividual differences compared to the other food model in which basic tastes were modulated. However, two groups were identified differing in their liking of the coolest sample, Moderate Coolness Dislikers that described this sample as neither liked nor disliked and Extreme Coolness Dislikers that described this sample as moderately disliked. Generally, the sweetness balancing of mint syrup operated with glucose-fructose syrup worked well, as the Extreme Coolness Dislikers perceived constant sweetness as well as sourness across samples. On the opposite, Moderate Coolness Dislikers sweetness perception decreased and sourness perception increased as concentration increased.

Overall, Extreme Coolness Dislikers showed higher perceived intensity for all the assessed sensations compared to Moderate Coolness Dislikers. So that, the lower liking scores for the sample with 240 g of mint syrup could derive from the higher perception of taste and trigeminal sensations that characterize this cluster.

In the chickpea cream model, globally, participants detected increasing sweetness intensity as glucose-fructose syrup concentration increased and decreasing sourness as citric acid solution decreased, with a liking curve that followed an inverted U shape, with an optimal level at the intermediate concentration of 50 and 100 g of glucose-fructose syrup.

In line with previous results [9], we found that the liking response is predicated upon sensory intensity. The studies on hedonic responses to water solutions showed different liking patterns [7,10] and findings from the present study confirmed that different sensory-hedonic patterns exist across participants in both food models when individual differences were considered.

Consistently with previous results on sucrose solutions and food models [3,6,10] three groups were found to differ for sweetness liking patterns; our results established that sweet-liking patterns observed in sucrose-solutions can be extended in food matrices, which allow to have a more ecological and representative assessment. Liking increased for Sweet Likers and decreased for Sweet Dislikers group as the sweetness intensity increased, while a third group was also identified in line with previous results characterized by a inverted U-shaped liking curve. Results also confirmed that SD perceived sweetness as more intense compared to SL [57], while they report a lower perceived intensity of sourness at the highest concentration compared to SL and IU [4].

This approach also allowed to identify the level of sensory properties that minimized rejection and maximized liking across clusters: the sensory characteristics which are in-between samples added with 50 and 100 g of glucose-fructose syrup reached the maximum consensus between the different groups. Nevertheless, the three clusters showed very different liking optima and sensory-like patterns. Sweet Likers' liking increased as sweetness perception increased and sourness decreased. On the contrary, Sweet Dislikers' liking decreased as sweet perception increased and sourness decreased. For Inverted U-shaped participants liking increased up to the optimum point 50/100 g glucose-fructose syrup and then decreased.

Sweet likers, characterized by a greater liking and a lower perception of sweet taste, resulted to be the youngest participants. The same group was also characterized by the highest levels of sensitivity to reward [58,59]. Our findings suggested that younger people are more likely to be higher in sensitivity to reward, in line with previous results [5,59].

On the opposite, Inverted U-shaped participants, whose liking reached an optimum in the two intermediate samples, were found to be the oldest and the lowest in sensitivity to reward.

Sweet Dislikers, whose liking showed a decreasing trend and perceived higher sweetness intensity, did not show to differ in age from the other clusters, with an in-between mean age and sensitivity to reward score.

Results on PROP status related to the different sweet liking clusters confirmed previous findings of [60,61] showing no effect of PROP group on the perception and liking of sweet taste.

Overall, in light of the results obtained from this study, it is possible to suggest the use of food models to study food preferences in individuals complaining about sensory alterations. This approach could provide information about interindividual variability and could track changes in perceived sensation intensity and liking among this population of patients.

One of the study limits is that mean age might not be representative for a further study on cancer patients, whose mean age is expected to be higher, while in this study participants were relatively younger. Another weak point is represented by the produced variation of the trigeminal sensation using mint syrup. As a matter of fact, adding mint syrup instead of menthol there is an increase of sweetness that might interfere with the intensity of the sensations and that should be controlled (as it was in the study). Finally, some participants could not complete the whole study due to time constraints.

Conclusion

The present study demonstrated the interindividual variability for sensory-hedonic responses to food matrices in which target sensations of sweetness, sourness and cooling were manipulated.

Overall, it is possible to encourage the use of real food matrices as an ecological and reliable method for the study of sensory-hedonic responses to food in healthy and vulnerable individuals, in addition/alternative to aqueous solutions. Moreover, the present study expands previous results pointing to the importance of considering the interindividual variation for sensory-hedonic responses to food for the study and development of new food products even in vulnerable populations. On this study basis, further research is suggested to study sensory-hedonic responses to food models in cancer patients undergoing treatment. The methodology used here could shed light on sensory alterations during cancer therapy, providing a more complete and ecological assessment than water solutions.

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CRediT author statement

A. Lippi: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing—original draft preparation, Writing—review and editing. **C. Dinnella**: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing—review and editing, Supervision. **S. Spinelli**: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing—review and editing, Visualization, Supervision. **A. Giboreau**: Methodology, Investigation, Writing—review and editing, Supervision, Funding acquisition. **V. Mourier**: Investigation, Funding acquisition. **E. Monteleone**: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing—review and editing, Supervision, Project administration, Funding acquisition.

All authors have read and agreed to the published version of the manuscript.

Conflicts of 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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.nutos.2024.06.005.

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