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Liking for saltiness is associated with preference for fattier and more caloric foods

Cristina Proserpio [a], Sara Spinelli [b,*], Camilla Cattaneo [a], Caterina Dinnella [b], Monica Laureati [a], Erminio Monteleone [b], Ella Pagliarini [a]

[a] Sensory & Consumer Science Lab (SCS_Lab), Department of Food, Environmental and Nutritional Sciences (DeFENS), University of Milan, 20133 Milan, Italy
[b] SensoryLab, Department of Agriculture, Food, Environment and Forestry (DAGRI), University of Florence, Florence, Italy

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ABSTRACT

The high consumption of foods rich in salt, fat and sugar represents a risk factor for adverse health outcomes, and while strategies for the reduction of these ingredients have been developed, results have been inconclusive. One reason for this may be that the relationship between preferences for salty, fat and sweet foods is unclear. The aim of this study was to investigate whether individuals showing a higher liking for salty foods also prefer fattier foods, whether savoury or non-savoury/sweet. Liking and intensity responses for a model food (bean purée with increasing concentrations of salt, NaCl, added) were provided by 395 subjects to identify groups of consumers with different responses to saltiness.

Hierarchical cluster analysis based on liking scores revealed that one group of subjects (Cluster 1: Salt likers, n = 285) liked the bean purée samples with higher NaCl concentrations significantly more than did those belonging to Cluster 2 (Salt dislikers, n = 110). Salt dislikers also rated saltiness, umami taste, and overall flavour as significantly more intense than did salt likers. These differences were also present in assessment of tastes in water solutions, while no differences between clusters in fungiform papillae density and in attitudes toward health and taste were found. Significant differences between the two clusters were found in terms of food choices, with salt likers choosing foods – both savoury and non-savoury/sweet – that are fattier, more caloric, and thus perceived as less healthy, more frequently than did salt dislikers.

These results suggest that subjects preferring saltier foods generally also prefer fattier foods, whether savoury or not-savoury. Thus, the approach of segmenting individuals on salty taste preferences appears to be a useful way of identifying consumers groups more prone to make less healthy food choices in general.

1. Introduction

In recent decades, many countries have implemented policies aimed at reducing the consumption of foods that are high in salt, fat, and sugar, as a way of reducing the burden of non-communicable diseases (Bouhlal et al., 2011; WHO, 2003, WHO, 2013). In particular, the high consumption of foods rich in salt represents a health risk factor due to its association with increased blood pressure, cardiovascular disease, and increased risk of stomach cancer (He et al., 2021). Such potential risks are essentially universal, since in 181 out of 187 countries surveyed by the WHO, sodium, particularly in the form of salt, is consumed above the recommended limit of 2 g per day (Powles et al., 2013). Common salt (sodium chloride; NaCl) is the major source of saltiness in foods, an essential ingredient since it is not only used for sensory reasons (e.g., as a flavour enhancer), but also for technological purposes (e.g., in bakery products stabilizes the gluten, decreasing the extensibility of the dough and making it less viscous, Ferrari et al., 2022; Man, 2007), and for the regulation of microbial growth (Ferrari et al., 2022). From a biological perspective, the liking for salt is related to the need to maintain sodium balance, but it is also driven by pleasure. It remains unclear whether the preference for salt is innate, but in any case, it typically develops very early, around 4 months of age or even earlier (Breslin, 2013; Hayes, 2020; Beauchamp, Cowart, & Moran, 1986).

The addition of salt to very many (especially savoury) foods increases liking for those foods, leading to greater food and energy intake (Bouhlal, Issanchou, & Nicklaus, 2011; Liem, Miremadi, & Keast, 2011; Bolhuis, Newman & Keast, 2016). Furthermore, a higher liking for salty foods has not only been associated with higher sodium intake (Hayes

* Corresponding author.
E-mail address: sara.spinelli@unifi.it (S. Spinelli).

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et al., 2010), but also with higher intakes of saturated fat and a lower intake of vegetables and fruits (Carbonneau et al., 2021). Salt is abundant in high energy dense foods where it is often combined with fat (e.g. chips, meat, cheese, and various fast foods; Méjean et al., 2014). It has been also suggested that variations in salt content are more closely related to food acceptability than variations in fat content in a tomato food soup model (Bolhuis, Newman & Keast, 2016). Salt has an important role in daily energy intake especially in relation to dietary fat over-consumption since fatty foods without a dominant taste (such as saltiness, savouriness/umami, or sweetness) are less palatable and unlikely to be consumed (Bolhuis et al., 2016).

Although there is considerable research on this topic, the relationship between liking for salty, sweet and fatty foods (Bolhuis, Costanzo, & Keast, 2018; Bolhuis, Costanzo, Newman, & Keast, 2016; Carbonneau et al., 2021; Lampuré et al., 2015; Bolhuis, Newman & Keast, 2016) is still unclear. A study on a large French adult cohort indicated that people with a strong liking for fat had poorer diet quality reporting higher intakes of total energy from savoury food-based fats, including from saturated fats, meat, butter, savoury sauces and snacks, but also increased intake of sweetened cream desserts and croissant-like pastries, when compared to people with lower liking for fat. Fat likers also consumed lower quantities of omega-3 fatty acids, fiber, fruits, vegetables and yogurt (Méjean et al., 2014). Although healthier diets have been found to be sweeter, as well as more bitter and less salty, the sweetness is primarily derived from sugars naturally present in foods (e.g. fruits) (Cox et al., 2018). In contrast, liking for added sugar was associated with higher BMI in women (Deglaire et al., 2015). No differences in fatty mouthfeel by diet quality was found (Cox et al., 2018).

Excessive eating and unhealthy food choices are among the most pressing health concerns facing both developed and developing countries. While a reduction in salt and sugar intake and a replacement of trans fats with unsaturated fats is strongly recommended to promote a transition to healthier diets, the achievement of these goals has proven to be very difficult, probably due to a complex interaction of factors. Traditional approaches applied to counteract overweight and obesity, such as dietary restriction and education, are not as effective as expected since consumers often have a low adherence to restricted diets (Hall & Kahan, 2018), usually associated with the presence of hedonic hunger, a desire to obtain pleasure from food (Lowe and Butryn, 2007).

Among multiple factors involved in eating behaviours, positive hedonic responses are significant drivers of food choices (Bublitz et al., 2010). Liking, in turn, is modulated by consumers' perception of the intensity of sensory qualities, especially tastes, with a negative correlation observed between the perception of salt intensity and liking (Hayes et al., 2010).

There is evidence that individuals vary in their overall taste, and possibly oral tactile, responsiveness (Bartoshuk, 1993, 2000), Hence, different measures have been proposed to act as indices of oral responsiveness and taste function. Among them, responsiveness to the bitter compound 6-n-propylthiouracil (PROP), or to suprathreshold standard solutions with varied stimuli concentrations, and the density of the tongue's fungiform papillae, have been widely applied to evaluate the taste functions (Cox, Hendrie, & Carty, 2016; Dinnella et al., 2018; Fischer et al., 2013; Webb, Bolhuis, Cicerale, Hayes, & Keast, 2015). It has been shown that PROP status and papillae number independently explained variability in consuming high-sodium foods by impacting salt sensation and/or liking (Hayes et al., 2010). Several studies have used actual food (Dinehart et al., 2006; Lanier et al., 2005) or model foods with varied concentrations of a tastant (Bolhuis, Costanzo, Newman, & Keast, 2016; Bolhuis, Lakemond, de Wijk, Luning, & de Graaf, 2012; Monteleone et al., 2017; Pagliarini et al., 2021; Bolhuis, Newman & Keast, 2016) to evaluate taste responsiveness, indicating sensory-hedonic linkages (Endrizzi et al., 2022; Spinelli et al. 2021, 2024).

Furthermore, a large amount of consumer research has shown that health, along with taste, represents a central aspect influencing consumers' food choices and preferences, with people differing in the extent to which they assign importance to taste and health motives in their food choices and women generally reporting a higher interest in health than men (Roininen & Tuorila, 1999; Roininen et al., 2001).

The aim of the present study was to investigate whether individuals showing a higher liking for salty taste make less healthy food choices, preferring also fattier and/or sweeter foods. To achieve this, liking and sensory responses to a model food, bean/potato purées spiked with increasing concentrations of NaCl, were measured to identify different hedonic patterns, namely consumer clusters that differed in their liking for saltiness of the model food. We hypothesised that those showing greater hedonic responses to saltiness (salt likers) would more commonly make less healthy food choices in general, not only limited to savoury products but extended also to sweet foods. To test this hypothesis, we studied if clusters differed in preference for foods when presented with pairs of products differing in fattiness and saltiness, fattiness and sweetness, or only different levels of sweetness. Furthermore, we studied if the identified clusters differ also in sweet liking, using responses to a model food (chocolate pudding spiked with increasing concentrations of sucrose). Clusters were then characterised for their sex, age, taste responsiveness using different measures and indices (PROP status, fungiform papillae density, and response to tastes in aqueous solutions and model foods).

2. Material and methods

2.1. Subjects

Three hundred ninety-five subjects (females = 58 %; age range: 18–60 years; mean age: 34.4 ± 13.4) from Northern and Central Italy were recruited through mailing lists, pamphlet distribution, word of mouth, announcements on social networks, participant universities and research centres' websites and articles in national newspapers. Inclusion criteria were not being pregnant or breastfeeding at the moment of the test, being born, or having lived for more than twenty years, in Italy.

The study was conducted within the Italian Taste project (Monteleone et al. 2017) in adherence with the principles laid down the Declaration of Helsinki and in agreement with the Italian ethical requirements on research activities and personal data protection (D.L. 30.6.03n. 196). The research protocol was approved by the Ethics Committee of Trieste University, and prior to participating in the study, subjects provided their written informed consent.

2.2. Procedure

After completing an online questionnaire providing demographic information, subjects were invited to attend two laboratory sessions. On day one, the hedonic evaluation of the chocolate pudding and bean/potato puree samples, PROP responsiveness, and fungiform papillae count were performed. The intensity of sensory attributes in bean/potato puree samples as well as sensory evaluation of aqueous solutions were collected on day two. For a detailed overview of the data collection procedures, see Monteleone et al., (2017). Evaluations were performed in individual booths under white light. After the tasting session, participants filled in the questionnaires. Data were collected with the software Fizz (ver. 2.51. A86, Biosystèmes).

2.3. Sensory stimuli and taste function assessment

2.3.1. Taste function assessment

2.3.1.1. Intensity of chemosensory stimuli in water solutions. To evaluate subjects' responsiveness to chemosensory stimuli, aqueous solutions containing the stimuli corresponding to the basic tastes (bitterness, sourness, sweetness, saltiness, and umami), as well as solutions corresponding to the chemesthetic sensation of pungency, and the tactile sensation of astringency were included in the study. The solutions were prepared by dissolving in water: citric acid, 4 g/kg (sourness), caffeine, 3 g/kg (bitterness); sucrose, 200 g/kg (sweetness); sodium chloride, 15 g/kg (saltiness); monosodium glutamate, 10 g/kg (umami); capsaicin, 1.5 mg/kg (pungent) and aluminium sulphate, 0.8 g/kg (astringency). These concentrations were chosen based on previously published data (see Monteleone et al., 2017). All reagents were in line with European Pharmacopoeia Reference Standard and provided by Sigma-Aldrich, Milano, Italy.

Tastant solutions (10 mL) were presented in random order in plastic cups identified by a 3-digit code, and subjects were instructed to hold the whole tastant solution in their mouth for 3 s, expectorate, and then wait 60 s before evaluating its intensity. Prior to the evaluation, subjects were extensively instructed on the use of the general Labelled Magnitude Scale (gLMS; 0: no sensation; 100: the strongest imaginable sensation of any kind; Bartoshuk et al., 2004), in particular to interpret the "strongest imaginable sensation" as the most intense sensation they could ever imagine experiencing. Published standard procedures were applied to familiarize the participants with the scale anchors (Bartoshuk, 2000; Kalva et al., 2014; Webb et al., 2015).

2.3.1.2. Fungiform papillae density. Fungiform papillae density was measured according to the procedure described by Monteleone et al., (2017) and Masi et al. (2015). In brief, the anterior portion of the tongue was swabbed with blue food colouring using a cotton-tipped applicator to make the fungiform papillae visible as pink structures against the blue background of the tongue. Images were recorded using a digital microscope (MicroCapture, version 2.0 for 20×–400×) and, after selecting the clearest image, the fungiform papillae number was counted in two 0.6 cm diameter circles, one on right side and one on left side of tongue, 0.5 cm from the tip and 0.5 cm from the tongue midline. The fungiform papillae were manually counted by two researchers independently according to Denver Papillae Protocol and then these counts were averaged (Nuessle et al., 2015). Papillary density was calculated using the following formula: FP density = [FP number/(9 × pi)] × 100 (Fischer et al., 2013).

2.3.1.3. Responsiveness to 6-n-propyl-2-thiouracil (PROP). PROP responsiveness was measured using a 3.2 mM PROP solution prepared by dissolving 0.5447 g/L of 6-n-propyl-2-thiouracil (European Pharmacopoeia Reference Standard, Sigma Aldrich, Milano, IT) into deionized water (Prescott et al., 2004) in duplicate (Masi et al. 2015). Subjects were instructed to hold the whole PROP solution (10 mL) in their mouth for 3 s, expectorate, and then wait 90 s before evaluating its bitterness using the gLMS (Bartoshuk et al., 2004). A mean of the two replicates was considered in the analyses.

2.3.2. Model foods

2.3.2.1. Model food preparation. Bean/potato puree was selected as an appropriate food matrix for testing salty perception in model foods (Monteleone et al., 2017) by meeting a number of criteria: being food widely consumed and distributed in Italy; being simple and reproducible to prepare, to handle and homogeneous in composition and aspect, allowing it to be easily portioned. In addition, bean/potato puree typically has a low salt content, thereby allowing the addition of salt at different levels in the experimental samples. The use of such a model food in preference to solutions at different NaCl concentrations is also more representative of food perceptions, which are almost always multisensory in character.

The bean/potato puree base formulation was prepared by mixing 150 g of beans with 100 mL of water for 2 min at high speed (Kenwood type FDM 78 – 1000 W – 220/240 V – 50/60 Hz). This base formulation was mixed 1:1 with a potato puree obtained by boiling a commercial potato puree powder (ingredients: potato flakes from sustainable agriculture 99 %; emulsifier: mono and diglycerides of fatty acids; stabilizer: diphosphates; aromas; antioxidant: sodium metabisulphite; Pfanni, Unilever, Rome, Italy) in 500 mL of water at 80 ∘C. Four bean/potato puree samples were prepared by adding increasing amounts of NaCl to the base formulation ($B_{2.0} = 2.0$; $B_{6.1} = 6.1$; $B_{10.7} = 10.7$; $B_{18.8} =$ 18.8 g/kg NaCl) to base formulations. These tastant concentrations were selected to elicit variations in the rated intensity of the target sensations (saltiness, umami and overall flavor) from weak ($B_{2.0)}$) to more than strong ($B_{18.8)}$) (Endrizzi et al., 2022).

Chocolate pudding spiked with varying concentrations of sucrose was used as a model to gauge sweetness preferences in a dessert (sweet/fat) model. The samples were prepared one day prior to evaluation by mixing an instant chocolate pudding (98 g/kg "prepared for sweetened chocolate pudding", Cameo S.p.A., Brescia, Italy) with bitter cocoa powder (40 g/kg, Perugina, Nestlè, Italy) at different levels of sucrose ($C_{38} = 38$; $C_{83} = 83$; $C_{119} = 119$; $C_{233} = 233$ g/kg sucrose) dissolved in water (1:1 ratio). They were then microwaved for six minutes at 900 W, followed by an additional 4 min at 450 W, stirring every 2 min. Subsequently, the samples were refrigerated at 4 °C and removed two hours prior to the test to reach room temperature. The chosen sucrose concentrations aimed to produce a range of sweetness intensities, as determined by previous investigations (Spinelli et al., 2021).

2.3.2.2. Evaluation of liking and sensory properties. Bean/potato puree and chocolate pudding samples (both 15 g) were presented in a balanced random order within each series in plastic cups identified by a 3-digit code. On day 1, participants were instructed to eat a full spoonful, swallow and then rate their liking for each sample on a Labelled Affective Magnitude (LAM) scale ranging from 'greatest imaginable dislike' (0) to 'greatest imaginable like' (100), with 'neither liked nor disliked' set at 50 (Cardello and Schutz, 2004). On day 2, participants evaluated the intensity of target sensations using a gLMS. Between samples, subjects were instructed to rinse their mouth with water for 30 s, eat plain crackers for 30 s, and then rinse again with water for further 30 s.

2.4. Health and Taste Attitude Scale (HTAS)

The HTAS (Roininen and Tuorila, 1999; validated in Italian by Saba et al., 2019) was applied to investigate individual attitudes towards health and taste in food. The questionnaire consists of three health subscales (General Health Interest GHI, Light Product Interest LPI, Natural Product Interest NPI; 20 items in total) and three taste subscales (Craving for Sweet Foods CSW, Using Food as a Reward UFR, Pleasure, 18 items in total), with each subscale having an equal number of positively and negatively worded statements (Roininen and Tuorila, 1999). The "Pleasure" subscale was not considered due to the very low internal reliability obtained in previous large-scale studies involving Italian subjects (Monteleone et al., 2017; Saba et al., 2019; Pagliarini et al., 2021). Subjects were asked to indicate their agreement for each statement on a seven-point Likert scale ranging from "strongly disagree" (1) to "strongly agree" (7). A mean score, after reversing the negatively worded statements, was calculated for each participant and each subscale.

2.5. Food choice assessment

Food pairs (Table 1), consisting of two options differing in saltiness, sweetness, fatness, calories and healthiness, were selected from the IT-Food Choice Questionnaire among different food categories (Monteleone et al., 2017). For each pair, subjects were asked to indicate which option they would choose in an appropriate context, such as a main meal – either lunch or dinner, or for breakfast. The presentation order of the pairs of food items (and of the items within each pair) was randomized across participants. A preliminary study using a Check-All-

Table 1
Food pairs selected from the IT-Food Choice Questionnaire and results of the preliminary study to verify consumers' expected perception of sensory characteristics (saltiness, fattiness and sweetness) as well as caloric amount and healthiness of each food product within each pair. The emboldened option in each food pair was perceived as fattier, saltier, more caloric and/or less healthy, sweeter $^{(+)}$ or less $^{(-)}$ sweet, than the other option (p-value ≤ 0.05, confirmed with McNemar post hoc test).

Food items		Perceived sensory attributes *(p-value)*			Perceived calorie amount *(p-value)*	Perceived healthiness *(p-value)*
		Fat	*Salty*	*Sweet*		
Savory products						
Pizza margherita	**Pizza quattro Stagioni**	**0.003**	**<0.0001**	1	**<0.0001**	**0.001**
Pasta with tomato sauce	**Creamy pasta, ham, mushrooms**	**<0.0001**	**0.014**	0.063	**<0.0001**	**<0.0001**
Chicken with almonds	**Roast chicken**	**0.011**	**<0.0001**	**<0.0001**$^{(-)}$	**<0.0001**$^{(-)}$	0.34
Beef carpaccio	**Sliced beef steak**	**<0.0001**	**0.001**	**0.006**$^{(-)}$	**<0.0001**	**0.02**
Veal chop	**Lamb chop**	**<0.0001**	0.38	**0.01**$^{(+)}$	**0.0002**	**0.0002**
Grilled veal	**Schnitzel**	**<0.0001**	**<0.0001**	0.63	**<0.0001**	**<0.0001**
Chicken fillet	**Sausage**	**<0.0001**	**<0.0001**	0.46	**<0.0001**	**<0.0001**
Cooked ham	**Dry cured ham**	**0.004**	**<0.0001**	0.06	0.06	0.17
Cooked ham	**Mortadella**	**<0.0001**	**<0.0001**	**<0.0001**$^{(-)}$	**0.0002**	**<0.0001**
Fresh tuna	**Fresh salmon**	**<0.0001**	0.50	0.84	**<0.0001**	**0.0002**
Sole	**Salted Cod**	**<0.0001**	**<0.0001**	**<0.0001**$^{(-)}$	**<0.0001**	**<0.0001**
Oven-baked bream	**Mixed fried fish and seafood**	**<0.0001**	**<0.0001**	**0.002**$^{(-)}$	**<0.0001**	**<0.0001**
Boiled egg	**Fried egg**	**<0.0001**	**<0.0001**	1	**0.0003**	**<0.0001**
Cow mozzarella	**Buffalo mozzarella**	**<0.0001**	**<0.0001**	0.13	**<0.0001**	**0.003**
Stracchino	**Gorgonzola**	**<0.0001**	**<0.0001**	0.08	**<0.0001**	**<0.0001**
Sweets and beverages						
Croissant	**Cream/jam filled croissant**	**0.00002**	–	0.096	**<0.0001**	**<0.0001**
Dry biscuit	**Shortbread butter biscuit**	**<0.0001**	–	0.03ˆ	**<0.0001**	**<0.0001**
Cereal bar	**Snack**	**<0.0001**	–	0.08	**<0.0001**	**<0.0001**
Dark chocolate pudding	**Panna cotta**	**<0.0001**		**<0.0001**$^{(+)}$	0.41	0.19
Dark chocolate bar	**Milk chocolate**	**<0.0001**	–	**<0.0001**$^{(+)}$	**<0.0001**	**<0.0001**
Lemon sorbet	**Apple cake with custard**	**<0.0001**	–	**<0.0001**$^{(+)}$	**<0.0001**	**<0.0001**
Citrus yogurt	**Vanilla yogurt**	**<0.0001**		**<0.0001**$^{(+)}$	**<0.0001**	**<0.0001**
Low-fat white yogurt	**White whole yogurt**	**<0.0001**	–	**<0.0001**$^{(+)}$	**<0.0001**	**<0.0001**
Semi-skimmed milk	**Whole milk**	**<0.0001**	–	**0.0006**$^{(+)}$	**<0.0001**	**<0.0001**
Unsweetened coffee	**Sweetened coffee**	–	–	**<0.0001**$^{(+)}$	**<0.0001**	**<0.0001**
Unsweetened tea	**Sweetened tea**	–	–	**<0.0001**$^{(+)}$	**<0.0001**	**<0.0001**
Orange juice	**ACE (orange, carrot and lime) juice**	–	–	**0.003**$^{(+)}$	**<0.0001**	**<0.0001**
Grapefruit juice	**Pineapple juice**	–	–	**<0.0001**$^{(+)}$	**0.0001**	0.63
Iced lemon tea	**Coca-Cola/Orange Soda**	–	–	**0.008**$^{(+)}$	**<0.0001**	**<0.0001**
Sparkling water	**Coca-Cola/Orange Soda**	–	–	**<0.0001**$^{(+)}$	**<0.0001**	**<0.0001**

– not evaluated;ˆpost hoc test not significant ($p < 0.05$).

That-Apply (CATA) questionnaire (Adams et al., 2007) was conducted on the selected food pair items (presented monadically as food names) to verify consumers' perception of sensory characteristics (saltiness, fattiness and sweetness) as well as perceived caloric content and healthiness of each food product within each pair (Table 1). For this purpose, between 171 and 188 adult subjects (depending on the product category) participated in the CATA tests in which each food item was presented monadically in randomised order. Products were not tastes but presented as food names. Significant differences for the target sensations (saltiness, fattiness and sweetness) as well as for caloric amount and healthiness were then tested by means of Cochran's Q test (Table 1**).** In the selected savoury pairs, the option perceived as fattier/more caloric was perceived also as saltier, with the exceptions of lamb chop (*vs* veal chop) and fresh salmon (*vs* the tuna) for which significant differences between the pairs were not found for saltiness.

2.6. Data analyses

Age was considered both as continuous and categorical variable (subjects were divided into three age groups: group A = 18–30 years (45 %), group B = 31–45 years (28 %) and group C = 46–60 years (27 %). Repeated measure ANOVAs using mixed models on liking and intensity ratings of sensory attributes (salty, umami and overall flavor) of bean/potato puree were applied, considering subjects as random factors, samples (four concentrations) as a repeated factor, and sex (females and males), age (groups A, B and C) and their two-way interactions as fixed factors. The models were recalculated sequentially removing the non-significant factors and the final models were calculated including only the factors with a significant effect ($p < 0.05$). Satterthwaite's approximation method was used to correct for unbalanced samples.

Hierarchical cluster analysis was applied on liking data as clustering model, after trying different approaches, to find groups of consumers that showed different liking patterns for saltiness (Salt likers *vs* Salt dislikers). The dendrogram, the evolution of indices, the elbow plot and Principal Component Analysis loading plots (as recommended in Naes, Varela, & Berget, 2018) exploring solutions with a different number of clusters to select the number of clusters to retain (see Supplementary material).

Repeated measure ANOVAs on liking and intensity ratings of sensory attributes (salty, umami and overall flavor) of the bean/potato puree and chocolate pudding were applied, considering samples (four concentrations) as repeated factor, subjects as random factors, and clusters (Salt likers; Salt dislikers), and their two-way interactions as fixed factors. Satterthwaite's approximation method was used to correct for unbalanced samples.

The clusters obtained where characterized for sex and age class using Chi-square tests. The association between clusters and food choice (IT-TASTE choice questionnaire) was tested with Chi-square tests, followed by Fisher exact test per cell. When $p \leq 0.1$, a z-test for two proportion was used to determine if the proportion of choice for the fattier/more caloric/saltier/sweeter option was higher in the Salt likers (alpha = 0.05). Taste function (responsiveness to basic tastes in water solutions, PROP responsiveness, and fungiform papillae density), and food behaviour (HTAS) were evaluated using ANOVA models considering cluster as a factor. Potential differences between clusters by PROP responsiveness were also evaluated using a Chi-square test, considering PROP ratings as a categorical variable, as follows: non tasters (NT bitterness on gLMS < 17), medium tasters (MT: 17 < bitterness on gLMS < very strong, 53), and super tasters (ST bitterness on gLMS > 53). Adjusted Pearson residuals were calculated to study cell-by-cell comparisons (Agresti, 2013). In order to examine the construct validity of the HTAS, the internal consistency reliability of the subscales was preliminarily explored using Cronbach's alpha. When a significant difference ($p < 0.05$) was found in the ANOVA models, a LSD post-hoc test was performed for multiple comparisons. All the analyses were performed using IBM SPSS Statistics for Windows, Version 28.0.1.1 (IBM Corp., Armonk, NY, USA) and XLSTAT 19.4.1 (Addinsoft).

3. Results

3.1. Liking and sensory attribute perception of the bean/potato purees

Repeated measure ANOVA showed a significant effect of the repeated factor, concentration ($p < 0.0001$), on liking ($F = 140.20$, $p < 0.0001$) and all the sensory properties (salty, $F = 317.86$, $p < 0.0001$; umami, $F = 48.08$, $p < 0.0001$; overall flavour, $F = 201.23$, $p < 0.0001$). The mean hedonic patterns follow an inverted U-shape, with the salt addition leading to a significant increase ($B_{6.1}$) and then decrease in the hedonic evaluation, with the sample with the highest salt concentration ($B_{18.8}$) being the least liked sample (M = 41.7 ± 0.9 SEM). Saltiness ratings increased with the amount of salt added in the samples ($B_{2.0}$ = 5.7 ± 0.6; $B_{6.1}$ = 11.9 ± 0.7; $B_{10.7}$ = 20.5 ± 0.6; $B_{18.8}$ = 36.9 ± 0.7). A similar trend was also found for overall flavour ($B_{2.0}$ = 13.4 ± 0.7; $B_{6.1}$ = 19.4 ± 0.6; $B_{10.7}$ = 25.8 ± 0.7; $B_{18.8}$ = 34.9 ± 0.7). Umami also increased as the concentration of salt increased, but less strongly, increasing from ratings of "barely detectable" to "moderate" on gLMS.

A significant sex effect on liking data ($F = 11.09$, $p = 0.001$) was found, with males providing higher liking scores (54.19 ± 2.04) than females (51.10 ± 2.04), while the sexes did not differ in the assessment of the sensory properties of the model food. A significant sample*sex effect was found on liking ($F = 3{,}52$, $p = 0.015$), saltiness ($F = 3.46$, $p = 0.008$), and overall flavor ($F = 3.64$, $p = 0.006$), and a trend for umami was observed ($F = 2.29$, $p < 0.059$) – see Fig. 1**(a–c)**. In both males and females, the hedonic pattern followed an inverted U-shape, with an optimum at the concentration 6.1 g/kg NaCl. With increasing concentration, liking decreased in females, while in males liking plateaued up to concentration 10.7 g/kg NaCl. Females reported significant lower liking for the samples with higher sodium chloride concentrations ($B_{10.7}$ 54.24 ± 1.55; $B_{18.8}$ 38.48 ± 1.69), than did males ($B_{10.7}$; 58.73 ± 1.55; $B_{18.8}$ 45.92 ± 1.69).

Females rated the highest NaCl sample ($B_{18.8}$) as saltier (38.58 ± 1.11), and with a more intense overall flavour (37.09 ± 1.07), compared to males (salty: 35.95 ± 1.22; overall flavour: 33.95 ± 1.17). Instead, females rated the sample $B_{6.1}$ as less salty than did males. Age did not have a significant effect on none of the variables investigated, and the remaining interactions were not significant.

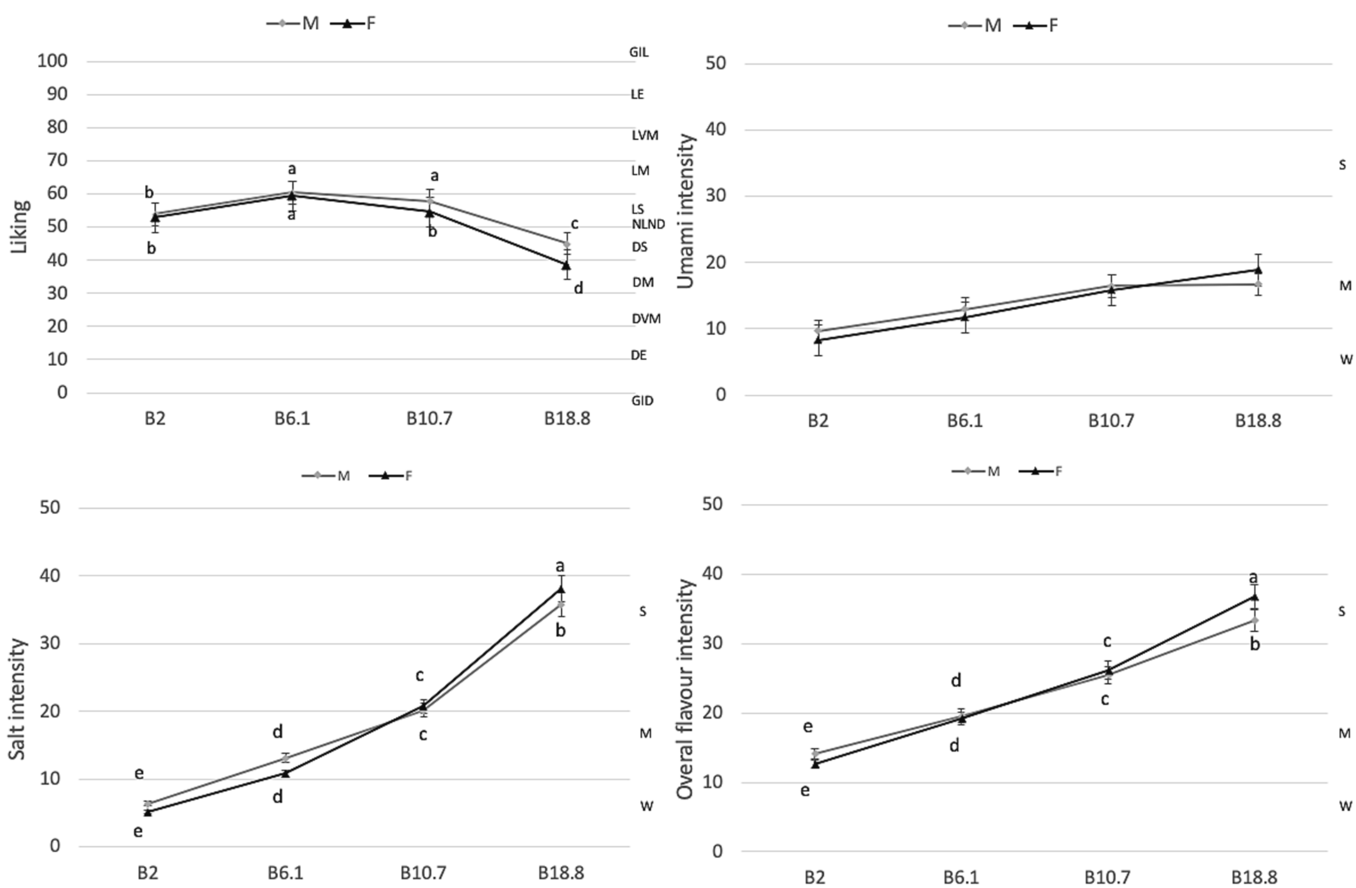

Fig. 1. a–c. Liking, salt, umami and overall flavor mean intensity ratings for the bean puree food model by samples ($B_{2.0}$, $B_{6.1}$, $B_{10.7}$ and $B_{18.8}$) and sex. Different letters indicate significant differences ($p < 0.05$) for each variable according to Fisher *post-hoc* test. GIL, LE, LVM, LM, LS, NLND, DS, DM, DVM, DE, GID indicate respectively Greatest Imaginable Dislike, Like Extremely, Like Very Much, Like Slightly, Neither Like nor Dislike, Dislike Slightly, Dislike Moderately, Dislike Very Much, Dislike Extremely, Greatest Imaginable Dislike on the LAM scale, and W, M and S indicate respectively weak, moderate and strong intensity on gLMS.

3.2. Individual differences in liking patterns for salty taste

Hierarchical cluster analyses performed on liking scores allowed the identification of two clusters of subjects (n = 285 and n = 110, respectively). Repeated measure ANOVA results revealed a significant effect of the sample ($F = 156.27$; $p < 0.0001$) and cluster effect on liking ($F = 426.26$, $p < 0.0001$). In particular, the largest cluster (Salt likers, SL) generally provided significant higher mean liking ratings (58.1 ± 0.4) compared to the smaller group (Salt dislikers, SD: 39.1 ± 0.6). A sample*cluster interaction was found ($F = 45.35$; $p < 0.0001$; Fig. 2), with the Salt likers providing liking ratings for all samples at or above the middle of the scale. This group had an inverted-U shaped liking pattern, with samples $B_{6.1}$ and $B_{10.7}$ being preferred (around "like moderately" on LAM scale: 65.08 ± 0.8 and 63.8 ± 0.7, respectively), whereas sample $B_{2.0}$ and $B_{18.8}$ were less liked (between "like slightly" and "dislike slightly" on LAM scale: 55.19 ± 0.8 and 48.41 ± 0.7, respectively). The Salt dislikers provided similar liking scores to samples $B_{2.0}$ (48.7 ± 1.3) and $B_{6.1}$ (47.5 ± 1.2) ("neither liked nor disliked"), after which liking decreased with increasing sodium concentrations ($B_{10.7} = 36.24 \pm 1.3$; $B_{18.8} = 24.14 \pm 1.2$, between "dislike moderately" and "dislike very much").

3.3. Food choice and liking for sweetness in salt likers (SL) and salt dislikers (SD)

The salt liking clusters differed in the proportions of choice of many savoury and sweet foods and for milk (Fig. 3**a–b)**. The SL chose the options that are fattier, caloric and perceived as less healthy (usually also the saltier ones), more often. The Salt likers preferred the mortadella over the cooked ham and the sausage over the chicken filet, while Salt dislikers inversely preferred the cooked ham and chicken filet. In some cases, both groups had the same preferred option, but SL more often chose higher fat/salt (cod, fried fish and a trend for fried egg) and fattier options, even if the latter were not saltier (lamb chop), than did the SD. More often than the SD, SL choose sweet options that were fattier and more caloric, e.g., the snack (over the cereal bar), milk chocolate (over the dark chocolate), whole milk (over the semi-skimmed milk), and a trend was observed also for the choice of butter rather than dry biscuits. No significant difference between the clusters was found for the stated preference for beverages or any of the other tested pairs.

The clusters were found to differ in liking for samples of chocolate puddings differing in sucrose content. Salt-likers reported higher overall liking for the samples ($F = 8.34$, $p = 0.004$), and in particular for the sweetest sample (233 g/kg), and the samples with 38 and 83 g/Kg of added sucrose ($F = 145.83$, $p < 0.0001$) – see Fig. 4.

3.4. Cluster differences in taste responsiveness

There were significant cluster differences for ratings of tastes and other oral sensations in solution. Salt dislikers perceived salty, umami and spicy solutions as significant more intense compared to Salt likers (Table 2). In the model foods, Salt dislikers rated saltiness and umami taste as significant more intense than did Salt likers. Significant sample*cluster effects were found indicating that Salt likers perceived the samples with the highest concentration of sodium chloride as less salty ($F = 3.30$, $p < 0.020$), and as less intense in overall flavour ($F = 3.230$, $p = 0.022$) than did the SD – see Fig. 5.

No significant differences were found in terms of fungiform papillae number and PROP responsiveness between clusters. However, when testing PROP status distribution in the two clusters, even if the Chi square test was not significant ($p = 0.114$), the adjusted residuals were significantly higher than expected in the Salt likers (+2.026) and lower than expected in the Salt dislikers (−2.026) in PROP non-tasters (alpha 0.05), indicating that there is a trend for non-tasters to be more likely to be SL than SD.

3.5. Cluster characterization in sex, age, and attitudes toward health and taste

The clusters did not differ significantly in mean age, while they did differ by sex, with the Salt dislikers cluster including a higher percentage of females (66.45 % over 54 %) compared to Salt likers ($p = 0.02$; Table 2).

Cronbach's alpha indicated that the internal reliability for HTAS subscales was satisfactory for each subscale (GHI: 0.83, range values: 1–6.7; LPI: 0.84, range values: 1–6.8; NPI: 0.80, range values: 1–7; CSW:

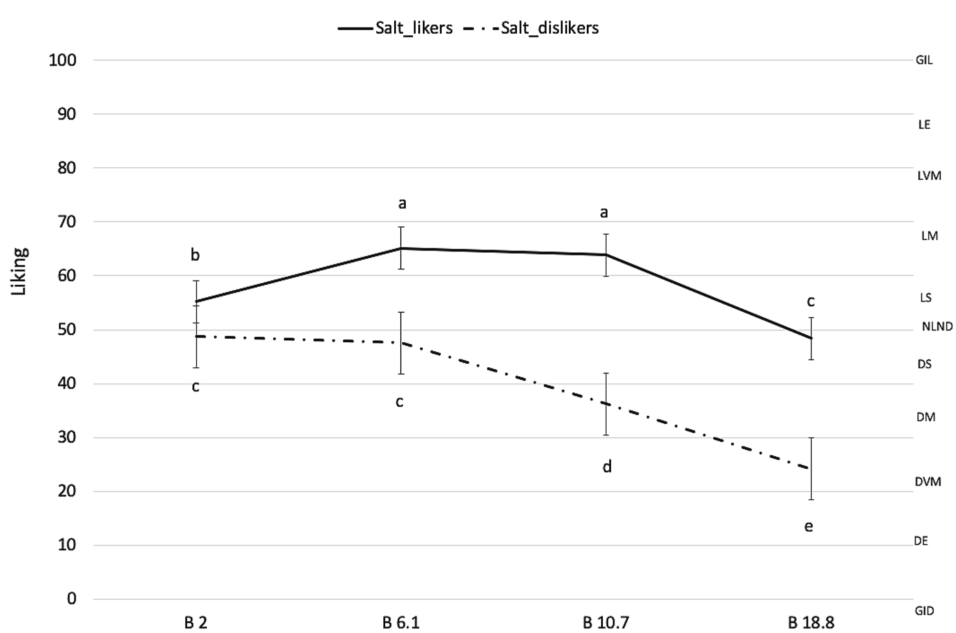

Fig. 2. Liking mean intensity ratings (±SEM) for the bean puree samples ($B_{2.0}$, $B_{6.1}$, $B_{10.7}$ and $B_{18.8}$) by cluster (Salt_likers and Salt_dislikers). Different letters indicate significant differences ($p < 0.05$) according to Fisher *post-hoc* test. GIL, LE, LVM, LM, LS, NLND, DS, DM, DVM, DE, GID indicate respectively Greatest Imaginable Dislike, Like Extremely, Like Very Much, Like Slightly, Neither Like nor Dislike, Dislike Slightly, Dislike Moderately, Dislike Very Much, Dislike Extremely, Greatest Imaginable Dislike on the LAM scale.

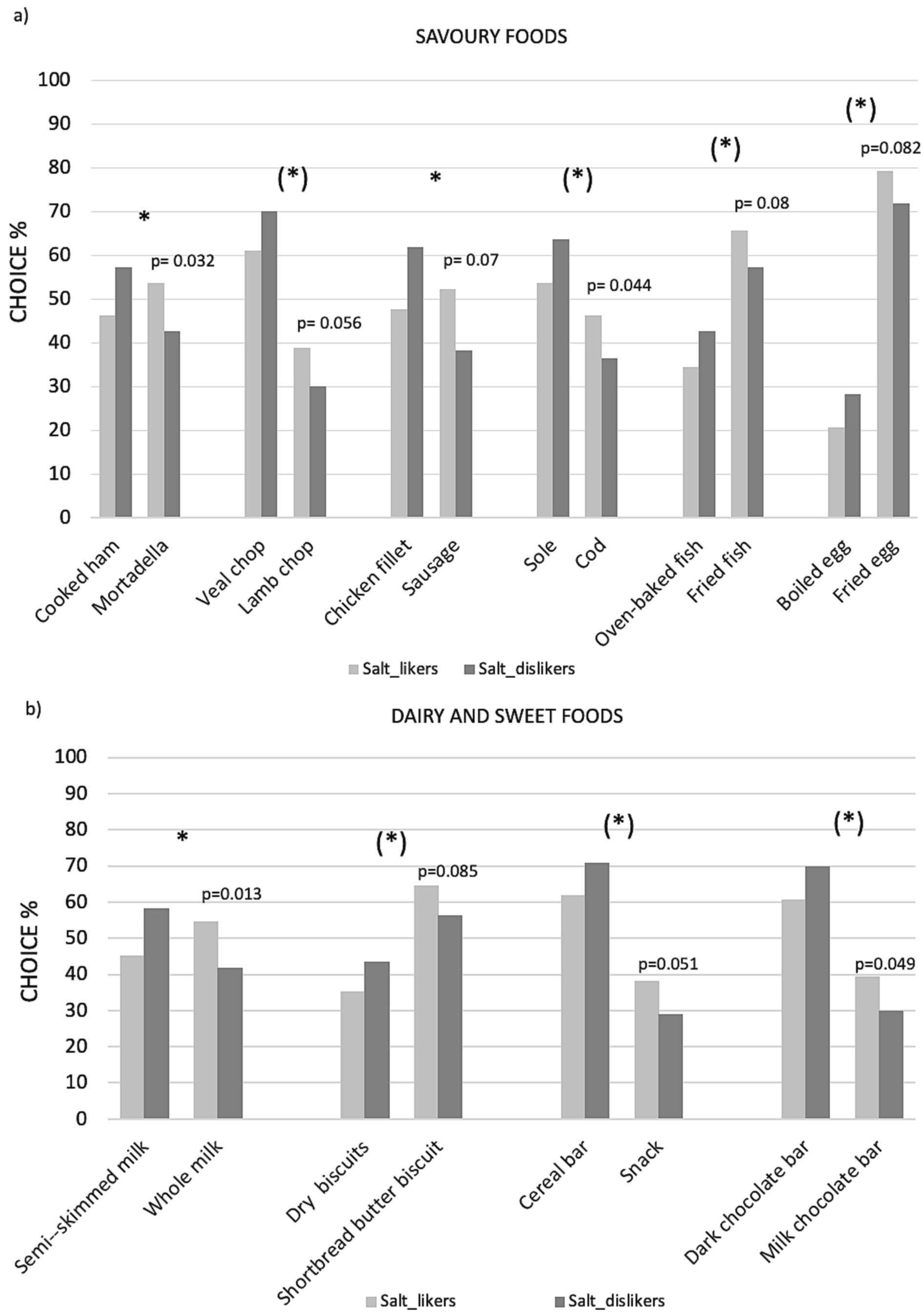

Fig. 3. a–b. Food choice (%) by cluster (Salt_likers and Salt_dislikers) for savoury (a) and sweet/milk (b) products. Only results with p-values ≤ 0.1 (*$p \leq 0.05$, (*), $p \leq 0.1$) were reported. p-values of the two proportion tests between clusters for the fattier/more caloric/saltier/sweeter options are reported.

0.88, range values: 1–7; UFR: 0.85, range values: 1–7). The two clusters did not differ in any of the attitudes measured using the HTAS ($p > 0.05$).

4. Discussion

This study was designed to investigate individual differences in salt liking and perception and to determine if subjects showing a higher liking for saltiness make generally less healthy food choices not only by preferring saltier foods, but also choosing fattier and sweeter foods. Using a bean/potato puree model food containing increasing concentrations of NaCl, the study revealed two clusters of consumers differing in saltiness liking. Salt likers (72.15 % of the sample) considered all samples acceptable (scores above the middle of the hedonic scale) and showed an inverted-U shape liking pattern with an optimum liking (close to "like moderately") for the intermediate concentrations. On the other hand, with the Salt dislikers (27.85 % of the sample), liking decreased monotonically as NaCl concentration increased.

We hypothesized that the differences in salt liking between the clusters would be reflected in differences in food preferences, not only for savoury foods, but also for fattier and higher calorie sweet and dairy foods. This was confirmed: Salt likers more often than salt dislikers preferred options that were fattier and more caloric, which often were perceived also as less healthy and saltier. These subjects preferred more often than the Salt dislikers even many options that were fattier and more caloric compared to the alternative options, but not saltier: this was the case of several sweet products (biscuits, chocolate bars, snacks) and of milk (whole *vs* semi-skimmed) but also of lamb meat.

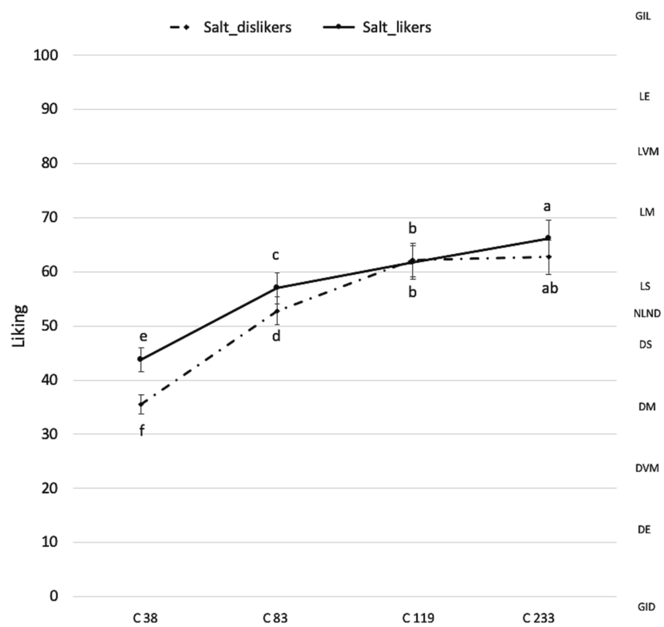

Fig. 4. Liking mean intensity ratings (±SEM) for the chocolate pudding samples (C_{38}, C_{83}, C_{119}, C_{233}) by cluster (Salt_likers and Salt_dislikers). Different letters indicate significant differences ($p < 0.05$) according to Fisher *post-hoc* test. GIL, LE, LVM, LM, LS, NLND, DS, DM, DVM, DE, GID indicate respectively Greatest Imaginable Dislike, Like Extremely, Like Very Much, Like Slightly, Neither Like nor Dislike, Dislike Slightly, Dislike Moderately, Dislike Very Much, Dislike Extremely, Greatest Imaginable Dislike on the LAM scale.

Interestingly, these results suggest that salt liking affects food choices beyond the savoury domain. Individuals liking more salt in the foods also preferred saltier options that were often also fattier and more caloric, as well as fattier and caloric non-savoury foods. This pattern is reinforced by the finding that Salt likers also gave higher liking ratings than Salt dislikers to a chocolate pudding containing increasing concentrations of sucrose, in particular for the sweetest sample, but even to samples with lower concentrations of sucrose, suggestive of a general preference for sweet foods. Instead, no difference between the two clusters was found for beverages that differed in sweetness but not in fattiness.

Taken together, these results suggest a link between salt liking and unhealthier food choices, specifically related to the presence of fat. We suggest one possibility for such results lies in the fact that many savoury foods that are rich in fat are also rich in salt: because salt preference is modified through dietary salt intake (Bertino et al., 1986; Kim and Lee, 2009; Methven et al., 2012), repeated exposure to fat savoury foods determines salt liking. However, at present, it is not clear if it is an initial preference for fat that promotes preference for salt through exposure to high fat-salty foods or, conversely, a preference for salt that promotes a preference for fat through exposure to high fat-salty foods. Combined mechanisms of flavour-flavour learning and flavour-consequence learning may also play a role thanks to the post-ingestive effect of dietary fat and the positive hedonic value of certain levels of salt in foods (Yeomans, 2010, Prescott 2024).

Individual differences in sensory responses may also play a role in determining salt preferences (Hayes et al., 2010, Endrizzi et al., 2022). In the current study, Salt dislikers gave higher intensity ratings than SL for salty and umami taste in both the model food and the aqueous solutions, and to the spicy solution and the overall flavour of the bean purée. Furthermore, we observed a trend for PROP non-tasters to be less represented in the Salt disliker cluster, in line with a heightened responsiveness of this group. However, since no difference in sweet responsiveness in aqueous solutions was found between clusters, taste responsiveness alone cannot explain this association between

Table 2
Clusters characterization according to sex, age, taste responsiveness and attitudes toward foods (HTAS: General Health Interest, GHI; Light Product Interest, LPI; Natural Product Interest, NPI; Craving for Sweet Food, CSW; Using Food as Reward, UFR). Sex and PROP status is reported as % whiles all the other variables as mean (±SEM).

		Salt_likers	Salt_dislikers	Statistic	
				F/χ^2	p-Value
Sex (%)	Females	54	66.4	4.93	**0.026**
	Males	46	33.6		
Age (years)		34.4	34.5	0.01	0.93
Fungiform papillae density (cm^2)		29.84 ± 1.3	30.27 ± 0.8	0.07	0.78
PROP responsiveness		40.0 ± 0.8	44.5 ± 1.4	1.85	0.17
PROP Status (%)	Non Tasters	28.07	18.18	4.35	0.11
	Medium Tasters	38.95	41.82		
	Supertasters	32.98	40.00		
Sensory attributes in water solutions	Sweet	38.5 ± 1.1	39.2 ± 1.7	0.13	0.72
	Salty	34.5 ± 1.1	41.1 ± 1.0	8.49	**0.004**
	Umami	24.3 ± 0.9	29.7 ± 2.0	7.36	**0.007**
	Sour	32.8 ± 1.2	34.6 ± 2.2	0.62	0.43
	Bitter	31.3 ± 1.1	33.2 ± 2.0	0.70	0.40
	Astringency	20.8 ± 1.1	20.8 ± 1.8	0.00	0.97
	Spicy	45.1 ± 1.2	53.0 ± 1.1	10.37	**0.001**
Sensory attributes in model food	Salty	18.1 ± 0.5	21.2 ± 0.8	10.05	**0.002**
	Umami	13.4 ± 0.4	15.5 ± 0.6	3.92	**0.049**
	Overall flavor	23.1 ± 0.4	24.9 ± 0.7	3.21	0.074
Health and Taste Attitude Scale	GHI	4.6 ± 0.1	4.7 ± 0.1	0.89	0.34
	LPI	3.4 ± 0.1	3.4 ± 0.1	0.04	0.84
	NPI	4.3 ± 0.1	4.2 ± 0.2	0.49	0.48
	CSW	4.9 ± 1.4	4.9 ± 0.1	0.18	0.67
	UFR	4.6 ± 0.1	4.4 ± 0.1	2.71	0.10

preferences for fat-salty and fat-sweet/non-savoury foods.

No differences between clusters in fungiform papillae density was found. Fungiform papillae, along with circumvallate and foliate papillae, are the key anatomic structures responsible for taste perception. However, some recent large-scale studies have suggested a lack of association between taste solution intensity and fungiform papillae density, and there are indications of a more complex interplay with other factors such as taste pore and taste bud density or papillae size (Fischer et al., 2013; Webb et al., 2015; Dinnella et al., 2018, Piochi et al., 2018, 2019).

Another potential explanation for the links found here between salt liking and "unhealthy" food choices may be that individuals who use more salt are less likely to be concerned about health, and so may be more indulgent preferring in general foods that are less healthy (e.g., sweeter, fattier). However, in our sample, the two clusters did not differ in general health interest, nor in any of the other domains of the Health and Taste Questionnaire. Several attitudes and personality traits not included in this study do affect food preferences and may be found in subsequent studies to differentiate the salt liking clusters. A recent

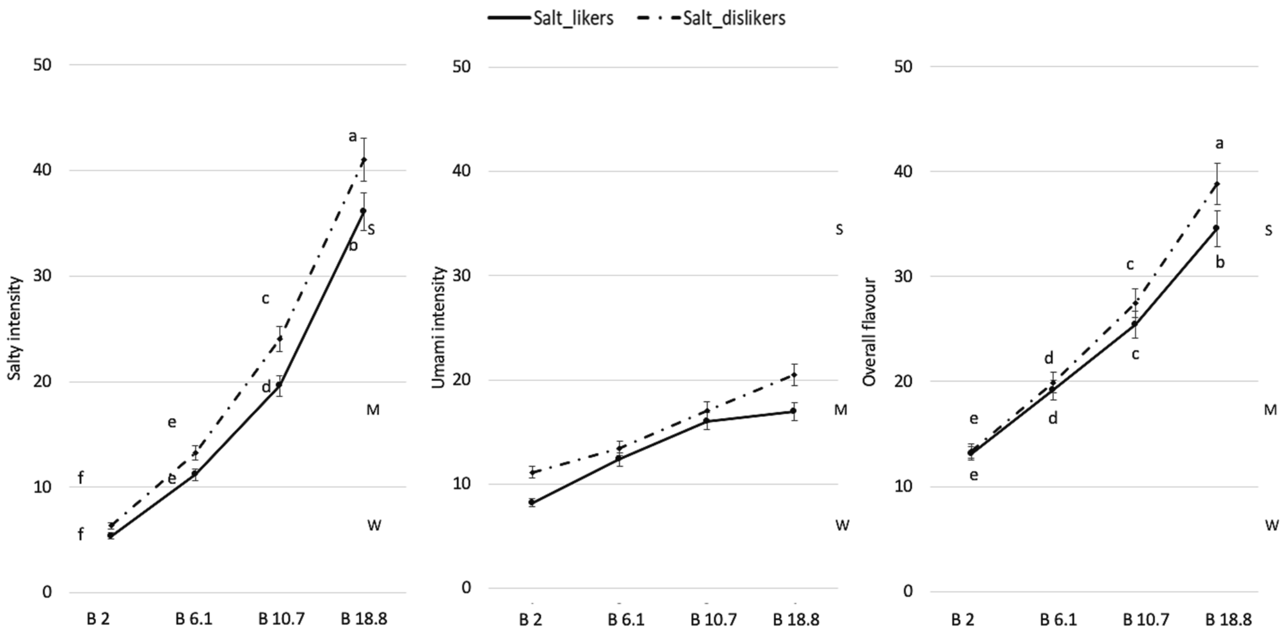

Fig. 5. Salt, umami and overall flavor mean intensity ratings for the bean puree food model by samples ($B_{2.0}$, $B_{6.1}$, $B_{10.7}$ and $B_{18.8}$) and cluster. Different letters indicate significant differences ($p < 0.05$) for each variable according to Fisher *post-hoc* test. W, M and S indicate respectively weak, moderate and strong intensity on gLMS.

study, for example, points to an association between salt liking and depression, anxiety, and stress (Ferraris et al., 2023).

It may be worthwhile considering the impact of sex differences on these findings. While the Salt likers cluster was quite balanced in terms of sex, the Salt dislikers cluster consisted mainly of females (66.4 %). Differences in hedonic responses to salty foods as a function of gender have been previously reported (Carbonneau et al., 2021; Lampuré et al., 2015), with women reporting a lower liking for salty and sweet foods compared to men. This has been explained by the documented tendency of women to exhibit greater cognitive dietary restraint compared to men (French et al., 1994; Provencher et al., 2003), which has been linked with a reduced preference for unhealthy foods (Lampuré et al., 2015). Furthermore, small but significant sex differences were found even before clustering, indicating that females have reduced acceptability of salt in the model food, although their perception of salty, umami and overall flavour was only higher than males at the maximum concentration (18.8 g/Kg NaCl).

5. Conclusions

This study highlights individual differences in salt liking, with different groups having an inverted-U shaped liking pattern (Salt likers) and a decrease in liking as salt content increases (Salt dislikers). Furthermore, this study shows that the Salt likers tend to report higher preferences for fattier and more caloric foods, not only when these foods are saltier but also in absence of difference in saltiness (e.g. in sweet foods and milk). Further studies are needed to elucidate causal relationships; however, these results suggest that salt liking could be considered as a risk factor for less healthy eating behaviours not only limited to salt consumption but also extended to fat and added sugar.

Given the sex differences in salt liking and perception and between the clusters, analyses disaggregated by sex on a larger sample are also recommended as they may help shed light on the mechanisms that affect food behaviours in males and females.

CRediT authorship contribution statement

Cristina Proserpio: Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Sara Spinelli:** Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Camilla Cattaneo:** Writing – review & editing, Investigation, Conceptualization. **Caterina Dinnella:** Writing – review & editing, Investigation. **Monica Laureati:** Writing – review & editing, Investigation. **Erminio Monteleone:** Writing – review & editing, Project administration, Methodology, Conceptualization. **Ella Pagliarini:** Writing – review & editing, Conceptualization.

Declaration of competing interest

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

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Ethics declaration

All procedures were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008. Informed consent was obtained from all participants included in the study. The study was approved by the Ethics Committee of the University of Trieste (n. 64, 9.6.2015).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodqual.2024.105355.

Data availability

Data will be made available on request.

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